CIRCULAR FURNITURE DESIGN GUIDE

CIRCULAR ECONOMY OFFICE

RESEARCH ON :

NEW WORK

CIRCULAR DESIGN PRINCIPLES

OFFICE FURNITURE DESIGN

TECHNOLOGICAL PROCESSES

Interreg North Sea
Co-funded by the European Union

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Producers, retailers, office managers we all must turn to the circular economy!

CEO brings together 13 partners from 6 countries. The consortium is led by **HiiCCE Hamburg Institute for Innovation, Climate Protection and Circular Economy GmbH**.

The partners are categorized as follows:

Local municipalities and public organizations:

Municipality of Copenhagen, **Communauté de Communes Pévèle Carembault**, **City of Utrecht**, **City of Malmö**, and **Ontwikkelingsmaatschappij Oost-Nederland**.
These partners will implement circular office pilots throughout the NSR, testing concepts and exchanging knowledge on specific challenges. Their diverse maturity levels enable mutual learning and growth.

Expert partners and consultancies:

Public Waste Agency of Flanders/Circular Flanders contributes extensive knowledge on circularity, procurement, and CBM. **INDEED Innovation** is an expert in system mapping and includes human behavior components and stakeholder mapping in their approach. **WOOD.BE** and **Institut Technologique Forêt Cellulose Bois-construction Ameublement** are experts in the wood and furniture industry, providing insights into circular design and its application in the conception and redesign of circular offices. They collaborate closely with local SMEs.

Suppliers of office equipment and SMEs in the furniture industry:

De Kringwinkel Antwerp has insights into the second-hand furniture industry and expertise in furniture refurbishment. They collaborate with **ONBETAALBAAR**, circular design experts.

Our partner **Enschede Textielstad Innovatie** specializes in producing circular textile fibers suitable for office environments. Their expertise is applied in various pilot activities of the CEO project, starting with the pilot in the East of the Netherlands.

Collectively, the consortium partners possess comprehensive knowledge, expertise and influence across the entire value chain of office furniture in the European North Sea region.

CIRCULAR ECONOMY OFFICE

Introduction and context

CONTEXT OF THE OFFICE FURNITURE SECTOR IN THE EUROPEAN UNION

The office furniture sector is still dominated by the traditional linear model in which the industry manufactures and sells products that will be discarded at their end-of-life. The discarded office furniture in the EU represents 10.5 millions of tons per year, of which 80 to 90% are incinerated or landfilled. This leads to unnecessary material waste and CO_2 emissions. At the opposite of the linear model, circular economy is emerging and growing to keep the product value high for as long as possible and reduce raw material extraction. The 2020 EU Circular Economy Action Plan paves the way to legislate in the Member States on circular measurements. At national level, the French AGEC law includes in Public Procurement criteria a minimum of 20% of circular purchases for office furniture.

At the same time, the work environment is changing, due to digitalization and globalization, and the changes were accelerated by the COVID-19 pandemic. New demands is for remote, flexible and hybrid work life. Workspaces are evolving to respond to this demand, and have sometimes become too large when a part of the employees work remote. A link needs to be established between sustainable office furniture management and changing demands in the work environment.

THE CEO PROJECT

The CEO (Circular Economy Office) project aims to establish this link to accelerate the office furniture sector's advancement towards an innovative, resource efficient and circular economy through transnational cooperation in the North-Sea Region. By moving to scale, improving legal framework, introducing modularity and adaptability in product design, the lifetime of products is extended and waste reduced. CEO encourages public and private stakeholders along the value chain to foster the circular economy mindset and build sustainable practices, products and solutions.
CEO implements 7 pilots that develop different aspects of the system approach to circular office furniture, e.g. procurement, skills and training, new working principles, digital tools, circular textiles, furnish a new office and circular business models. The aim is to move existing ideas to scale, test innovative approaches, facilitate sustainable transformation and uptake of the sector including a legal framework while ensuring flexibility, climate protection and establishing territorial connections.

OBJECTIVE OF THIS GUIDE

In the framework of the CEO project, this guide of recommendations for CIRCULAR BUSINESS MODELS has been produced to raise awareness in the furniture value chain and help the actors implement circular economy approaches that effectively reduce waste and lengthen the lifetime of products and their value.
In addition to the circular business model principles and examples, several complementary axes are covered:

- **classification of circular business models (in furniture)**
- **embracing digitalisation and data-driven solutions**
- **circular business model tools**
- **barriers and opportunities**
- **upscaling**

TRANSFORMING THE OFFICE FURNITURE INDUSTRY FOR THE NEW WAY OF WORKING

In today's rapidly evolving business landscape, companies are increasingly embracing sustainability and circularity as integral components of their operations. This shift is still a challenge at a large scale in the furniture industry, where traditional linear models of production and consumption are being replaced by circular business models. This guide aims to explore the concept of circularity within the context of office furniture, with a focus on how it aligns with the emerging trends in the way we work.

Circular business models are centered around the idea of maximizing the value of resources and minimizing waste by keeping products and materials in use for as long as possible. This involves designing products for durability, reuse, and recycling, as well as implementing strategies for extending product lifecycles through repair, refurbishment, and remanufacturing.

Target audience of this guide:

- **Furniture designers:** be inspired, understand environmental constraints as a source of creativity, address issues in a preventive approach.
- **Furniture brands:** rethink a product offering, look ahead to the products and services of tomorrow, define a strategy.
- **Furniture manufacturers:** identify new solutions, adopt a preventive approach to meet the challenges of waste and environmental impacts.
- **Interior architects:** be inspired, reconsider the workspace in terms of circularity, innovate and dare to mix new with used and refurbished.
- **Public procurement:** understand the importance of circularity, adopt a strategy for circular public procurements.

This guide, which presents circular business models guidelines for office furniture, is first and foremost an awareness-raising tool.

While the recommendations put forward are of potential environmental and circular interest, their relevance cannot be guaranteed. The circular benefits of these actions (e.g. waste reduction, lifetime extension,..), depends on the specific context of the product and the company implementing them.

Contents

1.

WHAT ARE THE NEW WORK TRENDS?

1.1 THE (FLEX) OFFICE

New work trends appeared already several years ago and were propelled forward by the COVID-19 pandemic. These trends changes the structure of many public and private office organizations.

Here is an overview of these trends in the different workplaces:

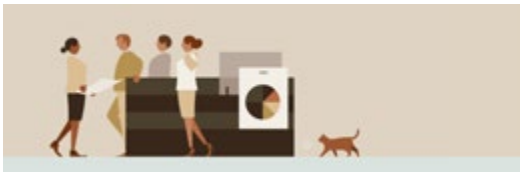
The workplace strategy has to face many challenges when selecting the right combination of spaces and technologies to support current knowledge workers and to adapt the workplace to new organizational needs and requirements when strategy changes and new workers are brought on board. A good workplace comes from a series of choices and compromises in the selection and use of space in the office. It has to adapt to the various modes of work that coexist in the office.

COMPARISON

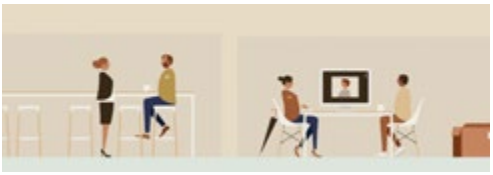
TOGETHER

Huddle
Huddle occurs when a team needs to adress an urgent issue, or discuss and receive instructions for a plan of action. The goal is shared resolution and accountability.

Co-Create
Co-Create is the generation of new ideas and content among groups. The activity may range in scale and formality a quick problem-solving exercise at a white board, to a multi-day retreat with an elaborate agenda.



Warm up- cool down
Warm-up and cool-down take place directly before and after a meeting. The warm-up involves final preparations or informal conversations with colleagues, helping to set the tone. The cool-down allows time to reflect on the discussion, clarify key points, and align on next steps.

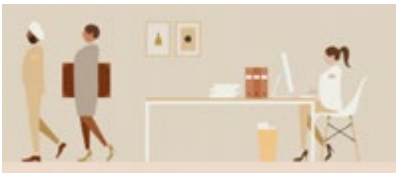


Chat
Chat is an incidental and impromptu interaction with a colleague. It offers a chance to catch up, ask a quick question, or seek out an opinion.

Converse
Converse is a proposeful interaction between two or three cplleagues who adress a defined topic.

ALONE

Create
It occurs when a person engages with the specific content associated with their role, solves problems and develops deliverables.



Progress & Response
It is the work generated by work. It occurs in response to the feedback loop of emails, phone calls, texts and messanges that drive work forward.

Contemplate
Contemplate is an oppurtunity for an individual to pause and consider the best way forward in their work, or ignore it momentarily and provide respite.

Illustration by Daniel Carlsten, courtesy of Herman Miller, 2014.

Due to the growing need for project based work, companies are driven towards implementing increasingly flexible spaces. Flexible spaces offer several benefits for the organization: repurpose spaces and onboard new workers cost-efficiently, foster a sense of team awareness and belongingness, facilitate collaboration. One of the trends is the flex office, where the employees don't have an assigned workstation, allowing a gain of space in the office because less than one workstation per employee is needed. This is often associated with remote work. If a company relocates with the same number of employees, it will relocate in a space that is 25% smaller than the surface area it is vacating. Already today, 21% of employees work without an assigned desk, compared with 6% in 2017 (Upside consultancy, 2023).

The design of a flex office has to be flexible to be valuable for employees. Some adjustment are necessary, like the possibility to make quiet (video) call with digital accessories such as a webcam or speakers (in a meeting room or a phone booth for instance), having concentration rooms or spaces, having mobile and adjustable furniture
However, flexible spaces can limit a sense of individual ownership (many office workers are attracted by physical barriers like walls and offices, associated with privacy and confidentiality) and detract from workers' ability to concentrate on tasks that require a great focus. Companies are continuing to look for modern offices that are adapted to new ways of organizing work and that meet their expectations in terms of sustainable development and services.

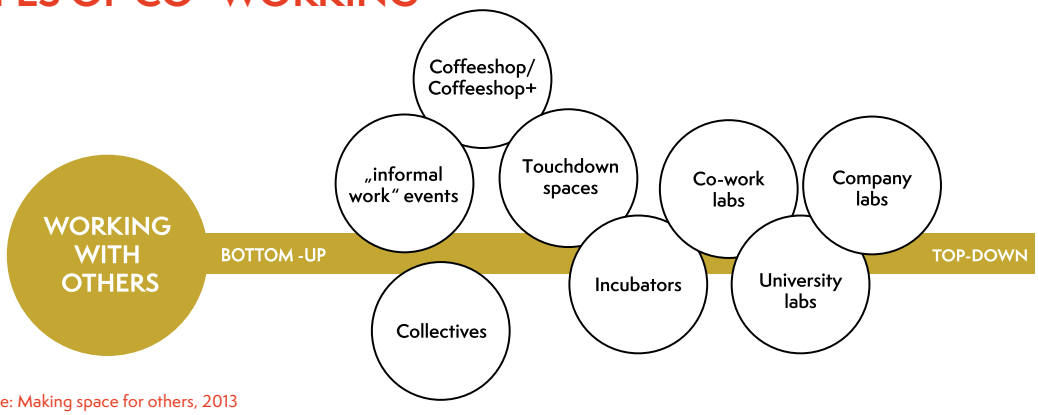
1.2 REMOTE WORK

Better, easier to use and faster mobile devices have increased employee's mobility, enabling them to work from home or a range of public spaces. But of course this trend was highly accelerated by the COVID-19 pandemic and has highly changed the way to see and work in a company, leading to hybrid working.
Today, 42% of the employees are working at least one day per month from home, and 36% at least once per week. 88% of them are satisfied by this situation, and 65% would even like to work from home more frequently (Actineo barometer, French quality of life at work observatory, 2023). What they find advantageous in home working is the organizational autonomy, the good working conditions (pleasant breaks, absence of noise, etc.), the improvement of the work-life balance. Several studies have also pointed out that during the lockdown periods, the productivity of the employees' work increased. Most of the employees are also attracted to working for employers who offer the opportunity to work remotely (Hybrid working requires flexible design, Ahrend).
The recent enthusiasm for remote work and especially home working shouldn't hide some generational disparities. According to a report of Morning Consult in 2023, half of the employees under 35 years old find that home working degrades intergenerational relations, and a majority of the students find homeworking inappropriate for their first job. Gen Z workers are the generation willing to work the most at the office. The reasons are that, given their low incomes linked to their budding careers, their small homes are not always suited to work from home. But also the office is a place where you build your professional self, and interaction with more experienced colleagues helps you to learn and socialize, which you can't do from behind a computer.

1.3 CO-WORKING AREAS

Co-working spaces spread rapidly across the globe. In 2017, there were already 10 000 co-working locations, and over 1.2 million people were member of a co-working service (source: Deskman, a specialist co-working journal). Co-working services offer fully equipped work environment that are informal, welcoming and friendly, with excellent amenities (coffee, food and beverages) and learning and network event.

TYPES OF CO- WORKING



source: Making space for others, 2013

There are several types of co-working facilities. These include:

Coffeeshop and Coffeeshop+: Some coffee shops verge on co-working spaces. These are small independent, more often community coffee shops that see the potential in the remote workforce and offer up the best wifi, small tables and power connections; they are known as "coffee shop+".

Collectives: Collectives differ from co-working spaces in that they usually have a co-op business model. They all invest in space together, and are more often than not made up of people in the same discipline.

Incubators: Incubators are designed to support start-ups and entrepreneurs. They provide all the basics and structure startups need to get going, and often host a number of small start-ups at once.

Co-working labs: Co-working labs are where businesses study their users and focus on innovation. Here companies experiment with customer service, usage patterns, etc. Examples include NextDoor in Chicago run by StateFarm Insurance and conceived by IDEO, Google campus in London, and ING Cafes.

Touchdown spaces: Touchdown spaces are established workstations and corporate virtual offices, executive suites and touchdown service concepts like Regus.

Company Labs: Labs are innovation hubs separate from a parent company. Advertising companies (BBH), Tech companies (Google), and even retail (Nordstrom and IKEA) and Newspapers (New York Times) have adopted the new lab structure within their companies. University Labs: There are innovation labs where students in a highly charged environment solve common problems, brainstorm and ultimately create future start-up and transformative ideas. Examples include Harvard iLab, The MIT CoLab and Media Innovation Lab.

1.4 WHAT ARE THE EXPECTATIONS OF THE WORKERS?

For most of the workers, the office is a place where they can talk and work with other people, which leads to social interaction and conviviality. Facing the hybrid work, employees have simple expectations (Facilities magazine, 2023-2024):

- maintain spatial attachment to a team
- find a workstation easily when they come to the office
- having an optimal environment (lighting and noise): according to the Actineo barometer, 43% of people working in an open space find it difficult to concentrate, and 48% suffer from noise. But at the same time, some employees prefer to work with background noise. Therefore it is necessary to offer a variety of workspaces that correspond to the different habits of employees.
- avoid wasting time with technology

It is important to notice that every individual is different facing hybrid work: Some employees prefer to work from home all the time, while others find it important to keep work and personal life strictly separate and prefer to 'go to the office' every day.
Hybrid working highlights the need of workers that offices should facilitate both individual work and collaboration. In some organizations, they should also cater to care and relaxation needs. They should be inviting and create a pleasant working environment.
Answering the needs of the workers for their work environment will allow the companies to enhance the well-being of their employees, gain in productivity and develop attachment and trust in the company.
To summarize, the challenges related to the new work trends for the companies are multiple. The office as workplace must provide maximum comfort and well-being, and guarantee employees' health. Hybrid working with the possibility of remote work must retain employees and not lose them, must increase productivity at work and not reduce it, and must be used as a springboard to completely rethink the way we work together and the vision of the future of businesses. Change management might be needed in some companies to learn or relearn to work differently.

1.5 HOW CAN CIRCULAR FURNITURE AND WORKSPACES ADAPT TO NEW WAYS OF WORKING?

This question has been asked during two workshops in the framework of the CEO project: the first one during the Flemish Stakeholder event (February 2024) gathering Flemish stakeholders in the office furniture sector, and the second during the CEO Consortium meeting of September 2024, with all CEO project partners.

Furniture level:

- The modularity and multi-functionality of office furniture adapt particularly in flex offices where different work activities are taking place. For that purpose, wheels is an essential accessories, that can be put under tables, desk pedestal etc. The combination with lightweight furniture makes them easier to move around the space.
- The design for disassembly is synonymous with the possibility to upgrade furniture to respond to new needs or a change of employees. But also when furniture have to be changed, the ease of disassembly furniture allows a smooth and circular end-of-use, e.g. refurbishing or remanufacturing. See as well the Design for flexibility and Design for disassembly principles.
- Circular furniture that are refurbished or upcycled can also be installed in new workspaces, as their customization can be tailor-made to the needs and visual identity of the company. Some examples can be seen in the Chapter Technological processes for circular manufacturing. Companies are more and more aware of the durability of these practices.
- A new design trend for office furniture is to adopt a (timeless) design that make them feel like home, and less like in a work environment, because employees appreciate this comfort. Additionally, this can make the office furniture fit at home, which is particularly interesting for companies that implement a loan of furniture for their employees.

EXAMPLE

KETTAL

Figure 3: Solutions to the emerging needs of modern life, this is the motto of the furniture brand Kettal. This example of product is designed to adapt in the office as well as home.

https://www.kettal.com/living/de/collection/Landscape

Workspace level:

- Each office setup is unique. It should be tailored to the specific needs and culture of each organization. Therefore, it is advisable to thoroughly analyze the way of working before starting the (re)design of office. Additionally, considerations should be given to the flow of movement within the space.
- Attention to acoustics and lighting is gaining importance in office designs. Rightfully so, as they significantly impact productivity. The growing focus on biophilic design is also noteworthy. This form of interior design integrates natural light, plants, and natural materials to make indoor spaces healthier and more pleasant.
- Modularity in space usage is becoming crucial. Offices need to be flexible in their use of space, especially if some space is let empty because of hybrid work. It is an opportunity to turn it into co-working spaces with shared facilities. Business parks with office buildings are becoming outdated. The future lies in buildings where functions (living, working, caring, relaxation, etc.) blend together. This promotes inclusivity and accessibility.
- Sharing of office furniture is becoming a new circular practice. Depending on the work legislation in the country, it can be possible for the employee to add in their salary package the lease of office furniture for homeworking, as it already exist for company cars.
- Design uniformity with reused or repurposed furniture can be a challenge for large scale workspaces, which is a main argument for companies to buy new furniture. The issue of interior architects or companies is how to get uniformity withing diversity in the workspace. To promote circularity, it is therefore advisable to "find beauty in chaos", designing a unique look with furniture from different styles or even periods.

EXAMPLE

CLEN

Figure 4: From informal meetings to lunch on the run, the wide variety of Nouvelle Vague collaboration tables encourages exchange in more convivial and dynamic permeable zones. Nouvelle Vague, Clen

https://clen.fr

EXAMPLE

NOWY STYL

Figure 5: The need of privacy, the specifics of a particular workstation or the necessity to arrange a space that is not always tailor-made is possible with the modular line of Tepee from Nowy Styl.

www.nowystyl.com/pl/

1.6 FURNITURE SOLUTIONS ADAPTED TO THE NEW WORK TRENDS

Furniture manufacturers are offering a range of products to respond to today's new workplaces (home, coworking and open space, café, outdoor, hotel) and hybrid working models. Here some solutions are presented.

- The emergence of small convivial spaces is equipped with soft seating, spaces for hybrid meetings, meeting places for formal or informal meetings, acoustic cabins and small semi-enclosed individual workspaces.
- For comfort and ergonomics: screen support arms, ergonomic chairs with adjustable armrests, seats, headrests and lumbar support, anti-fatigue mats for standing work, sit-stand desks (change posture and adapt to all morphologies), sometimes combined with a bicycle, treadmill or dynamic chairs.
- Moving furniture and partition walls around the building: tables, footstools, podiums, partitions, etc. are on wheels. Work surfaces, chairs and partition walls can be folded and stacked, and spaces can be easily reoriented to suit different activities.

EXAMPLE

BLA BLA CUBE

Figure 6: from one to six persons, the emergence of acoustic pods guarantees calm and concentration in workspaces with traffic areas. They come with high comfort and connectivity for hybrid meetings. Premium, Blabla-cube.

EXAMPLE

PACHAMAMA

Figure 7: making possible to work at the office in all wanted conditions is also possible for breast-feeding mothers. Pachamama is the first solution to enable women to express milk in the workplace.

https://pachamama-solutions.com

ACTIU

Figure 8: Depending on the manufacturer, sit-stand desks come in single, double or triple round versions. The system for raising and lowering the tabletop is either electric, manual or gas-powered. Product series Mobility, Actiu.

https://www.actiu.com/es/

EXAMPLE

HUMANSCALE

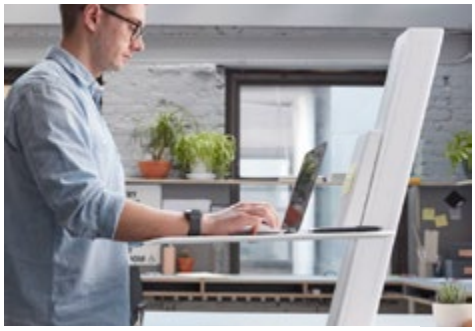


Figure 9: portable sit-stand desks rest on the table, which allows to use the same table. Quickstand Eco, Humanscale.

https://de.humanscale.com

EXAMPLE

CLEN

Figure 11: Getting together and working on a project spontaneously around tables on wheels promises to be a productive, fun and flexible way of brainstorming. Wigwam, Clen.

https://clen.fr

EXAMPLE

DOOOR

Figure 12: folding doors feature opening systems designed to enhance spaces of various kinds, at the office or at home. Dooor.

https://dooor.it/en/

EXAMPLE

SITIS

Figure 10: After folding the table top from horizontal to vertical position, the furniture is less space-consuming when stored, making the perfect solution for meeting rooms. TIPPO, Sitis®

https://www.sitis.be/fr/tippo

EXAMPLE

FURNITURE TIPS

FURNITURE TIPS FOR HYBRID MEETINGS, BY KINNARPS:

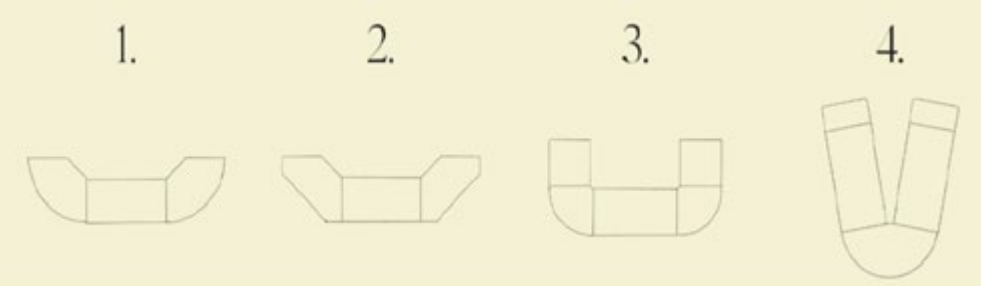
A U-shaped or V-shaped table top is the best option. This means that the people closest to the camera are seated at the ends. This makes it easier for remote participants to make eye contact with those sitting in the meeting room.

The light position will change how the people are visible. If the light comes from behind, you'll hardly be visible. And the type of ceiling lights is also to consider. Build-in ceiling lights are good, they generally provide sufficient general lighting.

It's important to be able to move silently around the table to minimise distractions during a meeting. At the very least, chairs should be fitted with wheels.

Good acoustics in the meeting room are important for the meeting. You can achieve this with acoustic wall panels and upholstered furniture.

Take a look at the walls too. They should be as neutral as possible - walls that are too 'busy' will distract attention.



www.kinnarps.com/knowledge/design-for-hybrid-meetings

Technology is a facilitator of the flex office: it allows spaces to be reserved in flex layouts, hybrid meetings to be organized, unused spaces to be managed to save energy, etc.

EXAMPLE

CLEN

Figure 13: Fewer dedicated workplaces and more shared spaces call for a new approach to personal and secure storage solutions such as lockers. Personal and secure storage solutions are a response to today's changing organization of workspaces. Spinbox, Clen.

https://clen.fr

EXAMPLE

MOFFI

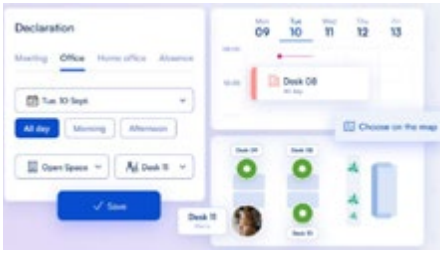
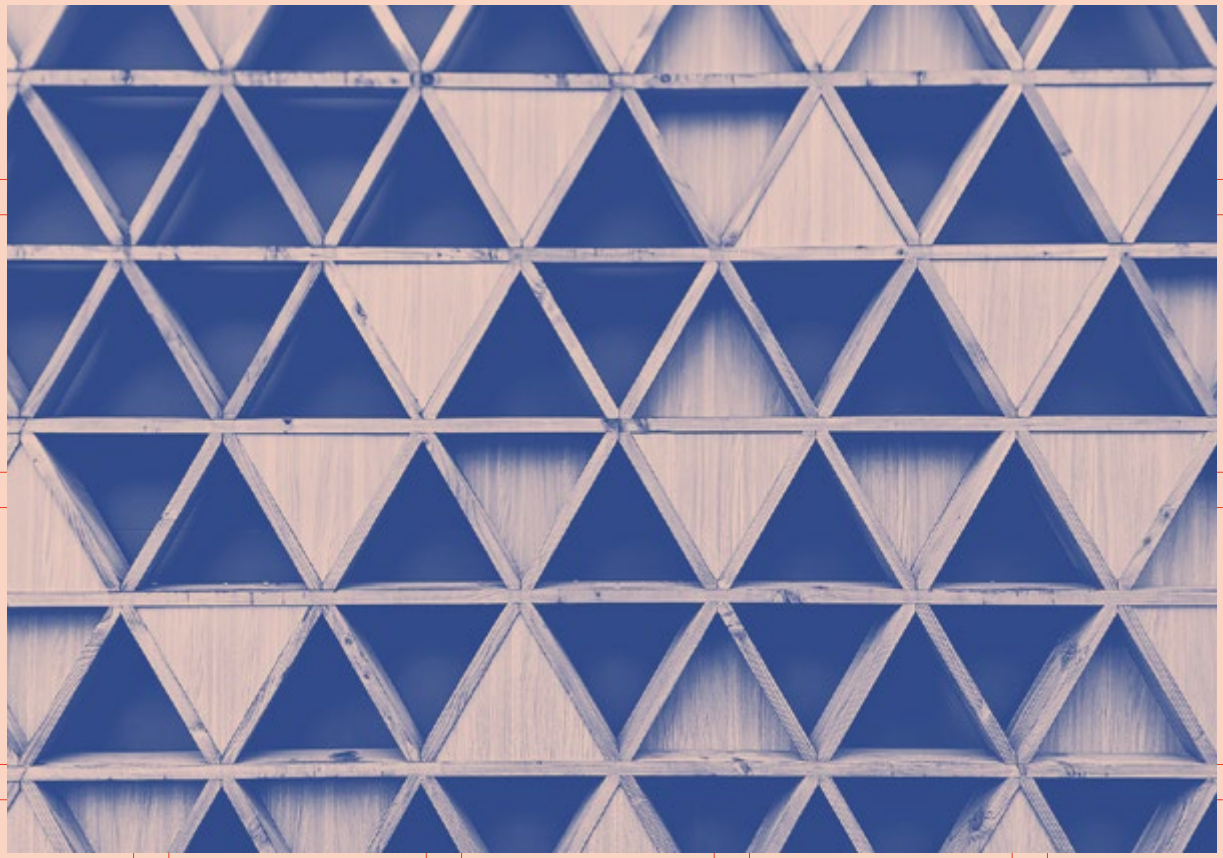


Figure 14: Remote working, in the office, or on vacation, softwares allow to keep track of the teams at a glance and manage meeting rooms and workplace. MOFFI

https://www.moffi.io

2.

PRINCIPLES OF CIRCULAR DESIGN



The field of eco-design is well recognized and defined with a range of guiding principles, strategies and methods. The more recent attention for the circular economy has led design researchers to question the validity of these guiding principles, strategies, and methods when attempting to design for a circular economy. The following paragraphs will explain this transition.

2.1 ECO-DESIGN

Systematic approach that considers environmental aspects in design and development with the aim to reduce adverse environmental impacts throughout the life cycle of a product (ISO 14006:2020)

The aim of eco-design is to fulfill a need with the least environmental impact, meaning that the function of the product or service should be the point of departure for design and development. This upstream approach of a design process aims to find the best balance between environmental, social, technical and economic requirements in the design and development of products and services.

- An eco-design approach relies on 4 principles:
- A multi-phase approach: the entire life-cycle is covered, from the extraction of raw materials, production, transport, use, recycling and disposal.
- A systemic approach: the scope of the study is essential, it should contain all elements needed to carry out the function of the product
- A multicriteria approach: environmental impacts are multiples. Priority environmental issues must be defined and any transfer of impacts avoided or arbitrated.
- Consideration of the service provided: reducing environmental impacts of the product comes along with an increase of the service provided to the user.

The field of eco-design is well developed and recognized. The concept of eco-design started in the 90s with the first development of ecodesign principles, methods and strategies. One of them is the eco-design strategy wheel from Brezet and Van Hemel[1].

ECO- DESIGN STRATEGY

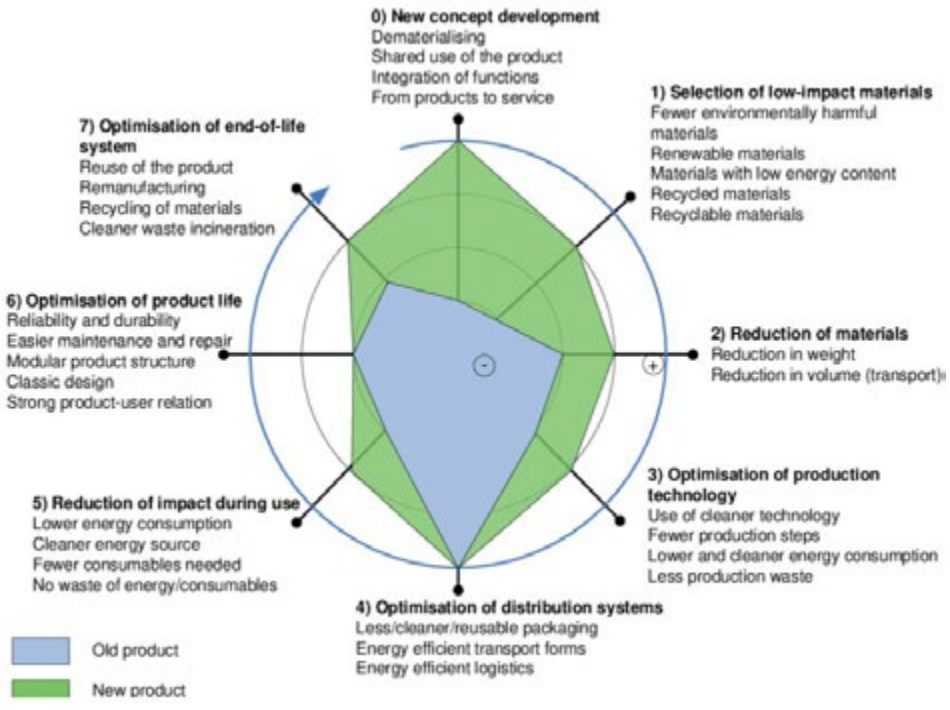


Figure 15: the eco-design strategy wheel is a qualitative tool that enables to identify the design issues of a product or service in order to redesign it and ameliorate the environmental impact. It is structured into 8 general principles. Source: Rikke et al.2

Another complementary guiding principle of eco-design is the waste hierarchy, described in the 2009 European Waste Framework Directive, see Figure. The waste hierarchy is the priority order for managing waste, from the prevention of waste (the preferred option), to reuse, recycling, recovery (e.g. energetic valorization) and disposal (the least preferred option).

Let's break down the key shifts within the business model architecture:

DIAGRAM

WASTE HIERACHY

Figure 16: Waste hierarchy. Source: European Waste Framework Directive3into 8 general principles.

Prevention: measures taken before a substance, material or product has become waste
Reuse: any operation by which products or components that are not waste are used again for the same purpose for which they were conceived
Recycling: any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes
Recovery: any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy
Disposal: any operation which is not recovery even where the operation

The participants of the CEO Flemish Stakeholder event have said:

Eco-design is the strategy of designing products and services to minimize their environmental impact. It encompasses **all stages of the lifecycle**, from design and production to distribution and lifespan extension. During discussions on this topic, five critical questions were raised about eco-design and circular office furniture.

Should the focus of eco-design be more on design or material choice?
It's evident that material choice is crucial (local, sustainable, etc.). But design is equally critical. Products must be easy to maintain, repair, and disassemble. Everyone agreed that eco-design requires a holistic **approach**, considering the overall impact of a product on ecological, social, and economic aspects. **Co-creation and chain cooperation** are essential, as they enable the entire value chain to be incorporated into the design.

Does the new generation of designers prioritize eco-design?
According to participants, they certainly do. Eco-design is now addressed more quickly in education, leading to **greater awareness**. However, there's significant variation in approach and attention among different educational institutions. Additionally, while young designers may learn how to design ecologically, ultimately, it's the market that determines demand for their more sustainable products.

Does eco-design add value for the customer?
That's certainly the intention - ideally on various levels. But is the added value **affordable**? Are customers willing to pay the price? Are consumers willing to think long-term? Are they aware of sustainable alternatives that meet their needs? The business model behind the design and consumer motivation to purchase the product are crucial for the success of eco-design. Behavioural nudges can help but are certainly not easy.

Do you see opportunities in the new EU eco-design regulations?
The new eco-design regulations definitely offer opportunities. They include **responsibility**, appealing to traditional manufacturers and creating **opportunities** for the Belgian and European industries. However, there are also challenges. For example, there's **no**

[3] https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

consistent standardization for circular products, and certain materials cannot be optimally utilized due to **restrictive regulations.**

Who is responsible for giving a product multiple lifetimes?
Everyone shares responsibility. From the designer, manufacturer, and distributor who create, take back, repair, refurbish... to the customers who use it. Multiple lifetimes are only possible when everyone takes responsibility to extend the product's lifecycle.

(February 2024)

2.2 CIRCULAR ECONOMY

The circular economy can be defined as an economic system of exchange and production which, at every stage in the life cycle of products (goods and services), aims to increase the efficiency of resource use resources and reduce environmental impact, while enhancing the well-being being of individuals (ADEME, Frenc environmental agency).
Circular economy fosters the recognition that the linear economy model (extraction of materials, use of products and disposal of waste) is unsustainable and needs to be redesigned. It aims to radically limit the extraction of raw materials and the production of waste, by lengthening the life of the products and recovering and reusing as many of the products and materials as possible, in a systemic way, over and over again. The economic and environmental value of materials is preserved for as long as possible by keeping them in the economic system. The notion of waste no longer exists in a circular economy, because products and materials are, in principle, reused and cycled indefinitely.
Although there will always be a certain amount of unavoidable dissipation, the intention of a circular economy is to work toward a closed loop.
This concept was popularized in the 90s by some states like China in response to economic growth and natural resource limitations. A recognized model of circular economy was proposed in 2019 by the Ellen MacArthur Foundation, inspired by the Cradle-to-cradle principle of Michael Braungart and William McDonough[4].

DIAGRAM

THE BUTTERFLY- DIAGRAM

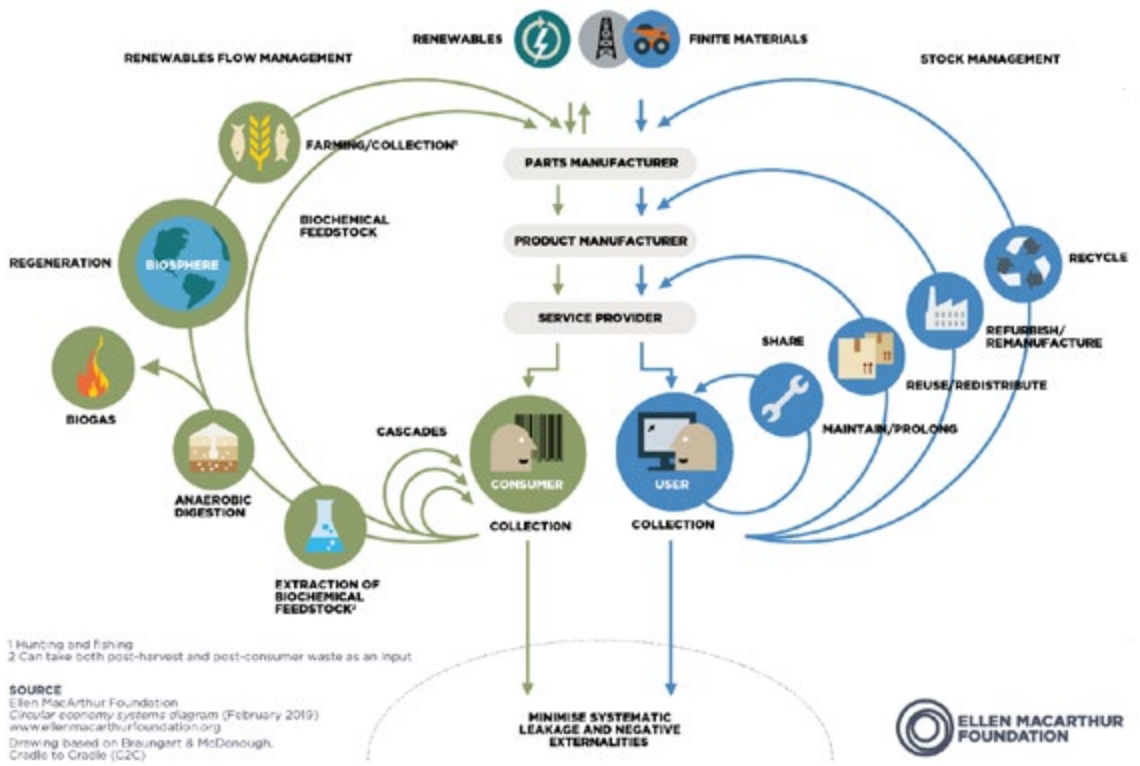


Figure 17: the "butterfly diagram" of the circular economy.
Source: Circular economy system diagram (2019), Ellen MacArthur Foundation

[4] Michael Braungart and William McDonough (2002), Cradle to Cradle: Remaking the Way We Make Things

The "butterfly diagram" of the circular economy separates the biological cycle (biodegradable materials that returns to earth) from the techno-cycle (non-biodegradable materials). Focusing on the technical cycle (where the majority of the products belongs), there are several circular loops that allow material to remain in use rather than becoming waste, and thus the economic and environmental value of the material is preserved for as long as possible. The smaller the loop, the more product value is captured, because small loops retain more of the embedded value of a product by keeping it whole. The small loops also represent a cost saving to customers and businesses as they make use of products and materials already in circulation, rather than investing in making them new.
Therefore, the order of importance of the circular economy loops is the following:

SHARING – MAINTAINING – REUSING – REFURBISHING – REMANUFACTURING – RECYCLING

It is important to bear in mind that each of these loops will work best if the products and services are designed for that loop, i.e. considering the need of an intensive use, long lifetime, disassembly of the components, etc. Therefore, a specific product and service design for a circular economy, called **circular product design** should come into place.

Sharing:
increasing the intensity of the use of products by sharing the product by a large number of users.Digital platforms are a great enabler. Often, the user pays for the use of the product and not the ownership (e.g. bike renting).

Maintaining:
prolonging the usable life of a product thought maintenance, for instance by cleaning, repairing or replacing consumables (fuels, filters, lubricants, ...). It can be done by the user or a third party.

Reusing:
keeping products in use in their original form and for their original purpose, but for another user. Second hand shops and platforms and reuse business models are cropping up everywhere.

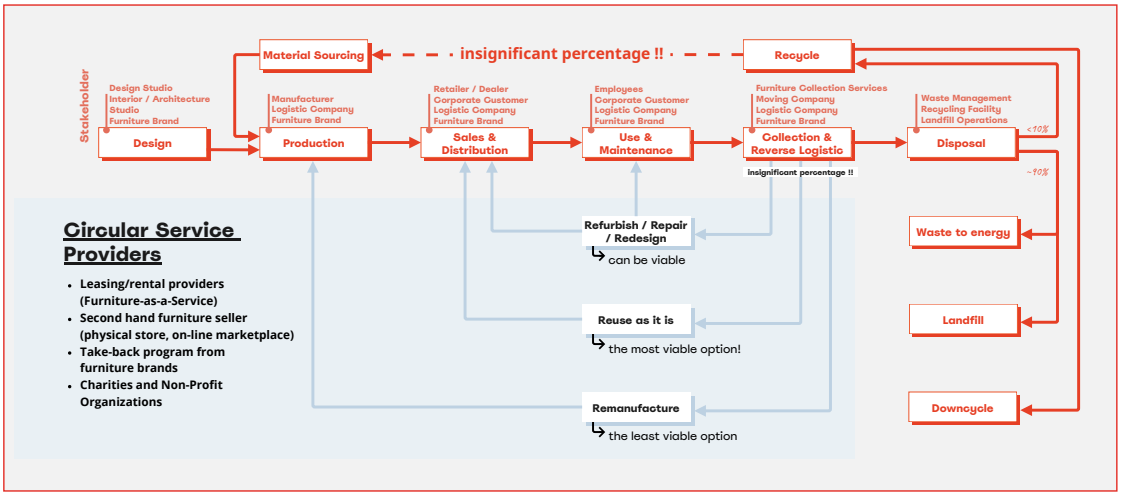
Refurbishing (or reconditioning):
turning an obsolete product to a satisfactory working and/or cosmetic condition (that may be inferior than the new specifications). Often done by specialists, it includes repairing, replacing or refinishing the damaged components, updating specifications.

Remanufacturing:
re-engineering products by disassembling obsolete components and recombining with used or new components, to manufacture products with the original specifications, certified by a warranty. For branding and intellectual property, remanufacturing is done by the manufacturer, a contracted third party or a third party licensed to carry the brand name.

Recycling:
Transforming a product into its basic materials and reprocessing them into new products. The embedded value of a product – the time and energy invested in making it – is lost, but the value of the materials is retained.

ECOSYSTEM MAP

In the framework of the CEO project, an Ecosystem Map for the office furniture sector in Europe has been drawn, with the visualization of the life-cycle of a piece of furniture (including the circular economy loops, similarly to the butterfly diagram), the stakeholders and the circularity principles. The map presents as well the challenges and opportunities of the various office furniture stakeholders. This map can be seen through this link.



2.3 FROM ECO-DESIGN TO CIRCULAR DESIGN FOR A CIRCULAR ECONOMY

By definition, the circular economy and eco-design are two approaches that share the objective of reducing environmental impacts and the integration of stages of the life cycle. However, there is fundamental distinctions to be made between eco-design and circular economy:
The concept of waste differs between the two principles. In eco-design, following the waste hierarchy, the current definitions of prevention, reuse, recycling and recovery, all hinge on the assumption that a product at a certain point will inevitably become waste, whereas in circular economy, the concept of waste (ideally) does not exist[5].

The scopes of eco-design and circular economy are different: eco-design is a "product system" approach (in the sense goods and services), while the circular economy is a more general concept which addresses the "economic system"[6].

To meet the challenges of the circular economy, circular product design requires a new, or at least an adapted, set of guiding principles, strategies, and methods.

The following part will define new definitions and concepts based on the literature that are necessary to understand circular product design for a circular economy.

THE INERTIA PRINCIPLE

In 2010, Walter Stahel introduced a guiding principle for circular design, called the inertia principle[7]:

Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system
- Walter Stahel

The intention of the inertia principle is to keep the product in this state, or in a state as close as possible to the original product, for as long as possible, thus minimizing and ideally eliminating environmental costs when performing interventions to preserve or restore the product's added economic value over time.

PRINCIPLE

[5] Marcel C. den Hollander, Conny A. Bakker, and Erik Jan Hultink (2017). Product Design in a Circular Economy - Development of a Typology of Key Concepts and Terms. Journal of Industrial Ecology
[6] Guide d'éco-conception pour les mobiliers meublants, Recommandations pour l'éco-conception dans une dynamique d'économie circulaire, ADEME, 2024
[7] Walter R. Stahel (2010). The Performance Economy. PALGRAVE MACMILLAN

CONCEPT

THE CONCEPT OF PRODUCT LIFETIME IN CIRCULAR PRODUCT DESIGN

In addition, product lifetime is a key concept in a circular economy, where the products have to stay as valuable as possible before, during and after their use, and possibly for different users. Thus, the concept of obsolescence (i.e. when a product is no longer considered useful by its user, that means ultimately a loss of perceived value) is not irremediable in a circular economy, and can be reversed, giving the product a new life (i.e. recovery). Rather than defining only the product lifetime and end-of-life (like in the eco-design strategy wheel), the circular product design defines in addition the concept of product use cycle and end-of-use.

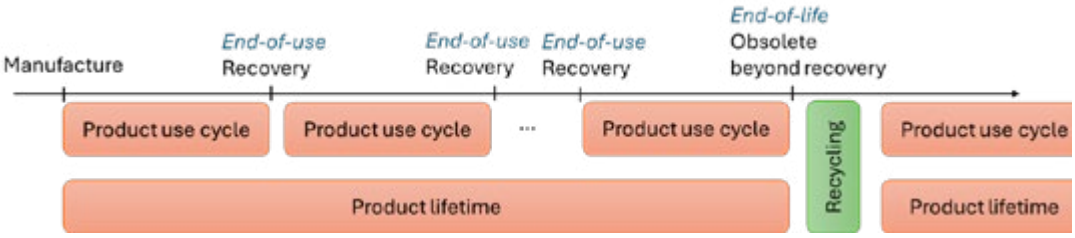


Figure 18: illustration of the concepts of end-of-use, end-of-life, product use cycle, product lifetime and recovery (adapted from den Hollander et al.8). The duration of product use cycles and product lifetime are not only determined by the physical properties of the product, but rather by the perceived value within the context. The recycling process can lead to use the recycled material in the same product or another one.

CONCEPT

THE CONCEPT OF PRODUCT INTEGRITY IN CIRCULAR PRODUCT DESIGN

Through a literature review, den Hollander et al. have drawn up a typology of design approaches for the circular product design. This typology introduces the concept of design for product integrity which is directly related to the inertia principle: the product integrity is the degree to which a product remains identical to its original state over time. It aims at preventing and reversing obsolescence at product and component level. In that sense, the product integrity differs radically to the recycling of product, as the recycling is the disintegration of a product and components at a material level, which loses the product integrity and ends the product lifetime.

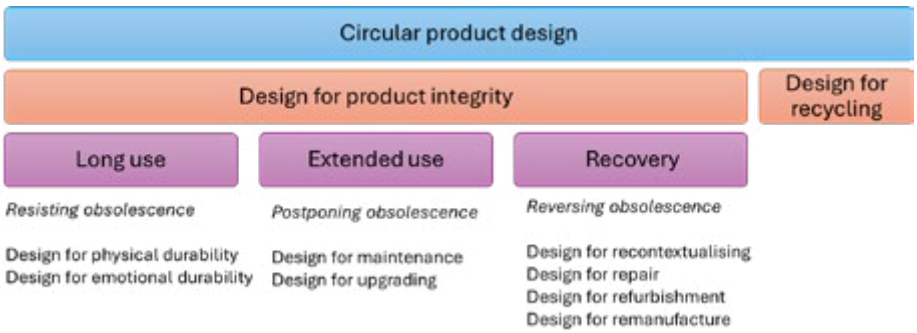


Figure 19: Typology of design principles for circular product design (from den Hollander et al.[9]). Design for recycling is an established concept and well described in the literature (e.g. De Aguiar et al.[10]).

[9] Marcel C. den Hollander, Conny A. Bakker, and Erik Jan Hultink (2017). Product Design in a Circular Economy - Development of a Typology of Key Concepts and Terms. Journal of Industrial Ecology

[10] J. De Aguiar, L. de Oliveira, J. O. da Silva, D. Bond, R. K. Scalice, and D. Becker (2017). A design tool to diagnose product recyclability during product design phase. Journal of Cleaner Production

- **Physical durability:**
  the performance of the product degrades slower over time than comparable products (by wear, fatigue, creep, corrosion).

- **Emotional durability:**
  provides a product attachment and emotional durability to the user.

- **Maintenance:**
  operations at regular intervals, like cleaning or replacing consumables, intended to retain the product in a functioning state and/or cosmetic condition.

- **Upgrading:**
  in a changing context of use of the product, enhancing the product's functional capabilities and/or cosmetic condition to the original design specification.

- **Recontextualizing:**
  use of an obsolete product (or its constituent components), without any remedial action, in a different context than it was (they were) originally designed for.

- **Repair:**
  correction of defects in an obsolete product, bringing the product back to working condition, whereby the warranty and/or state of the repaired product generally is less than those of the new product.

- **Refurbishing/reconditioning:**
  turning an obsolete product to a satisfactory working and/or cosmetic condition (that may be inferior than the new specifications), by repairing, replacing or refinishing all major damaged components.

- **Remanufacturing:**
  re-engineering products by disassembling obsolete components and recombining with used or new components, to manufacture products with the original specifications, certified by a warranty. For branding and intellectual property, remanufacturing is done by the manufacturer, a contracted third party or a third party licensed to carry the brand name.

3.

INTEGRATION OF CIRCULAR DESIGN PRINCIPLES INTO OFFICE FURNITURE

3.1 ADAPTED CIRCULAR DESIGN PRINCIPLES

The previous paragraph introduced a typology of design principles for circular product design, based on the work of den Hollander et al.. In this guide, we aim to present practical design principles that enhance the circularity of office furniture. These principles are intended to serve multiple circular loops, meaning they should be cross-cutting in nature to improve overall efficiency. To achieve this goal, the typology of design principles shown in Figure X appeared insufficiently transversal to address multiple circular loops (for example, the principle of design for remanufacturing is primarily focused on remanufacturing alone).
For the purpose of this guide, we have partially adapted the typology of design principles presented in Figure X, resulting in a new structure of design principles organized in a matrix format. This revised structure ensures that the principles are more transversal, enabling them to address several circular loops as outlined in the Circular Economy paragraph. For each circular design principle, we will provide guidance on how to integrate these principles into the design and manufacturing processes of office furniture.

Additionally, these circular principles will be linked to the challenges faced by office furniture stakeholders, detailing how they can contribute to solving these issues (an overview of these challenges is available in the Office Furniture Ecosystem Map). Regarding the evolving work trends, we will explain how circular furniture design can adapt to new ways of working and meet the changing needs of the workplace. Lastly, to illustrate the circular design principles, we will present a compilation of case studies and best practices from office furniture manufacturers.

PRINCIPLES

	Intense use	Extended use			Recovery at end-of-use			Recovery at end-of-life
	Sharing	Maintaining	Reusing	Redistributing	Repair	Refurbishing/reconditioning	Remanufacturing	Recycling
Design for physical durability - Quality of materials and connections	X	X	X	X		x	x	
Timeless and attractive design - Product attachment and trust		X			X			
Strategic material selection - chemicals and substances of concern -Less (types of) materials -Circular materials -Recyclable materials (dyes, color)					x	X X X	X X X	X X X X
Design for flexibility -Standardisation -Upgrading -Modularity -Multi-functionality								
Design for disassembly & reassembly -Reversible connections (easy to open, esay accessible) -Easy and few tools		X	x			X	X	X
Design for storage and transport (incl. Collection and take-back) -Flat-pack and less volume -Packaging (reusable, smart)	x	x	x	x		X	X	X
Design for identification & traceability (labelling & documentation, DPP) -Instruction to use and recovery (manual, DPP, QR Code) -Digital traçability (RFID) (Alvero, sorting)	x	x	x	x		x	x	x

X: major influence
x: minor influence

A. DESIGN FOR PHYSICAL DURABILITY

Durability is a key physical property of a product. A product with high durability will maintain its performance over an extended period and experience a slower rate of degradation compared to similar products. The degradation of a product can result from factors such as wear, fatigue, creep, and corrosion, and may occur under both normal and abnormal usage conditions. Designing a durable product, therefore, requires a significant degree of creativity, as the designer must anticipate all potential scenarios that could impact the product throughout its lifecycle, including rare or atypical use cases. Important questions to consider include: "What is the primary reason for the product's disposal?" and "What is the weakest point of the product and its components, and how can it be eliminated?"

Guidance for design and case studies for office furniture

- Design for physical durability requires a high quality of materials and connections. Material with high longevity and resistant connections should be used. Reinforce areas/parts at risk due to use and avoid weak points.
- The right material and component for the right purpose should be chosen: intelligent combination of high-quality components such as surface materials, adhesives and fittings with suitable materials (wood, wood-based materials, plastics, metals).
- Materials that have a lifespan in line with the lifespan of the other materials and components of the products should be chosen (thickness or suitable reinforcements), to keep the value of the product as high as possible over the longest possible period.
- The longevity of the materials and connections should be tested on prototypes (see paragraph below) or at least estimated. Alternatives for the weakest link (through stress or wear) should be found, or options to replace it during the products life.
- Materials that lose strength, become brittle, fail easily, get discolored, corrode, or stain should be avoided.

With high-quality materials and connections, the design for physical durability promotes robust and durable products, significantly extending the use of the products (by sharing, maintaining, reusing, redistributing), and guarantying less repair needed. To a less extent, refurbishing and remanufacturing are also advantaged by robust materials and connections.

EXAMPLES

KVADRAT ACOUSTICS

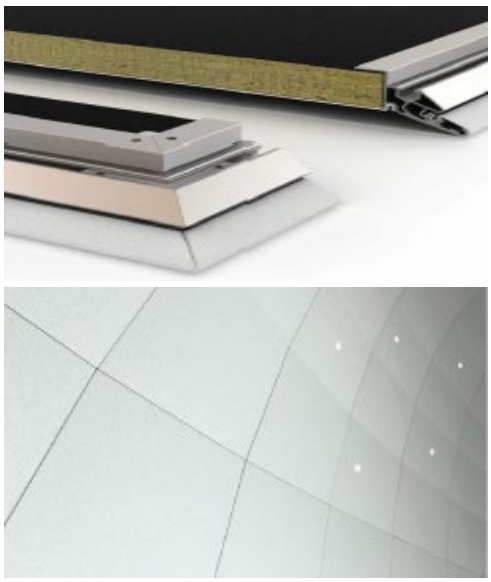


Figure 20: Kvadrat Acoustics© panels possess exceptional longevity and come with a warranty that guarantees their durability over time. Resistant to heat and humidity, these panels maintain their usual condition for years, thanks to a patented tensioning mechanism. With an estimated lifetime of 50 years, the panels offer a long-lasting solution for acoustic needs. They are designed to be reused by refurbishing to reach new settings, and reupholstering

https://www.kvadrat.dk/de

ARCO

Figure 21: ARCO Extend© is an extendable table skillfully build for longevity. Its design is based on a sandwich construction: a thin layer of premium-quality solid hardwood is bonded to the top and underside of a supporting core, such as poplar, to create a highly stable sandwich construction. This provides an economical use of high-quality wood, with the result of more stability and longer product life.

https://www.arco.nl

FENIX

Figure 22: The FENIX laminates are made of several layers of paper impregnated in a thermosetting resin and pressed through heat and pressure to obtain a homogeneous non-porous product. The outer surface is treated with next generation acrylic resin which is hardened and fixed through an electron beam curing process. The result is a surface with properties of thermal healing of superficial micro-scratches: heating the surface can reactivate the cross-linked polymer network that will remove micro-scratches, making a surface highly durable.

https://www.fenixforinteriors.com

Focus on the mechanical tests for furniture:

The following list presents some normative testing for furniture product and components to guarantee the resistance of the product among different stresses. This list has not the intention to be exhaustive.

Physical properties of materials:

- EN 310 : Bending properties of wood-based panels
- EN 311: Surface soundness of wood-based panels
- EN 317: Thickness swelling of wood-based panels after immersion in water
- EN 319: Internal bond strength of wood-based panels
- EN 320: Axial withdrawal of screws in wood-based panels
- SO 527-1/-2: Tensile properties of moulding and extrusion plastics
- ISO 178: Flexural properties of plastics
- ISO 604: Compressive properties of plastics (rigid and semirigid)
- ISO 899: Creep behavior of plastics
- ISO 13586: Fracture toughness of plastics
- ISO 2039: Hardness of plastics
- DIN 52189-1: Bending strength of wood timber

Moisture resistance:

- EN 321: Cyclic test for wood-based panels

Connection tests:

- EN13446: Withdrawal capacity of fasteners in wood-based panels
- EN 1382: Withdrawal capacity of timber fasteners in wood timber

Coating tests:

- EN 1464: Peel resistance of adhesive bond
- EN ISO 4624: Pull-off test for adhesion of paints and varnishes

Rubber- or plastics-coated fabrics:

- ISO 1421: Tensile strength of rubber- or plastics-coated fabrics
- EN ISO 13934-1: Tensile properties of textile
- ISO 4674: Tear resistance of rubber- or plastics-coated fabrics
- EN ISO 13937: Tear properties of fabrics
- ISO 12947-2: Abrasion resistance of textile

Flexible polymeric foam material:

- EN ISO 845: raw density
- EN ISO 1798: tensile strength
- EN ISO 1856: compression test
- EN ISO 2439: hardness through indentation technique
- EN ISO 3385: fatigue by constant load test
- EN ISO 3386: compressive stress
- EN ISO 8307: rebound resilience
- ISO 13362: wet compression set
- ISO 24999: fatigue by constant-strain procedure
- DIN 53579: indentation test on finished part
- NF T 56-114 : dynamic fatigue test through repeated compressions

Furniture fittings:

- EN 12527: castors and wheels
- EN 15338: extension elements, pull-outs
- EN 15570: hinges on a vertical axis
- EN 15828: hinges on a horizontal axis (flap holder)
- EN 15706: slide fittings for sliding doors and roll fronts
- EN 15939: wall attachment devices (cabinet suspension bracket)
- EN 16014 : furniture lock
- EN 16337 : shelf supports
- DIN 68501 : cabinet corner connectors

Furniture:

- EN 1022 : stability of furniture seating
- EN 1728: strength and durability of furniture seating
- EN 16139: strength, durability and safety of non-domestic seating
- EN 1729-2: safety of chairs and tables for educational institutions
- EN 1021: ignitability of upholstered furniture
- ISO 7170: strength, durability and stability of storage furniture
- ISO 21015: strength, stability and durability of office work chairs
- ISO 19682: stability, strength and durability of tables and desks
- EN1730: stability, strength and durability of tables
- EN 15372: strength, durability and safety of non-domestic tables
- EN 12521: strength, durability and safety of domestic tables
- EN 527-2: safety, strength and durability of office tables
- ANSI/BIFMA SOHO: performance and durability of small office/home office furniture

Challenges for the stakeholders

For furniture manufacturers and brands, sourcing reclaimed components—those obtained through take-back, reuse, or remanufacturing—presents a challenge. Unlike new materials, which come with standardized specifications, reclaimed components can vary significantly in condition and may require additional processing to meet manufacturing standards. These concerns regarding quality and consistency can be mitigated to some extent by using high-quality, durable materials. Such materials not only extend the lifespan of furniture, reducing the need for frequent replacements, but also preserve resources and value when repurposed as reclaimed materials for a second life. The benefits of reusing high-quality components are further enhanced when these components are accompanied by a digital product passport, providing manufacturers with detailed information about the standard specifications and exact composition of the materials (see Design for identification and traceability principle).

Benefits for the new work trends

By having durable office furniture with high-quality materials, companies can ensure a more intense use of the furniture, for instance in the case of flex work or in co-working spaces. For circular business models, durable furniture will particularly advantage the sharing of furniture through leasing, or reusing through resale companies.

B. TIMELESS AND ATTRACTIVE DESIGN

Social and emotional factors can be important in building consumer-product relationships. This product attachment and trust influence the replacement decisions, thus determining how long a product might last in use, and for how long it will remain desirable in the reuse market. A timeless and attractive product can be a product to which the consumer is emotionally attached, or a very reliable product that the consumer prefers to use instead of replacing it, even if it is not the latest, shiniest or most functional model.
Product attachment and emotional durability are influenced by many factors and some of them can be influenced and enhanced by designers, but are however difficult to control. Few research has been undertaken in this field, and there is no common structure of framework. In his review[11], Page concludes : "designers must think carefully about which attachment areas are appropriate to their product and consider their relevance for each consumer's situation".

Guidance for design and case studies for office furniture

In order to provide designers with a guidance on timeless and attractive design, it is important to first understand the main determinants of consumer-product attachment. The following content presents the results of the review research of Page12, to identify the main determinants of consumer-product attachment and the associated design strategy to postpone product replacement.

Determinants	Influencer factors	Design guide
Memories	Story of use, meanings and asssociations	Despite the circumstantial nature of memories, designers may have some ability to encourage the formation of associations with their products. When a product is used within a group scenario, associations and memories of the interactions with the group have the chance to form. Stimulating social contact by designing products that can be used by multiple people at once will increase the opportunity for shared memories to develop.
Please of use	Sensory pleasure and enjoyment	The tactile and sensory qualities of products are the most significant enjoyment area. Designers need to pay attention to every small detail when designing in order to create products that are pleasurable to interact with. Materials and surface finish of a product play an important role in the pleasurable experience of use.
Appearance	Color, form, materials and finishes	Appearance has particular significance in creating timeless products to keep and use for many years. Colors and patterns reflect consumers' personalities and are used as a form of self-expression, so that the appearance of the product can provoke memories. On the other hand, classical, minimalist and simplistic designed products were found to be more long lasting and favored to adapt easily to different places of use and user tastes. To encourage product longevity, designers need to create products that are timeless and simplistic in design so they can be maintained and updated to meet user needs

[11] Page, Tom. (2014). Product attachment and replacement: Implications for sustainable design. International Journal of Sustainable Design. 2. 265-282.

Determinants	Influencer factors	Design guide
Usability	Functionality, quality and effiacy	Product quality is very important in relation to usability. High quality products are linked to durability, tend to function better and last longer. Products that require little maintenance over the course of ownership are more usable.
Reliability	Longevity, durability, ease of repair	Increasing product reliability and durability is the key to implement long life guarantee. Products must be designed using appropriate materials and manufactured to a high standard to ensure they are physically durable and can be used time and time again. The satisfaction created by the performance of a product increases the perception of reliability of the consumers, that will choose to use it over others. Products that are easy to repair are more dependable as users could rely on them to last a long time. Designers must create upgradeable products to repair and mantain to encourange product longeevity.

A timeless and attractive design fosters a strong product-consumer relationship, which in turn extends the product's lifespan as the user is more inclined to maintain and repair it. If, for any reason, this product-consumer relationship is lost, a well-designed and enduring product will remain desirable in the reuse market, retaining its value and attractiveness.

EXAMPLES

VITRA

Figure 23: Eames Plastic Chair©, Vitra. Simplicity and functionality often help a product remain attractive for a longer time. A time-less design product is a product, even as fashions change, which is still attractive. An example of this is the legendary Eames Plastic Chair, designed in 1948 for the "Low-cost furniture" contest of the Museum of Modern Art. They were the first series-produced chairs, and customers still find its design current and fashionable. In close collaboration with the Eames Office, Vitra has developed and launched in 2019 an update of the colors.

www.vitra.com/de-de/home

KEWLOX

Figure 24: With its sleek design and intelligent system that stand the test of time, the storage unit Kewlox© has become a Belgian design icon that started in 1960.

www.kewlox.com/en/

EXAMPLE

PETER OVISIK

Figure 26: Launched in 1984 by designer Peter Opsvik, the HÅG Capisco chair was like no other office chair on the market. It was inspired by the dynamic posture of a horse rider. The saddle-like seat of the Capisco supports the user in either direction, whether they're sitting forwards, sideways, or backwards. The chair's success crossed the decades and continues to this day.

EXAMPLE

MARA

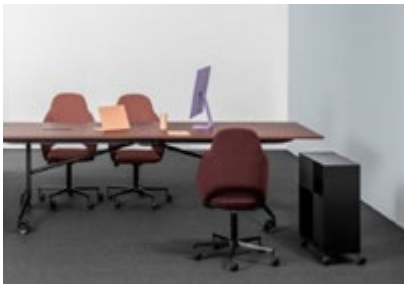


Figure 25: The italian furniture manufacturer Mara designed a range of office tables made with FENIX® laminates. Laura Marchina, Mara Managing Director : « We landed on a product that was attractive to look at, but also pleasant to the touch, with all the unique qualities that come with it: from its anti-fingerprint properties to its extremely matt appearance, along with its soft touch. The choice of colours immediately proved to be incredibly harmonious pairing for the various frames used for Mara's products.

www.marasrl.it/de/

EXAMPLE

Challenges for the stakeholders

One of the challenges in the design phase of the office furniture sector is the insufficient emphasis placed on the longevity and aesthetic appeal of the furniture. As we have observed, the emotional connection between the consumer and the product plays a crucial role in extending the furniture's lifespan. The risk lies in the fact that furniture with a design that is neither timeless nor visually appealing may quickly become outdated, increasing the likelihood of it being replaced and thus shortening its lifespan. To mitigate this, timeless and attractive design principles can assist furniture brands, design studios, and interior architecture firms in creating office furniture that fosters a strong emotional connection with users, ultimately promoting longer use.

Benefits for the new work trends

Having office furniture with strong emotional connections with the workers, through appearance and please of use, is highly beneficial for the new work trends. This will enhance the well-being of the employees at the workplace as well as during homework, and provide a feeling of being at home. Reliable and usable office furniture enhance the image of a trustable company. Minimalism and generic design can fit into different spaces, from the living room to the office. An attractive design will prevent furniture for being replaced after financial depreciation. Finally, office furniture that are sharable with colleagues for collective work or more informal discussions, create positive social contact and memories.

C. STRATEGIC MATERIAL SELECTION

Products are typically composed of multiple materials, and selecting and combining the appropriate materials is a critical factor in developing circular furniture while balancing technical, economic, aesthetic, and functional requirements. There is no inherently "right" or "wrong" material, but materials can be poorly utilized in inappropriate contexts. In other words, a material's ecological value is determined by how it is integrated into the product.
The principle of Design for Physical Durability, which emphasizes the importance of high-quality materials in creating durable products, has already been discussed. The principle of Strategic Material Selection, introduced in this section, focuses on additional key criteria. The goal is to ensure that material choices promote and incentivize circularity across all loops. Questions to consider include: Which materials today will still be viable for recovery in the future? How can waste be minimized in product design, and which circular materials are currently available?
To complement this chapter, Material Sheets are provided in Annex 1, offering insights into the challenges and best practices related to the recyclability of different materials.

Guidance for strategic material selection and case studies for office furniture

Optimization of the quantity of materials

1. Adapt the quantity of materials use to the lifetime of the product and condition of use (e.g. comfort). It should be ensured that the technical lifetime and useful lifetime are compatible. E.g. for a limited use lifetime, a simple material can be used, and in contrary, if a longer lifetime or use conditions are required, a more robust material is to be favored (See Design for physical durability principle).

2. Optimally sizing the product to reach the required functionality with minimum quantity of materials. Good practices can be:
   - Use topological optimization to make as many recesses as possible in components, without compromising the solidity and quality of the furniture.
   - Move towards parts manufacturing processes that use less raw material.
   - Use a rigid structure to support light, flexible trims.
   - Avoid solid elements wherever possible, in favor of wire and/or tubular structures.

→ The ultimate waste quantity is reduced because there is less material from the beginning.

3. Adding components or materials should be questioned in regards to the functional needs. Opt for a minimum number of material types (uniform streams and formulation). The production process will be simpler and with fewer production waste, and the number of post-disposal operation (dismantling, sorting, ...) is reduced, making their post-processing more economically interesting. Good practices can be:
   - Non-structural decorative element should be avoided.
   - Composite materials and blend textiles and plastics should be avoided.
   - If multiple material types are necessary, the parts and components should be easily separable, and/or components should be grouped into uniform material clusters as much as possible
   - (see Design for disassembly.

→ Less material types promotes a better, easier and cheaper separation of the materials of the product, which is highly needed for recycling to achieve clean fraction quickly and efficiently. Also the repair, refurbishing and remanufacturing are enhanced by an easy separation.

EXAMPLE

KARTELL

Figure 29: The furniture manufacturer Kartell and the designer Philippe Starck collaborated to create the chair A.I.©: a chair designed with the help of artificial intelligence and an algorithm that calculated the minimum quantity of material needed to obtain a stable and robust plastic chair manufactured in one piece by injection molding. The chair is also made with recycled material.

www.kartell.com

HERMAN MILLER

EXAMPLE

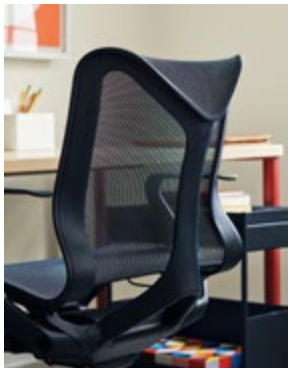


Figure 30: Herman Miller designed office chairs where the usual upholstery PU foam material is removed, and replaced by a polymeric flexible net stretched in a thin but strong flexible frame. Less material for a total support. credit: Photo by Pippa Drummond, courtesy of Herman Miller.

www.destore.hermanmiller.com

GREENGRIDZ, PAMI

EXAMPLE

Figure 27: #GREENGRIDZ is a furniture construction panel that consists of a patented grid system. This makes the panel stronger and stiffer than solid panels currently available on the market, and lightweight (there is 60 to 90% less material use depending on the thickness). The Belgian furniture manufacturer Pami is integrating this panel into its office desks.

www.pami.eu

OFFECT

EXAMPLE

Figure 28: The aluminum structure of the Circulus sofa from OFFECT has a lower thickness and is perforated with holes to reduce the material use. The shape of the flanged holes brings enough stiffness to compensate the material removal.

www.offecct.flokk.com

Chemicals and substances of concern

A material often contains various chemicals and additives that makes its particular properties and/or finishes. However, chemicals that are identified as being harmful and hazardous are more and more banned in European or national legislations. This is a risk for future recovery of materials and components (refurbishing, remanufacturing, recycling), as the recovery might not be possible in several years if in the meanwhile some chemicals contained in the material have been forbidden.

→ **Designers should prioritize selecting materials and finishes that contain minimal chemicals and substances of concern, and ideally avoid those that could be restricted in the future. This approach, based on the precautionary principle, ensures that the furniture can be easily refur bished, remanufactured, and recycled in the future. The material manufacturer or supplier should provide a technical data sheet detailing the complete composition of the materials. Therefore, furniture manufacturers should seek partnerships with suppliers who are transparent about the composition of their materials and committed to limiting the use of substances of concern.**

Focus on the main EU regulations:

European regulations for chemicals:

- The **REACH regulation** (Registration, Evaluation, Authorization and Restriction of Chemicals) drives the restriction of utilization of chemicals (in manufacturing processes and in products) to protect the human health and environment against chemical hazards. REACH identifies especially the Substances of Very high Concern (SVHCs). These substances should progressively be replaced by less dangerous substances or technologies where technically and economically feasible alternatives are available. In addition, a restriction list already identifies the substances restricted under REACH.
- The Classification, Labelling and Packaging of substances and mixtures (CLP) Regulation determines whether a substance displays properties that lead to a hazardous classification, with the aim of communication and labelling on the packaging. There are not restricted, but some classifications may be identified as SVHCs: carcinogenic, mutagenic or toxic for reproduction (CMR) category 1A or 1B.
- Persistent organic pollutants regulated under the POPs regulation are also subject to be prohibited or severely restricted in the production and on the market.

It is noticeable that the ESPR regulation will oblige the manufacturers or importers to trace in the digital product passport many substances categories from the above-mentioned regulations. Some chemicals will also be restricted to guarantee performance requirements in eco-design. See the Chapter Compliance of the circular design principles with the ESPR for more explanation.

LABELS

CHEMICALS

Figure 31: Labelling of hazardous substances under the CLP regulation

EXAMPLE

MR NAF

Figure 32: the Fibralux® MR NAF panel from Unilin is an MDF panel which doesn't contain added formaldehyde resin, resulting in low formaldehyde emissions (E1 class). The panel meets the requirements set by the California Air Resource Board (CARB - phase 2) and EPA (TSCA - Title VI).

Circular materials

Furniture produced with circular principles will be able to deliver materials and components for recovery at the end-of-use and recycling at end-of-life. The best way to incentivize these loops is to reuse the recovered products, components or materials into the manufacturing of furniture. Clear benefit is to reduce the extraction of virgin materials.

- Products should contain as much recycled materials as possible (post-consumer and pre-consumer waste). Pre-consumer waste are industrial waste, which can be valorized in many ways in furniture (e.g. wood-based panels).
- Reusing products and components, through refurbishing and remanufacturing, should be highly encouraged. In an open-loop system, it might be difficult for the manufacturers to find qualitative and quantitative streams of products and components (through waste collectors, sorting centers, dismantlers). Standardized components will help (see the Design for flexibility principle). A closed-loop system can be developed by the manufacturers to take-back their products at the end-of-use, which guarantee that the components are suitable for the products. Several circular business models exist (see the paragraph Challenges for the stakeholders).
- Circular materials will have a good redeployability after use and a high market demand in the future if they have a high market value. Universal and versatile materials (e.g. polyester) lead to a wider field of application, which increases the potential market demand and therefore increases the potential sales value.
- Local sourcing of raw materials, local manufacturing and local sales and distribution reduce the transport distance and has inevitably positive environmental consequences, but has also other benefits: a better understanding and control of the supply chain, allowing to favor suppliers who adopt better environmental practices; local sourcing can also be used as a lever to facilitate a transition into circular business model, and propose e.g. repair services, deposit or rental offers to use fewer resources and make products last longer.

Points of attention when using recycled materials:

- Which virgin material is really avoided? The choice of replacing a virgin low-impact material by a recycled technical material should be made in regards to the environmental impacts of both materials. Replacing virgin wood by recycled aluminum might have limited interest, which is not the case when replacing virgin aluminum.
- What is the technical quality of the recycled material? When a material is recycled, its technical qualities degraded to a greater or lesser extent depending on the material and the recycling conditions. Therefore, more recycled material might be needed to reach the same quality than virgin material. This is for instance the case for cardboard.

→ To support recycled material, the benefits and l loads should be measured and ensure that the circular economy approach is environmentally relevant.

For that, an easier method than the LCA (life-cycle assessment) is the Circular Footprint Formula (CFF)[13]: this formula was developed in the framework of the Product Environmental Footprint, the European harmonized LCA practices. It calculates the environmental impact of the "Materials" and "End-of-life" phases of a product made from recycled materials and/or recovered at end-of-life.

EXAMPLE

KATABA

Figure 33: Kataba's acoustic solutions, made out of up recycled acoustic ceilings. They deployed 2000 m² already, and it emits 80% less CO_2 compared to other upholstered acoustic products, with the same certified acoustic performance. The product is 30% cheaper than standard upholstered products. Image: 1400m2 for PRAEMIA - NOREA, 28 tons of CO2 eq. saved .

www.kataba.fr

[13] See the formula and full methodology here: https://publications.jrc.ec.europa.eu/repository/handle/JRC115959

EXAMPLE

MAXIMUM

Figure 34: the French furniture manufacturer Maximum has specialized in the sourcing of circular materials - production waste or post-consumer components – to design office furniture. Unwanted color mix plastic granulate or industrial epoxy paint, by-products from oak barrel production or industrial locksmith, office doors coming from office building deconstruction, out-of-order scaffolding tubes, and much more ... reclaimed materials find a second life in office furniture products. From left to right: Gravêne©, Bupo© and Clavex©, Maximum.

https://www.maximum.paris/en

EXAMPLE

KVADRAT

Figure 36: The Kvadrat Really Textile TabletopTM is a new recycled composite product, made of pre- and post-consumer end-of-use textile (cotton, polyester or wool), pressed with 30% of binder. Textile TabletopTM is pre-coated, either finished or semi-finished, and is directly applicable to existing and new table frames with no need for additional surface and edge treatment.

www.kvadrat.dk

RECYCLED PET FIBERS

EXAMPLE

Figure 37: Recycled PET fibers is easily obtained from recyclable plastic bottles after grinding and extrusion. Recycled PET fibers are used to produce felt panels that have high acoustic properties, making this material ideal for acoustic walls. From left to right: Re-Sound Interior©, texdecor SlimWall©, ACloud® ORIGIN©.

DIZY

EXAMPLE

Figure 40: Dizy is a furniture design studio for which eco-design is at the center of the reflexion. These tailor-made office lockers have been manufactured from the previous desk pedestral of the client.

www.dizydesign.com/

NYINK

EXAMPLE

Figure 35: NYINK manufactures a range of acoustic panel solutions for the office. The acoustic material is made of recycled textile : 3 blue jeans are recycled into 1 m² of panel.

www.nyink.nl/en

EXAMPLE

VEPA

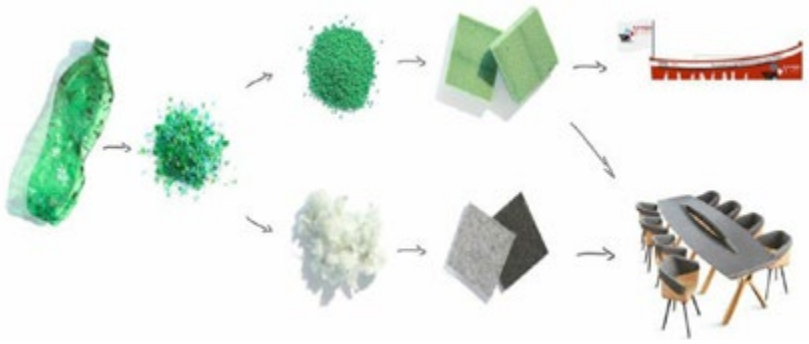


Figure 38: To source recycled PET felt, Vepa collaborated with Plastic Whale, a professional Dutch plastic fishing company.
The plastic bottles are collected in the canals of Amsterdam or other cities during cleanup events, and are recycled into plastic felt. In 2023, 26.758 PET bottles were collected, to create 13.462 furniture pieces made by Vepa. Whale Boardroom table© and Whale Tail Chair©.

https://vepa.nl

EXAMPLE

TARKETT

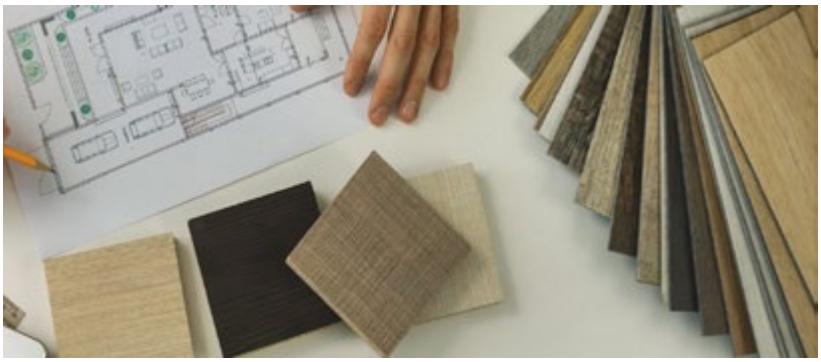


Figure 39: Tarkett has developed solutions to maximize the recycled content of their floor covering. They propose to their client the collection program ReStart® to take-back their products at the end-of-life and recycle them close-loop.

https://www.tarkett.de

- The carpet tiles are separated into the underlayer that is recycled (EcoBase®, C2C labeled and contains 75% of chalk from drinking water industry) and the PA6 textile is sent back to the producer Aquafil to be recycled into ECONYL® nylon yarn.
- Vinyl installation scraps are recycled into new vinyl floor covering, leading to a recycled content up to 40%.
- The linoleum, made of biobased raw material like linseed oil, wood and cork flour) is 100% recyclable and the production waste and installation scraps is recycled into new linoleum, leading to a recycled content up to 36%.

EXAMPLE

STUDIO WAE

Figure 41: Studio Wae is a design studio specialized in creating circular flooring and wall covering thanks to an innovative approach to upcycle waste material into high-quality aesthetic product. The Better Wae collection is composed of circular rugs, flooring and wall tiles made from waste materials such as old carpet tiles or tiles with defects (in collaboration with Interface and Tarkett).

www.studiowae.nl

EXAMPLE

COOLOO

Figure 42: Award-winning Ameba chair from Cooloo has been designed with the concept "less is more", and contains mostly recycled materials: the core is made out of recycled mattress foam that are grinded down into a consistency which can be pressed into the desired shape, and finished with the Cooloo's Endless Life® coatings. These coatings are made out of leather waste, recycled wine corks or jeans waste, are solvent and VOC-free, non-toxic, and are durably applicable on flexible surfaces like foams.

www.cooloo.nl

Recyclable materials

Refer to the Material sheets in the Annex X for more explanation about the recyclability good practices of each type of materials.

General guidelines for recyclable materials are:

- Having less material types and material modules or components that are easily separable will allow for more efficient recycling with high profitability. Separable connections for different types of materials are the key.
- The choice of recyclable materials should be made according to the existing waste collection system (e.g. EPR schemes) and recycling facilities on the territory of sales. Depending on the application and the required mechanical properties of the secondary material, injection of virgin material might also be necessary.
- The chosen materials should be recyclable without loss of quality (downgrading) and maximum retention of the required material properties. At present, there is no simple answer as to what extent chemicals do or do not affect the recycling process.
- The collection, sorting and recycling processes will highly be facilitated with a material identification system. See the Chapter Compliance of the circular design principles with the ESPR for the implementation of a digital product passport through the ESPR regulation.

→ Even if recycling is the last circular loop, recycling materials is the easiest recovery practice used today thanks to the existing and developing infrastructures. Using high-quality recyclable materials today will ensure more availability of recycled materials in the future.

Challenges for the stakeholders

Sourcing materials can be a significant challenge for furniture producers when selecting circular materials (such as reclaimed components or recycled materials) due to the wide variability in quality and condition. These materials often require additional processing to meet manufacturing standards. It is clear, however, that the materials used in today's products will become the circular materials of tomorrow. The opportunity lies in choosing non-toxic materials (with minimal substances of concern), prioritizing those with high recyclability potential, and designing products with less (type of) material types to enhance material circularity.
The cost and quality of some recycled materials can present obstacles, as they may not yet match the performance of virgin materials. However, increasing demand for recycled materials can send a positive signal to the market, encouraging the development of competitive recycling processes for high-quality secondary materials.
Furniture manufacturers aiming to incorporate more reclaimed components through refurbishment or remanufacturing often face a limited availability of these components in the market. Manufacturers can gain more control over their products at the end of use by adopting take-back systems and implementing appropriate circular business models (such as return initiatives or furniture-as-a-service models). By facilitating the return of furniture, the circularity of its components is significantly enhanced.material types to enhance material circularity.
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EXAMPLE

LIGNOLOC

Figure 43: LIGNOLOC® is a patented wooden nail that enables a new fastening technology of wood with wood, replacing the usual steel nails. Applied with a pneumatic nailer, the connection is robust and non-detachable. By avoiding using steel nails in massive wood furniture, not only the recyclability is bettered, but also the reconditioning and remanufacturing of furniture are enhanced – typically, cutting and sanding the wood surface will not damage the woodworking tools.

D. DESIGN FOR FLEXIBILITY

In a dynamic work environment, furniture can support new work trends by adapting to the changing needs of users or accommodating multiple users. The concept of "design for flexibility" encompasses several interconnected elements: standardization, upgrading, modularity, and multi-functionality.
Standardization refers to the integration of common components in furniture, widely accepted within the industry, ensuring compatibility and interchangeability with products from different brands. These components are supplied by vendors that serve numerous furniture manufacturers and brands. While designers and brands may view standardization as limiting their ability to differentiate in the market, it offers significant advantages for the circular economy, as discussed further below. Brands can still distinguish themselves and create added value through innovative business models (see to the Circular Business Models guide for more information).

Upgrading involves enhancing a product's functional capabilities or aesthetic condition beyond its original design specifications. This process is often facilitated by the modularity of the furniture. Modular furniture breaks down its components into individual modules, typically with the same function or material, making it easier to disassemble and reconfigure as needed.
Multi-functionality refers to a design approach that enables a product to meet multiple needs by incorporating various functions. Multi-functional furniture combines versatility, utility, and often serves as a space-saving solution.

Guidance for design for flexibility and case studies for office furniture

Standardisation:

- The product should contain standard components and fittings (lubricants included) that are universally usable in various products and applications. Try to standardize components by appearance, colors, shape, size, ...
- The universal standard components should be easily interchangeable with standard tools, or even better with no tools. The spare parts should be available long-term.

Modularity:

- Take into consideration a smart and modular structure early in the design phase: the product should be divided into smaller modules where similar functional parts are brought together and have a similar lifetime. All the parts that need to be exchanged or upgraded are into one single module, to lower the effort needed to upgrade the product. Complex parts into a module will be replaced and remanufactured by the company or a third-party, while quick and easy changes of damaged modules are done by the customer. Avoid cross-dependences between modules, so that repairing or updating an outdated module will have no consequence on the other working modules.

EXAMPLE

RESOURCE FURNITURE

Figure 44: Resource is a leader in multi-functional furniture to reinvent space at home. Among the products suitable for homeworking: The Dynamic collection of tables is convertible from coffee or side table to work table with the push of a lever, and the Flip-Down Desks are custom wall units with fold-away desks.

Upgradability:

- Upgrading of the product (with a modular structure or not) should be possible by style and by functionality, allowing the product to grow and adapt with the needs of the user or with another user.
- Propose solutions designed so as to have common parts between different products in the same range. This reduces the variety of parts and stocks, but also enables a certain degree of evolution and adaptability by the user with products from the same range.

Multifunctionality:

- Multifunctional furniture should respond to the needs of the users. Consider adding additional functions if, and only if, these functions meet a real need in terms of appropriation (value), use (function) and longevity (durability). Unnecessary secondary functions should be avoided.
- Identify complementary functions and pool them within a single product with the aim of sharing the use (avoid monofunctional product).
- Multifunctional furniture face the challenge that they might be underused for different reasons if the user is not aware of the multifunctionality feature, or if switching from one function to the other is not a quick and smooth process. Designers should counteract this challenge by proposing multifunctional furniture that are easy to switch through an intuitive process.

→ A modular product structure and a high degree of component standardization increase the ease of maintenance, repairability, refurbishing, remanufacturing and provide a smooth replacement of components. It makes as well upgrades easier to facilitate, which will positively influence the lifetime of the product.

→ Multi-functional products are fulfilling several needs and thus are used more intensely during their life time.

Modular furniture must often be as well easily to disassemble and to reassemble. For further guidance, see the Design for disassembly and reassembly chapter.

EXAMPLE

HERMAN MILLER

Figure 45: Herman Miller's Layout Studio is a versatile, modular platform that adapts seamlessly to diverse workplace needs and supports architecture and design firms in tailoring solutions to different floorplates and standards. Its circular, future-proof design meets sustainability expectations by emphasizing longevity, reconfiguration, and responsible material use. The system's clean, minimal aesthetic reduces visual clutter while aligning with contemporary design sensibilities and integrating easily into a wide range of interiors. Together, these qualities make Layout Studio a simple, intuitive, and specification-friendly solution

www.hermanmiller.com

EXAMPLE

TIPTOE

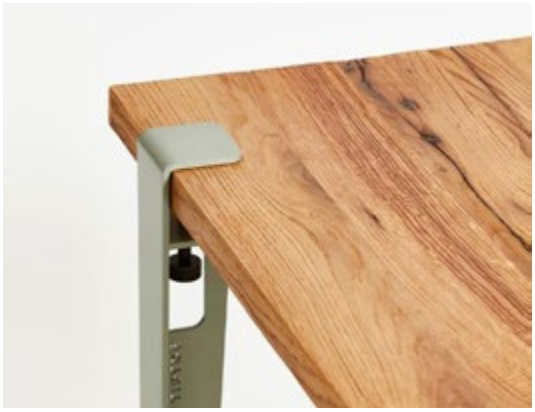


Figure 46: Tiptoe is a French design studio whose one of the design principles is the interchangeability and reparability. They designed versatile table legs that can adapt to different table top materials and shapes, to create from desk to dining or coffee tables.

www.tiptoe.fr

EXAMPLE

ROPIMEX

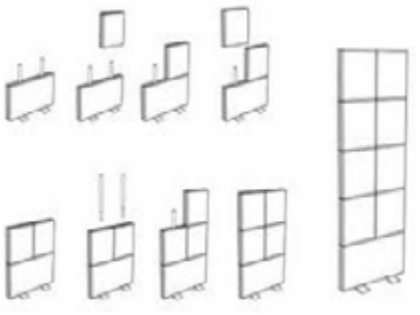


Figure 48: DIVI put.on® from Ropimex® is a modular acoustic wall system made of PET felt and wool. The individual cubes in 2 formats are easily assembled by sliding into tubes and doesn't require any wall attachment. The infinite configuration possible allows to create wall dividers for open spaces, bringing multifunctionality to the product.

www.ropimex.com

EXAMPLE

IKEA

Figure 47: The IKEA chair from Ondarreta is a foldable and mobile piece of furniture. The oakEwooden structure is combined with a robust leather strap that has the double functionality to serve as a backrest, but also to allow anybody to put the chair on its shoulder and easily take it anywhere. This chair can accompany the workers wherever they go and is a solution for an improvised meeting.

www.ikea.com

EXAMPLE

ARCO

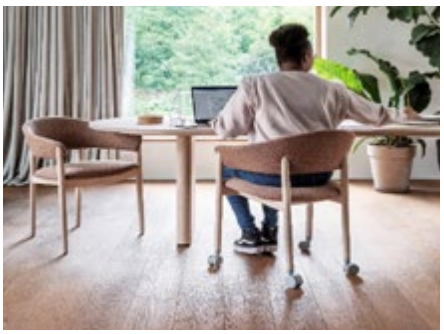


Figure 49: Home-Work® by ARCO is a chair inspired by the flexibility to adapt the home for work purpose and to make the work feel more like home. The chair has optional wheels that provides the mobility of an office chair.

www.arco.nl/de/

EXAMPLE

NYINK

Figure 53: The acoustic whiteboard by NYINK is very handy to use for many purposes, such as brainstorming sessions or meetings, as it integrates the double function of a whiteboard and an acoustic panel that reduces the sound reverberation of the multiple people present in the room.

www.nyink.nl/en

PAMI

Figure 52: Pami furniture accompanies several generations of workers and is rarely replaced due to wear and tear. This is because solid materials are by definition more durable, and intelligent design prolongs their lifespan. Through the program Circular Workspace Design, Pami enables companies to redesign their offices in an eco-responsible and circular way. After an inventory and analysis of the existing furniture, new space design according to the needs of the customer is created, where most Pami furniture items are repurposed and remanufactured, or can simply be given a new purpose or upgraded. As an example, in an office where less paper is needed and more flex offices are available, this shutter cabinet is upgraded into office lockers.

www.pami.eu

EXAMPLE

BLA STATION

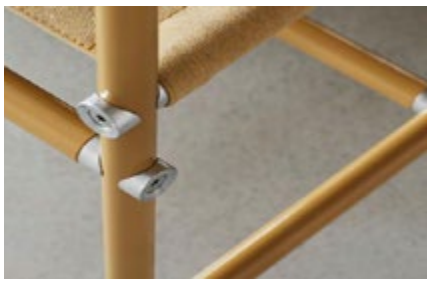


Figure 50: The ABLE chair by Blå Station is constructed in an easily separable structure, where the components can be changed, updated or renewed: materials and colors of the seat and backrest, height of the feet, addition of wheel, type of armrest are the parts that can be upgraded.

www.blastation.com

EXAMPLE

NOWYSTYL

Figure 51: The XIO 2.0 by NowyStyl is a meeting table with foldable table top. The battery-powered adjustable legs makes the table independent from cords and sockets for more mobility in the work space. Optionally it can be finished in White Gloss laminate which enables using the table top as a whiteboard and gives multifunctionality for using in conference rooms.

www.nowystyl.com/pl/

EXAMPLE

BFGF

Figure 54: PIANI by designer studio BFGF has a filigree but stable frame construction made of high-quality untreated solid wood forms that the supporting structure, while the shelf surfaces are filled with changeable and exchangeable inserts.

https://bfgf.de

EXAMPLE

MAGIS DESIGN

EXAMPLE

Figure 55 : COSTUME by Magis is a series of modular sofa that comes with four elements: the seating module which can be completed with a left or right armrest and an ottoman. A connector of plastic is pushed into the slots on the corners and serves to connect the elements. The elements can be assembled to form numerous combinations depending on requirements and space.

www.magisdesign.com

CASALA

EXAMPLE

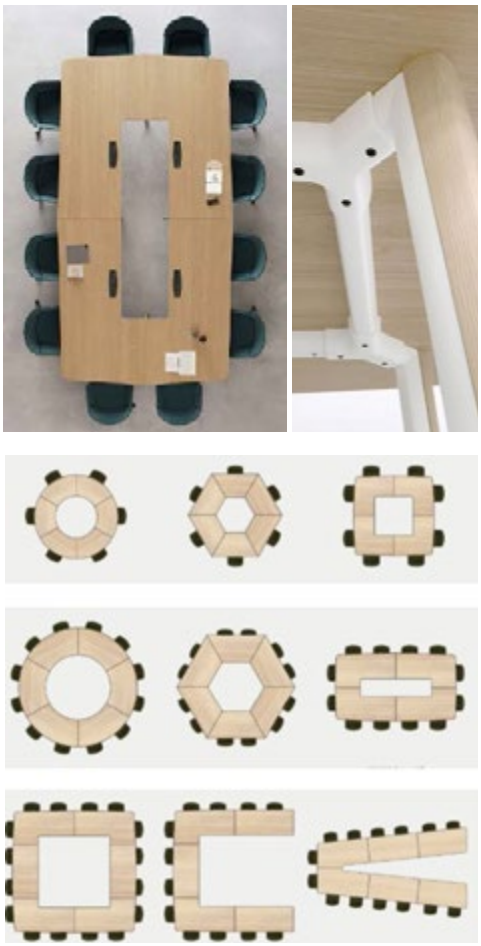


Figure 56: Metro by casala® is a modular table programme with unlimited possibilities in terms of shape and size. The T-, X- or Y-shaped aluminium connectors can be linked in many ways with frame tubular steel profiles, creating an entirely individual Metro network.

www.casala.com

STEELCASE

EXAMPLE

Figure 57: The G64 office chairs series by Orangebox are designed to be easily taken apart and put back together with standard components. Orangebox is expanding the range of chair designs it offers, whilst ensuring that its new lines are based on the same 'pieces' as those which make up the G64.

www.steelcase.com

EXAMPLE

SYSTEM 180

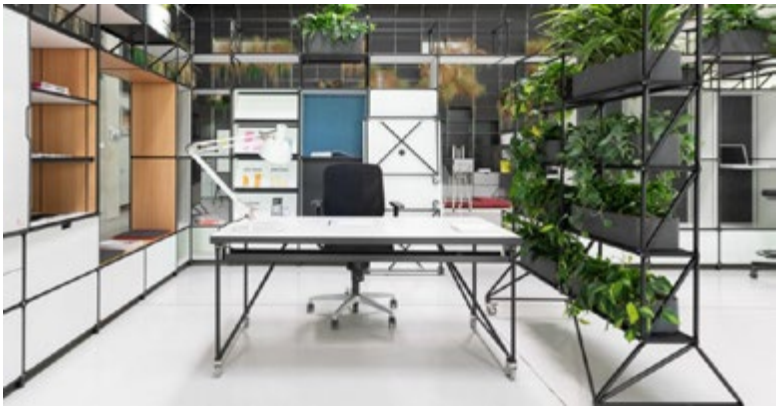


Figure 58: System 180 is, at its core, based on an unique principle that allows to combine multiple options of furniture components with complete freedom and modularity. The stainless tubes with different lengths and angles associate with wood-based panels and accessories (drawers, doors, wheels, ...) to build furniture with infinite shapes and configurations.

https://www.system180.com

Challenges for the stakeholders

Today, furniture brands and design studios may be reluctant to implement circular design principles that takes into consideration the end-of-use (disassembly, repair, refurbishment, ...) because these additional processes might be costly. Adopting or developing a standardized and modular design will allow for easy access to components and easy disassembly, that will reduce the cost of repair and refurbishment of furniture.

Benefits for the new work trends

The flexibility of furniture is crucial for flexible office environments, remote work settings, and co-working spaces. Modular, upgradable, and multi-functional furniture provide the adaptability required to accommodate changing workforce dynamics and work modes (see the paragraph The (flex) office) while ensuring that furniture evolves alongside shifting lifestyles and workstyles. The use of lightweight and modular furniture enables easy space reconfiguration. In the case of leasing, modular and upgradable furniture can also be adapted to align with a company's branding and visual identity. Multi-functional furniture offers the significant advantage of optimizing space utilization, both in offices and home environments. In urban settings, where space is often limited, such furniture proves to be an invaluable asset. By investing in a single multi-functional piece, companies and individuals can reduce the need for multiple furniture items, thereby minimizing consumption and waste generation.

E. DESIGN FOR DISASSEMBLY AND REASSEMBLY

When discussing circular design, "design for disassembly" is often the first concept that comes to mind. The process of breaking down a piece of furniture from its complete form into individual components enables a range of adaptations that support the circular economy and extend the product's lifespan. Design for disassembly involves working with materials and connections in a way that allows for the easy separation of components and materials, facilitating reuse. While many designers and furniture manufacturers emphasize material separation for recycling purposes, it is important to note that recycling is the final stage of the circular economy. The ability to disassemble and reassemble furniture offers broader benefits that extend beyond recycling. Disassembly can be managed by the customer, such as when replacing worn-out parts, or by the manufacturer or a third party for product recovery at the end of its lifecycle. Ensuring that products are easy and quick to dismantle is essential for making the separation process both efficient and cost-effective, thereby promoting circularity.

Guidance for design for disassembly and reassembly and case studies for office furniture

- The dismantling is simplified with fewer different materials, components, parts and connections in the products (see the Strategic material selection principle and Less (type of) materials guidance).
- Multiple disassemblies and reassemblies are better achieved when using qualitative, strong and resistant materials (see the Design for physical durability principle)
- Designing and grouping components into uniform material clusters will make the separation less complex.
- Fasteners and joining elements:
  - Easily accessible with the less amount of effort possible, preferably from one side.
  - Easily separable and reversible. If possible requiring no tools. If tools are needed, there should be as few different tools as possible to disassemble the whole products, by using standard tools.
  - Glues, bonding agents, welds, staples, nails, rivets and other destructive connections should be avoided because they will damage the material. Damaging the joining parts is acceptable as long as the material will not be damaged and can still be reused.
  - The joining elements should be disassemblable and reassemblable multiple times without much deterioration. Example: fixings which snap, clip or slot into place and out again.
- Transparency in the method of disassembly is crucial for an optimal processing, both for the user as for a third-party. For simple design, the use of symbols on the joining elements that are easy to see and understand and the use of standard tools might be enough. For more complex design, instruction provided on a manual, a label or through a digital product passport is very helpful (see the Design for identification and traceability principle).

→ Disassembling the product easily and in a reversible way is beneficial for the repair by the user, where the damaged parts can be removed and replaced without damaging or even discarding the rest of the product. In a more industrial process, at the manufacturer or a third-party, it allows the refurbishing/reconditioning of the product, or the remanufacturing by separating the reusable parts from the damaged parts. For the recycling, it is a great added-value for the dismantlers to achieve clean material flows quickly and efficiently, which in turn leads to higher recycling rates. Finally, as we have seen that the disassembly is often required for the modularity and upgrading of the product (see Design for flexibility principle), maintenance and reuse is as well improved.

EXAMPLE

KEWLOX

Figure 61: Kewlox© offers a range of storage furniture that are easily assemblable and disassemblable thanks to a nail- and screw-free assembly system. This makes the piece of furniture modular, upgradable and reparable (the spare parts are available by the manufacturer directly) and allows for a flat-packaging and delivery.

www.kewlox.com

EXAMPLE

JUUNOO

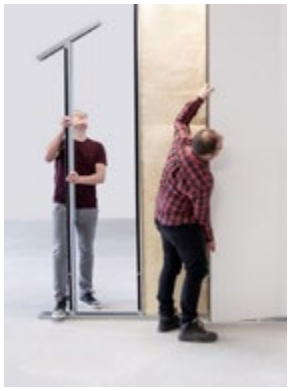


Figure 60: JuuNoo® Demountable Wall system is characterized by reversibility and simplicity of connection. In this way, walls can be placed quickly, but can also be moved or removed easily with a minimum of prior experience. Metal profiles are sufficiently robust to be reused without loss of value. The modular design is height-adjustable and angleable, and is compatible with systems currently on the market.

www.juunoo.com

EXAMPLE

STEELCASE

Figure 59: First C2C labellised product, the office chair Think from Steelcase takes approximately five minutes to disassembly and requires only common hand tools. It was designed with fewer parts and with a third of recycled materials.

www.steelcase.com

KVADRAT

Figure 62: the Soft Cells acoustic panels from Kvadrat Acoustics© are designed to be easily installed and reinstalled on various walls and ceilings. The panels are disassemblable effortless and can be repurposed or reupholstered through a take-back program.

www.kvadrat.dk

EXAMPLE

KRISTALIA

Figure 64: The Compas chair from Kristalia was developped to be easily disassembled into mono-material components: PA6 for the seat and aluminium for the legs.

www.kristalia.it

EXAMPLE

LOUIS

Figure 63: LOUIS manufactures office furniture in a durable and circular way. Their products are easily repairable and recondition-able to close the loop, thus easy disassembly is a must-have.

ww. louisinteriors.com

EXAMPLE

MAGIS

Figure 65: COSTUME is a modular sofa from Magis, where individual components can be easily dismantled and re-placed. Thanks to the elastic loops hooked into the base, the sofa can be undressed when needed for washing or replacing the cover. Even the thin polyurethane foam insert can be taken out and cleaned. The disassemblable system makes the components recyclable, and in addition, the polyethylene structure is made of recycled material

www.magisdesign.com

EXAMPLE

THE SNAP- iPRODUCTSTM

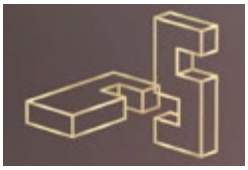


Figure 67: The SNAP-iPRODUCTSTM is an innovative modular joint without adhesive or screws or needs of tools, to fasten furniture parts seamlessly. Each of the individual parts has slots, parts are mutually clamped when they are snapped into each other. To build furniture products like the Adagio Double Workstation, the structural design consists of an interlocking sequence that creates mutual restraint parts which stabilizes the whole product. The modular structure allows to create a variety of workstation models. The Adagio Double Workstation designed by Space Symphony has received a Product Innovations award from BUILDINGS and interiors+sources.

EXAMPLE

EXAMPLE

TIPTOE

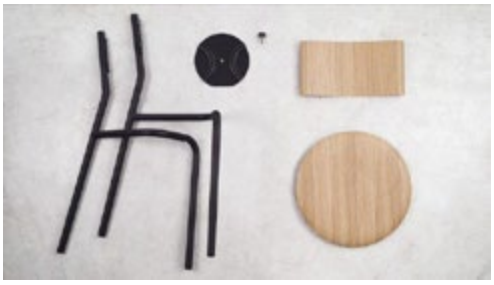


Figure 66: The SSD chair means for simple, solid and durable. Tiptoe designed this chair for everyday life while minimizing environmental impact at every stage of its life cycle. The assembly is obtained in less than 2 minutes with one single screw.

www.tiptoe.fr

EXAMPLE

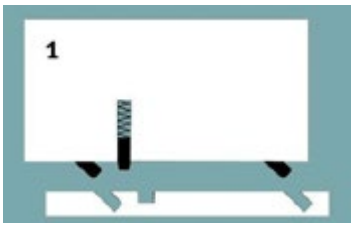
INTERFACE

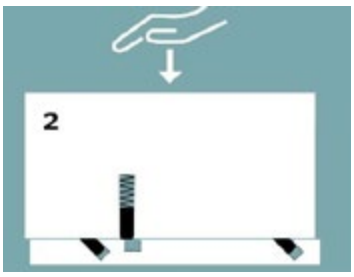
Figure 68: Inspired by the gecko's ability to seemingly "stick" to surfaces, TacTiles® from Interface is a glue-free carpet installation that connect carpet tiles to each other and to the subfloor. Removal and replacement of tiles is quick and easy, whether for the replacement of a single damaged tile or the overhauling of the whole office. The subfloor remains clean and the carpet tiles have no glue residue on them, being ready for reuse.

www.shop.interface.com

EXAMPLE

THREESPINE ID





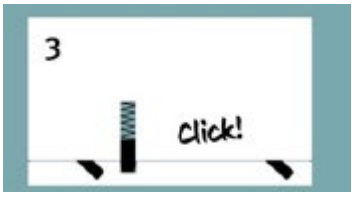


Figure 69: Threespine® ID is a click furniture technology from Välinge that enables furniture to be assembled and disassembled in a second without using any tools of fittings. The key features are the inclined dowels in combination with the flexible looking pin, that achieve a strong connection after positioning into the receiving holes and clicking. The applications are various. For the office furniture, the German furniture manufacturer Hammerbacher uses the Threespine® ID system to ensure a maximum of modularity of its FlexWall storage products.

www. valinge.com/threespine/

EXAMPLE

EXAMPLE

NIAGA TAG

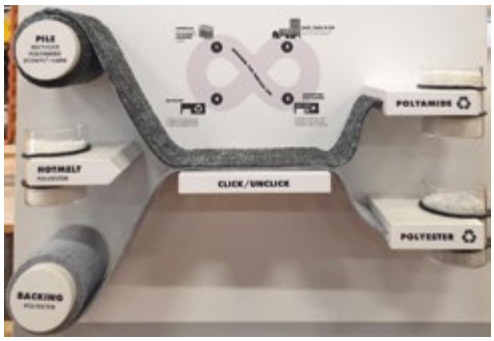


Figure 70: glues are necessary in some cases in furniture, making separation of the materials nearly impossible. The Niaga® tag is a click-unclick polyester adhesive that allows for easy ungluing of the materials by simply heating. This adhesive is used for instance:

- In the DUO carpets (OBJECT CARPET), where the two components of the carpet, polyamide and polyester, can be easily separated from each other and returned to the recycling loop (top picture)
- In the Circuboard (Vepa), where the chipboard can be reused after separating from the HPL top layer, making possible refurbishing of office desks (bottom picture).

Focus on standards about disassembly

Standard EN17902:2023: the CEN/TC 207 (the European Standards committee "Furniture") has decades of experience in writing standards for furniture and has produced many standards covering the evaluation of characteristics (mechanical, dimensional, ergonomic, etc.) of furniture. Its new Working Group 10 is dedicated on furniture circularity and has released in 2023 the standard EN17902: this document provides guidelines for the disassembly and reassembly capability of furniture within the circular economy framework. A set of criteria is established, on which to base an assessment of the ability to access and remove/replace/reassemble priority parts of products. The criteria provided are intended to be used when designing a product and are applicable to different designs, materials, or construction methods.

Standard NPR 8313-3:2024: this Dutch standard describes available measurements and indicators for circular product design. For the disassembly, several aspects are rated to give a final score in the proposed methodology to evaluate circular product design:

Ease of disassembly: number of steps to disassemble the part from the product, from < 3 to > 10.

- Tools required: no or standard tools (refers to NEN-EN 45554) ; specific tools generally available ; company-specific tools not available. If company-specific tools are supplied with the spare parts, they are considered as standard tools. If a combination of standard and company-specific tools is required to disassemble the part, the rating for the company-specific tools applies.
- Required professional skills: anyone without specific experience can carry out the dismantling after reading the manual ; anyone with proper training and tools but without specific manufacturer approval can carry out the dismantling ; only someone from or on behalf of the manufacturer can carry out the dismantling

CONCEPT

FASTENER

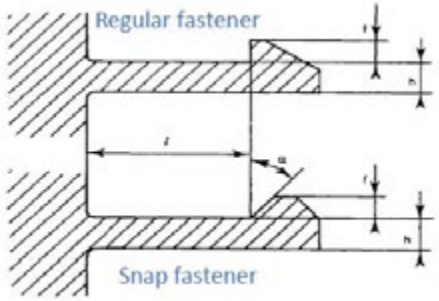


Figure 71: Difference in geometry for fasteners: while the snap fastener is easy to disassemble, the regular fastener with a right angle will require special tools and will risk breaking if not done carefully.

Focus on detachable connections

Detachable connections are crucial in design for disassembly and reassembly. The following presents some general concepts and non-exhaustive examples.

SCREWS

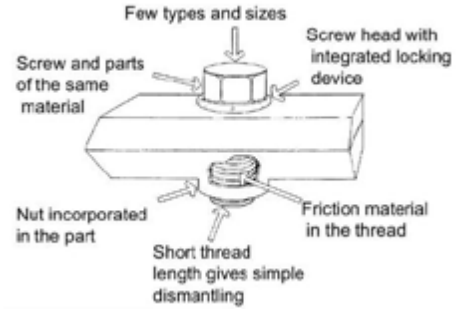


Figure 72: Guidance when using screws:

- The fewer the screws, the less time and effort to disassemble
- Only one type and size of screw (it requires only one tool, so no confusion during dismantling)
- Sturdy heads that are usable multiple times, like hex, Allen or Torx socket
- Making threads short and included in the body of the product

CONCEPT

CAM BOLT & CAM LOCK NUT

Figure 77: Cam bolt and cam lock nut are typically used when assembling ready-to-assemble furniture.

CONCEPT

KNAPP

Figure 73: The ZIPBOLTTM connector is a furniture frame connecting solution (without tool, self-tightening). Knapp®

Figure 74: Mod-eez® System and Mod-eez® Anti-Rotation clips, specifically designed for ready-to-assemble furniture and case goods. Knapp®

Figure 75: The DUO-System® is a dovetail frame connector (fast assembly without tool, self-tightening). Knapp®

Figure 76: Easy-con® is a universal and non-visible fastener for the assembly of staircases, panels, frames, and fixing of table legs. Knapp®

www.knapp-verbinder.com

CONCEPTS

HÄFELE

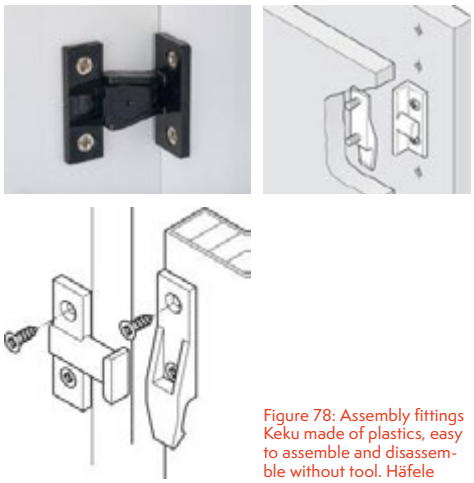


Figure 78: Assembly fittings Keku made of plastics, easy to assemble and disassemble without tool. Häfele

CONCEPT

CONCEPT

OVVO

Figure 79: Series of tool-free connectors by OVVO, clickable and easy disassemblable, for panels from 12 mm.

ww.ovvotech.com

LAMELLO

Figure 80: Clamex P-system is a demontable connector for panels from 12 mm Lamello

www.lamello.com

CONCEPT

Challenges for the stakeholders

For furniture manufacturer, the ease of accessing new materials compared to disassembling old furniture is challenging the use of circular materials and the adoption of circular principles. The complexity and cost of disassembly especially is a barrier because disassembling old furniture to recover components requires skilled labour and can be time-consuming, and the cost is more expensive than sourcing new materials and components. The opportunity is to adopt disassembly principles when designing furniture, to ensure the ease dismantlement of furniture into components and materials, and thus reducing the time and cost. Possibilities of reusing, refurbishing and remanufacturing businesses are facilitated, and even more if the manufacturer opts for circular business models in which the furniture is returned after use (i.e. the Furniture as a Service model, see the Circular Business Model guide).

Benefits for the new work trends
We have seen that disassembly principles are often linked to flexible, modular and upgradable furniture. Design for disassembly and reassembly is beneficial for the new work trends like flex offices, homeworking and co-working areas. In addition, it facilitates circular business models like Furniture as a Service, that companies can use when renting office spaces in office buildings.

F. DESIGN FOR STORAGE AND TRANSPORT

The manner in which a product is stored and transported can significantly impact the establishment of circular loops, making reverse logistics and the storage of returned products crucial elements. Optimizing the transportation of the product, along with its packaging, also results in cost savings for both manufacturers and distributors. From a circular economy perspective, packaging is regarded as a product with its own lifecycle. Consequently, all of the previously mentioned circular design principles are equally applicable to the packaging itself. Guidance for design for storage and transport and case studies for office furniture Optimal sizing of product and packaging Furniture and its packaging should be optimally sized to maximize the number of items that can be stored within a given space, thereby minimizing unused volume and avoiding the transportation of excess air. Both the furniture and packaging can be designed simultaneously, with considerations such as size, shape, and weight of the product. To achieve this, a disassemblable and/or modular structure can enable the furniture to be broken down into smaller subassemblies, making it more practical to transport and handle (e.g., flat-pack design), see Design for disassembly and reassembly and Design for flexibility principles.

-> Optimal sizing will reduce the need of additional packaging, thus using less material, and will increase the possibilities of take-back and reverse logistics (share or reuse by another user, sending a product to repair, collection for reconditioning, remanufacturing and even recycling)

Packaging

- **The packaging follows the hierarchy waste:**

- Prevention:
- minimizing the amount of packaging. Packaging should be avoided whenever possible, overpack omitted and tertiary packaging reduced.
- Thinner yet sufficiently rigid materials should be used.
- Reduce and unify the number of types of packaging as much as possible.
- Mutualize packaging, so that several products can be grouped together in the same package whenever possible

- Reuse: reusable packaging solutions exist and should be explored to be put in place by the manufacturer or the distributor. For instance, packaging that can be taken back immediately upon delivery.

- Recycling: recyclable packaging should be used according to the existing recycling systems. Using standardized packaging and materials is better to improve recycling. Limit the use of glue and ink.

EXAMPLE

STEELCASE

Classic Eco- Smart Eco- Smart+ Eco- Smart++

Figure 81: The Eco-Smart++ packaging from Steelcase has been reduced by 50% for optimal storage and transportation. It contains office chairs from the brand that are delivered into 4 pieces and assemblable in a few minutes. This tripled the number of chairs transported by trucks.

www.steelcase.com

EXAMPLE

NORMANN

Figure 82: A flat pack design for upholstered furniture seemed like a crazy idea for Normann Copenhagen. For the designer Hans Horneman, it was imperative that the flat pack principle should not imply any compromise with product quality and aesthetics. Thus was born the ACE lounge chair.

www.normann-copenhagen.com

Choice of materials:

- A minimum number of materials should be used, preferably a mono-material packaging system. For instance, use corner protectors made of the same material that the base packaging (in most cases cardboard). For corner protectors, expanded polystyrene (Styrofoam or EPS) should be banished.
- Paper and cardboard should come from sustainably managed forests having sustainable certification like PEFC or FSC. In addition, cardboard has the advantage to be reusable, recyclable and as well biodegradable. For the recycling and biodegradation, ink-free or water-based (natural) ink are preferred.
- Plastic films should be as thin as possible, made of high-quality recyclable homogeneous plastic (i.e. polyethylene) or with a maximum of recycled content. On plastics, printing has a bad impact on recycling rates, thus avoiding printing is preferred.
- If using wooden pallets for internal logistics or delivery, it is important to know that they can be repaired, either by the manufacturer itself (i.e. reinforcing the damaged connecting elements by hammering nails) or by sending them to a pallet repair specialist.
- **Fastening:**
- Staples and glues as a damageable connections should be avoided, unless for reusable packaging.
- The plastic films can be fastened by welding (it remains the same material) or with an adhesive that does not contaminate the recyclate.
- The adhesive tape and labelling should be from the same material than the packaging. Adhesive in addition should be without thread. An alternative solution for labelling is the use of a digital technology like the digital product passport (see Design for identification and traceability principle).

→ The choice of the packaging will highly influence if the packaging can be reused or recycle (in addition to the repair of the pallets).

Point of attention for a performant packaging:

Lightening the packaging is a way to save resources but it has as well some limits. A robust packaging allows to fully protect the product and avoid damaged and thus losses of products during the transport and distribution phases. A right balance has to be found between the quantity of material used and the function of the packaging (to protect the product during transport). Keep in mind that packaging is not a main contributor of the environmental impacts of the furniture along its life-cycle.
If damages occur after transport despite precautions, it is always better to sell the product at reduced price rather than discarding the product.

MATERIAL

MYCELIUM

Figure 83: The mycelium is the fungus' root network. It can be grown on a substrate of plant waste or sawdust to create a solid material that takes on the shape of the container in which it was grown. This material can replace expanded polystyrene in packaging. Several furniture distributors such as IKEA and Steelcase have launched initiatives using this material. After use, the material is biodegradable and compostable.

KINNARPS

Figure 84: The delivery of furniture for public environment is managed by Kinnarps itself , that controls all stages of the supply chain. For the packaging, Kinnarps uses blankets and reusable cardboard that are taken back and reused several times. This method of packing also enables 50% more furniture to be transported per trip because they are loaded in the truck like a Tetris, avoiding empty spaces. In this way, the quantity of packaging per truck is reduced by 270 kg.

EXAMPLE

Challenges for the stakeholders

Currently there are few drivers and underinvestment in the collection and logistics for furniture takeback. One of the reasons is the high cost of transportation (and labour skills) in many parts of the EU, making any reverse logistics for repair, reconditioning or remanufacturing costly. In general, economies of scale are needed to make these circular loops viable. A furniture design that optimally reduces the volume for transport is a step towards this economy of scale because less transport rotations are needed.

NOWYSTYL

Figure 85: NowyStyl has taken measurements to reduce the single-use cardboard and plastic film: reusable protective cover and blankets that come from their own fabric scraps ; tie-down straps and spacers for the internal logistics between the factories. These solutions allow to avoid the use of several tons of plastic films since 2020.

www.nowystyl.com

EXAMPLE

G. DESIGN FOR IDENTIFICATION AND TRACEABILITY

A product such as office furniture retains more of its value when data related to the product is accessible to all stakeholders in the value chain. This data includes information on materials, assembly processes, transactions, and the product's transportation, storage, and collection history. Such information is invaluable for efficiently managing end-of-use and end-of-life processes, helping to close product loops, and identifying new applications. Indeed, design for identification and traceability is a key element in several of the previously discussed circular design principles.
The new EU Eco-design for Sustainable Products Regulation (ESPR) will mandate the use of a Digital Product Passport (DPP) for certain product groups, including furniture, sold within the European market. The DPP will contain information related to eco-design and circularity, with specific requirements to be defined in the coming years through delegated acts. For more details, see Chapter 5 Compliance of the circular design principles with the ESPR.

Guidance for design for identification and traceability and case studies for office furniture

Instruction to use, maintain and recovery

- The instruction or documentation needed to use, handle and recover the furniture should be available for the corresponding stakeholder. Think about which information is essential to extend the lifetime and close loops. This means for instance (non-exhaustive list):
  - Use cases made this the products and use cases to avoid (e.g. outside use)
  - Exact composition of the product/parts/materials
  - Assembly and disassembly instruction
  - Maintenance and repair instructions (including sustainable cleaning product
  - recommandations), availability of spare parts and warranty
  - Collection and treatment facilities for the product/parts/materials, for reuse,
  - refurbishment, remanufacturing, and recycling
- The instruction or documentation should be easy to understand for every stakeholder. Think about amateurs that would like to repair the furniture without damaging it (and themselves).
- The manufacturer should guarantee a permanent or long-term availability of the instruction or documentation, e.g. through a manual guide, a QR-code, the manufacturer's website, etc.

→ A smooth exchange of instruction and documentation of the product among the actors of the value chain is one of the keys to enable and engage those actors to close loops. The availability of information are needed for all loops of the circular economy.

VAN HOECKE

Figure 86: Van Hoecke, manufacturer of drawer systems for kitchen and offices, has launched a web app where the customer can connect thanks to the QR code on the product. The app proposes after-sales services, like the reorder for restocking, the reporting of damage or the purchase for replacement of damaged parts.

www.vanhoecke.be

Digital traceability

A digital traceability of the product is a system to keep and save important data regarding each product sold (identified through a unique product identifier) and throughout its life-cycle. This means for instance (non-exhaustive list):

- composition of the product (model, parts, materials, connections, ...)
- location of purchase and location of the product, contact of the customer
- interventions performed on the product (i.e. repair, remanufacturing)
- quality of the product during use and reason of break

Thanks to a digital technology (see paragraph below), the manufacturer is able to identify, keep traceability and collect data of the product's life-cycle.

→ Keeping traceability and collecting data of the product is extremely valuable for the manufacturers that want to put in place (by themselves or through a third-party) a takeback or reverse logistic system for processing the reuse, reconditioning or remanufacturing of the product.

PLATFORM

ALVERO

Figure 87: Specialized in the renting of office furniture, Alvero integrates a furniture management platform for its clients. Thanks to a specific reader and an RFID tag affixed on each furniture, the customer is able to scan each furniture item over a distance of 50 meters, and get the inventory per area, room or floor. Information is also communicated like brand and model of furniture, maintenance history and foreseen maintenance cost, depreciation and residual value, circular economy value. This platform was developed by Alvero first for an internal need of inventory management.

www.alvero.de

SOLUTION

NIAGA

Figure 88: Niaga®, an adhesive manufacturer, collaborated with the mattress manufacturer Auping and proposed together the Niaga® tag, a label with a QR code, to enable a high recycling rate of mattresses. Among information on the composition of the mattress, the user finds by scanning the QR code instructions to return the mattress for recycling. In addition, they collaborate with the actors of the mattress value chain so that the discarded Auping mattresses in the usual collection routes will be recognized thanks to the tag and send to Auping for dismantling, reuse or high-quality recycling.

www.niaga.world

Focus on digital identification and traceability technologies

Several technologies exist and are already voluntary put in place for products (furniture or not). The ESPR didn't define the technology for the digital product passport, but only the minimum requirements needed for the information system. For the manufacturers, it is preferable to choose an identification standard in consultation with the bodies that have to identify end-of-use and endof-life products, to avoid a proliferation of different identification systems.

- Static and dynamic QR codes

QR codes (short for Quick Response code) can already be found everywhere in our lives. This black and white squares of pixels set in a grid can be scanned by a smartphone or a camera and quickly access a website where data is stored. As such, using a QR code is like typing an URL into a browser but is faster and more convenient.
While static QR code redirect to one URL address that can't be updated after being generated, dynamic QR code redirects to a second URL that can be changed on demand, if the content accessed by the QR code needs an update. This flexibility is often preferred if it is necessary to change the destination app or website.
A QR Code can be printed on different materials: on paper, on polypropylene or polyester at least. While paper is less durable and scratch-resistant than plastic, it is more compatible for recycling with wood and wood-based panels. On plastic furniture pieces or textile, it is recommended to put a QR code label of the same polymer type. On metalthe QR code label material is less significant because paper as well as plastics will decompose with heat at the metal recycling smelter.RFID (Radio Frequency Identification)

RFID is a wireless communication technology that is already used by many industries as tracking and inventory management solutions (i.e. in warehouse, logistics, retail). Through antennas, RFID readers communicate with electromagnetic radio frequency waves with tags (or chips) attached to the product, that store and transmit the data associated with the product. The readers can be static (like at the gates of shops) or mobile for volatile environments. The chips come in different shapes or sizes. It is composed of silicon for the circuit, copper, aluminium or conductive ink for the antenna, put on a substrate of PET or paper.

The use cases of RFID are various: tracking and assets management, to monitor each item's location and movement in a supply chain; supply chain management, to track at which stage the inventory of a company is; retail industry, especially in the clothing industry, to allow the retailers to automatically track the movement of individual garments through the store; but as well cargo logistics, healthcare industry, animal tracking, ...

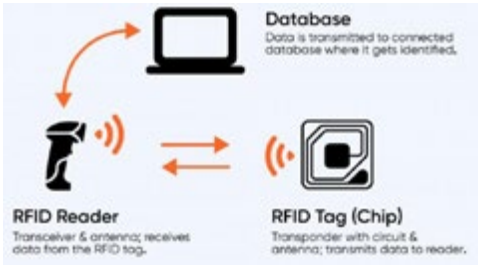
While RFID technology for tracking and sharing information is beneficial for recyclers to improve recycling rates, it is still uncertain if the materials of the chips, especially silicon, copper or aluminium, are a recycling disrupter or not. The risks exists of dissipating both toxic and valuable substances in the waste streams, and could disrupt the established recycling processes[14], but Aliaga et al. didn't report a decrease in the quality of the recycled plastic due to the presence of RFID tags[15].

- NFC tags

NFC – Near-Field Communication – is a subset of RFID technology, as NFC uses a shorter frequency range to communicate than RFID. Two devices, an NFC tag and a reader, are allowed to exchange data when they are near to each other (2-ways communication), usually less than 10 cm. The reader is able to read one tag at a time. This short-range limitation improves the security of data transmission, which makes NFC particularly suitable for sensitive operations such as payment with smartphone or cards and access control systems. Most modern smartphones or tablets are equipped with NFC reading capabilities. This greatly reduces the cost of implementing NFC tags, as users can read data simply by using their smartphones. A smartphone can read and write data on an NFC tag, access detailed metadata, launch apps or URLs. NFC is suitable for sharing information with customers and provide customer services, but also as track and trace system in warehouse and supply chain.

SOLUTION

RFID



ETAM

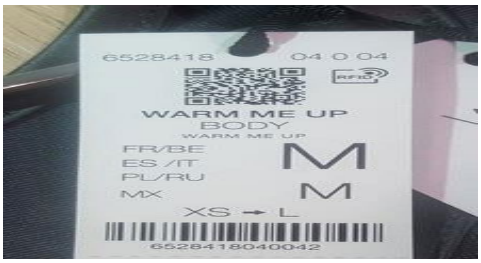
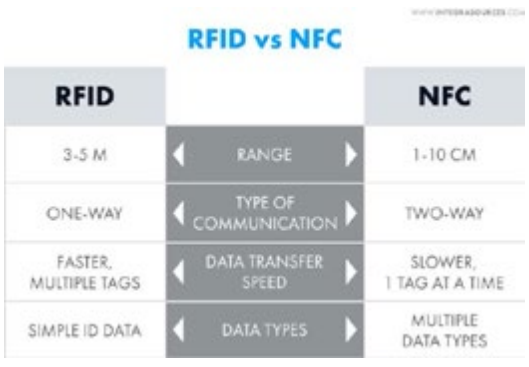


Figure 89: the French fashion and lingerie brand Etam deployed digital ID technology from Avery Dennison, which includes RFID and QR coded combined in one hangtag, which is a discreet solution to the need for both technologies, and avoids the inconvenience and cost of printing and attaching two separate tags to individual products. Clients can scan the product label by means of a QR code with their smartphone to get instant access to short videos that provide insights into the actual factory where the item was produced. The RFID inlay digitizes the whole value chain and processes, along with vendor shipments, store inventory accuracy and real-time stock levels, self-check-outs, returns or reverse logistics, e-commerce, and the retailer'game-changing Try@home initiative.

DIAGRAM

RFID VS NFC



[14] Abdoli, S. (2009). RFID Application in Municipal Solid Waste Management System, Int. J. Environ. Res., 3(3):447-454
[15] Aliaga, C., Ferreira, B. (2011). Influence of RFID tags on recyclability of plastic packaging, Waste Management Volume 31, Issue 6,

Challenges for the stakeholders

Challenges on identification and traceability of furniture are encountered in the use and maintenance phase. The companies, as furniture user, may not be aware of or fully understand the warranty period and services offered by most commercial furniture manufacturers. Warranty period ranges from 3 to 10 years depending on the type of product. This can lead to several missed opportunities to maintain or extend the life of office furniture, reducing the likelihood of furniture being repaired, refurbished or reused. Having a digital product passport as an industry standard (as foreseen in the ESPR) will make warranty and all relevant information clearly communicated and accessible to the companies. They will more likely use warranty and other maintenance services, thus extending the lifetime of furniture and reducing waste.
Another challenge is the ineffective or non-existent inventory management in office buildings. Without an effective inventory system, companies may struggle to identify when furniture is due for maintenance, repair or replacement, leading to unnecessary waste. It also makes it more difficult to prepare furniture for resale, donation, or reusing in different office spaces. Having a digital product passport for inventory management can facilitate the implementation of Furniture-As-A-Service (FAAS, see the Circular Business Models guide) by simplifying the return or exchange process, as the condition and history of each furniture can be easily accessed and verified. Digital product passport enables as well real-time tracking of furniture assets, including their location, condition and maintenance history.
The challenge of the disposal stage is to remain unclear to many stakeholders. Companies using office furniture might not be aware of the disposal possibilities among the take-back and reuse options explained above: which furniture collection services exist, where to deposit furniture, what will be recycled, incinerated or landfilled, etc. A Digital Product Passport (DPP) offers an effective way to communicate this information. Its value increases significantly if the technology system used can update the information in real time, ensuring the latest details about collection services and waste regulations are readily accessible.

Benefits for the new work trends

Having an identification and traceability technology on office furniture is beneficial for all stakeholders, including those of the new work trends. Co-working areas or flex office workplaces will gain time in their furniture inventory management thanks to a tracking system, and will be able to more easily repair furniture or return it for reuse or refurbishing, and thus reducing their waste and cost. Homeworkers using office furniture at home will get important information for maintaining and even self-repairing their furniture, thus extending the lifetime and reducing cost of purchase.

3.2 TOOLS TO MEASURE THE CIRCULARITY OF PRODUCTS

Knowing the different circular design principles and strategies for designers, tools are needed to compare conventional/linear products with newly circular products, in order to quantify the improvement. The most common and well-known tool for the quantification of the environmental impacts of a precise product (including its use and end-of-life scenario) is the Life-Cycle Assessment (LCA). However, LCA might not be suitable in our case for two reasons: 1) making a LCA study is quite time-consuming as it requires the collection of a lot of data, thus being less relevant at the design phase, and 2) LCA assesses the environmental impacts, which don't reveal clearly the circularity effort of the product.
In this chapter we focus on some simple tools that quantify the circularity effort of a product. It is thus easy to use at the design stage, comparing how the circularity measurement will evolve when implementing different circular aspects.

Material Circularity Indicator

The Material Circularity Indicator (MCI) aims to answer the simple question "How circular is a product?". Developed by the Ellen MacArthur Foundation, the MCI calculator requires to collect few data and allows to get started with a simplified look at the product and to add circular economy thinking in the product's design phase. The indicators can be used to take circularity into account as a criterion and input for design decisions. The indicators allow for comparing different versions ('what if' scenarios) of a product regarding its circularity at the design level.

The methodology[16] consists of calculating a single score, from 0 to 1, to assess the circularity of the product based on data to collect (see Table below). The calculator has been developed by thinkstepanz and consists of a free Excel-based tool[17]. The MCI is one of the circularity metrics that complies with the requirements of the new ISO 59020 standard on 'Circularity Metrics'[18]. It is to notice that the methodology can also be used at company-level.

MCI principles	Data collection
Sourcing biological materials from sustained sources	Quantity of biological materials (natural materials, bioplastics), sourced from sustained production
Using feedstock from reused or recycled sources	Quantity of reused, remanufactured and recycled materials
Keeping products in use longer (e.g., by reuse/redistribution/increase durability)	Lifetime of the product (vs. industry average lifetime)
Reusing components or recycling materials after the use of the product	Quantity of materials that will be reused, remanufactured, recycled (and collection rate)
Making more intensive use of products (e.g. via service, sharing or performance models)	Number of functional units achieved during the use of a product (vs. industry average functional unit)
Ensuring biological materials remain uncontaminated and biologically accessible	Quantity of biological materials that will be composted

MCI DIAGRAM

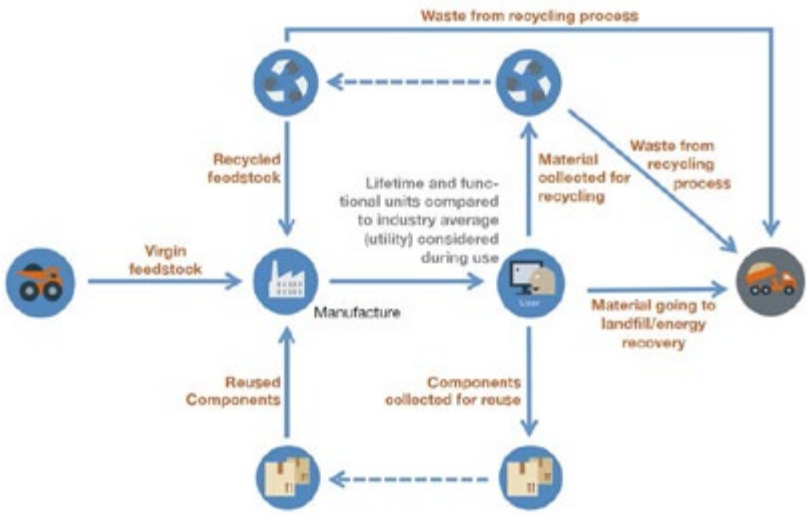


Figure 90: Material flows involved in the MCI (this diagram shows only the technical materials) and corresponding data needed.

FLOW

[16] To read the whole methodology and mathematical formula, see https://emf.thirdlight.com/link/3jtevhlkbukz9of4s4/@/preview/1?o

[17] Available on request here: https://www.thinkstep-anz.com/services/product/material-circularity-indicatormci-calculator/ISO 59020:2024

[18] Circular economy — Measuring and assessing circularity performance, published in 2024 https://www.iso.org/standard/80650.html

EXAMPLE MCI

EAMES WOOD SHELL CHAIR (BY VITRA)

Material	Quantity	Source	Destination	Lifetime
plywood shell - wood	1,30 kg	Virgin	Energy recovery	Same than industry average lifetime
plywood shell - glue	0,06 kg	Virgin	Energy recovery	
steel frame	2,50 kg	60:40 Virgin: recycled	Recycled	
Pads	0,10 kg	Virgin	Energy recovery	

Figure 91: As an example of use of the MCI, let's consider this Eames wood shell chair with standard materials and life-cycle scenario. According to the data in the table, the MCI = 0.55.

When applying some circularity aspects:

- The steel frame is remanufactured instead of new: MCI = 0.82
- The lifetime of the chair is 2 years longer than the industry average lifetime (thanks to material that last, timeless design and/or information for maintenance and repair for instance): MCI = 0.66
- The glue is biobased (and sustainably sourced) and not fossil-based: MCI = 0.56
- The steel frame is recovered at the end-of-use by the manufacturer for remanufacturing: MCI = 0.58

Circularity Potential Indicator

The Circular Potential Indicator (CPI)[19] aims at evaluating and improving the circularity potential of products during the design phases. The CPI is computed through a guided online questionnaire of twenty attributes impacting the circularity performance of a product, following the four building blocks of a circular economy defined by the Ellen MacArthur Foundation, namely: (i) circular product design, (ii) new business models, (iii) reverse systems, and (iv) enablers and system conditions. Each attribute is getting a score, which are aggregated into the Circularity Score of the product (out of 100).

[19] https://circulareconomyindicators.com/cpitool.php

METHOD

CPI

Circularity Performance Indicator Unlock the Circularity Potential of your Product		Circularity Score of the Product = (out of 100)
		43,42
	Selected option	
BB#1 – Circular Product Design (sub-score / 25)		12,3
ATT#1 – Materials selection and combination compatibility (sub-score / 5)		3,61
Number of differents materials	1 or 2	5
Technical recyclability of materials combination	Medium	2,5
Material contamination (coating, paints, and material mixing)	Low	3,33
ATT#2 – Modular product design, adaptability and flexibility		2,5
Is the product contained standardised components	Partly	1,67
Has the product being design with a modular mindset	Mainly	3,33

Product Circularity Data Sheet

The Product Circularity Data Sheet (PCDS)[20] is an inventory of data related to the circularity of a product. It helps manufacturers take the first steps towards transparency and product circularity. It can be used to establish how circular a product is and inform all relevant stakeholders about the circular path it was designed and manufactured for. The PCDS offers a standardized format with trustful data without scoring or ranking of these aspects. The tool consists of a data template containing standardized and trustworthy statements on the product circularity (free to download from the website), organized into 5 major sections which describe the key characteristics of product circularity. The system is completed by a third-party verification process (audit) to validate the content, and by a standardized data exchange protocol based on decentralized data storage.

Circularity Check

Developed by ecopreneur.eu and WeSustain21, the Circularity Check is a free online scan tool without external verification, that determines a circularity score for a specific product or service. The checklist consists of a questionnaire of about 60 questions divided into 5 indicators: design, procurement and production ; delivery ; use ; recovery ; sustainability. The outcome is a % of how circular the product or service is. Red flags are raisedfor a score of zero on one of the phases of the value cycle, or on sustainability. The checklist is especially helpful for self-assessment by companies – both SMEs and multinationals. It can serve in the design phase of a product or service by comparing the scores.

[20] The PCDS is an initiative by the Circularity Dataset Initiative, led by the government of Luxembourg: https://pcds.lu/pcds-system/#pcds

[21] https://ecopreneur.eu/publications/circularity-check-landing-page/

ISO 59000 circular economy series standards:

On May 22, 2024, The International Organization for Standardization (ISO) released a set of three new standards for implementing and measuring the circular economy:

- ISO 59004: Terminology, Principles, and Guidance for Implementation
- ISO 59010: Guidelines for the Transition of Business Models and Value Networks
- ISO 59020: Measurement and Evaluation of Circularity

The ISO 59000 family of standards is intended to harmonize the understanding of the circular economy and to support its implementation and measurement.

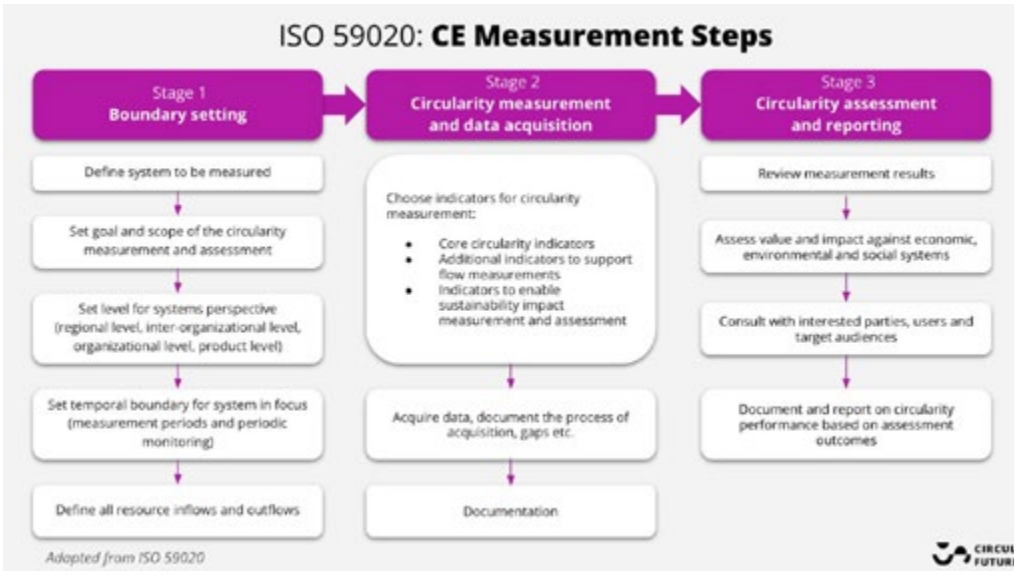
Together, the suite of ISO 59000 standards provides a framework for assessing, implementing and reporting on circular economy at different scales and enables companies to employ robust, measurable and transparent circular economy initiatives.
The ISO 59020 is particularly interesting to provide specific guidance on how to measure and assess circularity at different product, regional, organizational and inter-organizational levels.

NORMS

SUMMARY OF ISO CIRCULAR ECONOMY

NORMS

ISO 59020: CE MEASUREMENT STEPS



4.

COMPLIANCE OF THE CIRCULAR DESIGN PRINCIPLES WITH THE ESPR

4.1 WHAT IS THE NEW EU ESPR?

The new Eco-design for Sustainable Product Regulation (ESPR), entered into force on 18 July 2024, is a proposal from the European Commission to improve EU environmentally sustainable and circular products and their energy performance. Part of the EU Green Deal and the Circular Economy Action Plan, the ESPR establishes a framework legislation for setting eco-design requirements for sustainable products and to enable later adoption of specific measures.

The scope of products concerned are all products sold in the EU market (finished and semi-finished products), with the notable exceptions of: food; medicinal products for human use ; veterinary medicinal products; livings plants, animals and micro-organisms, products of human origin, and products of plants and animals; vehicles; products with the sole purpose of serving defense or national security.

Priority product groups for the implementation have been defined:

- iron, steel, aluminium
- textiles, notably garments and footwear
- furniture, including mattresses
- tyres
- detergents - paints - lubricants – chemicals

Delegated acts will be established within 5 years and per product groups with the following content presented in the Figure below. Among the eco-design requirements, the digital product passport and the substances of concern, which will be presented later in this guide, the other core elements of the ESPR are self-regulation, green public procurements, market surveillance and unsold consumer goods.

The EU Commission has the obligation to write the delegated acts per product group. Once the delegated acts are adopted, the Member states will have the obligation to adapt the delegated acts in the national legislation.

ESPR

PRODUCT GROUPS

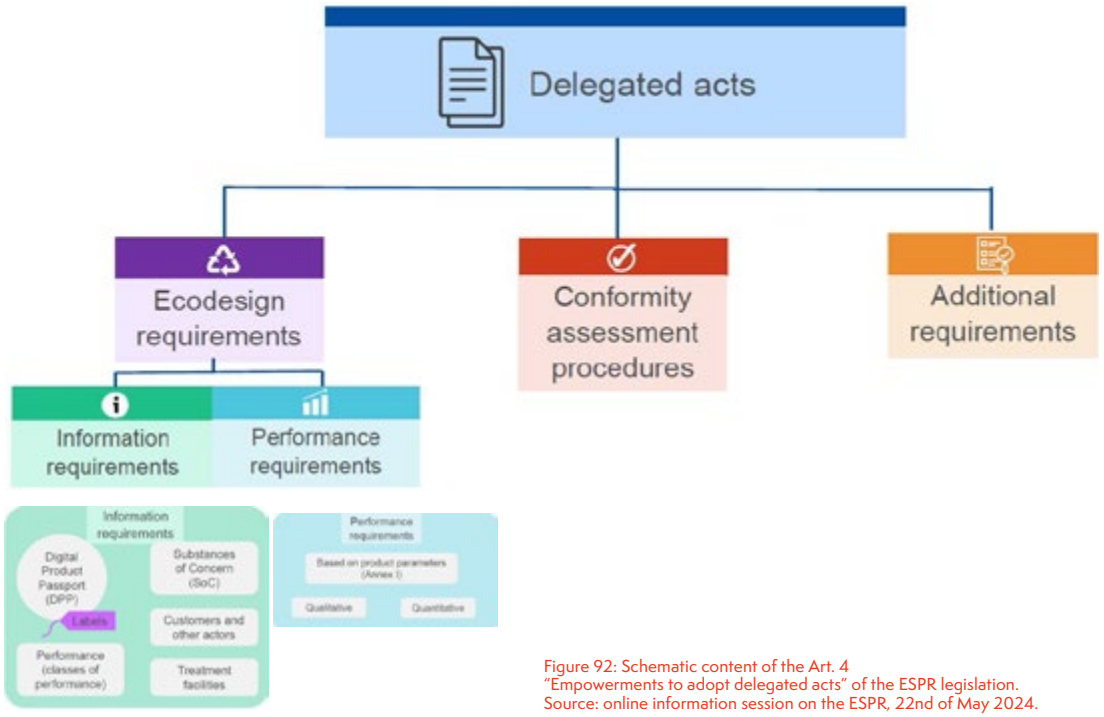


Figure 92: Schematic content of the Art. 4 "Empowerments to adopt delegated acts" of the ESPR legislation. Source: online information session on the ESPR, 22nd of May 2024.

The Figure below presents a tentative timeline and milestones of the adoption of the first ESPR measures, corresponding to the furniture product group, according to the information collected through our research[22].

TIMELINE

ADOPTION OF THE FIRST ESPR

Figure 93: Estimated timeline of the application of the ESPR measures for the furniture product group. Source: online information session on the ESPR, 22nd of May 2024.

[22] Disclaimer: the presented information for the estimated timeline and milestones of the ESPR implementation are the information collected at the time of the writing of this guide. Due to the hypothetical nature of milestones in the future, some dates may be different in reality, for which the authors of this guide cannot be held responsible

Eco-design requirements

The eco-design requirements, described in the Art. 5, aim to improve the environmental sustainability of specific product groups, and especially the following product aspects:

a. durability
b. reliability
c. reusability
d. upgradability
e. reparability
f. possibility of maintenance and refurbishment
g. presence of substances of concern
h. energy use or energy efficiency
i. water use and water efficiency
j. resource use or resource efficiency
k. recycled content
l. possibility of remanufacturing
m. recyclability
n. possibility of recovery of materials
o. environmental impacts, including carbon and environmental footprint
p. expected generation of waste materials.

PRODUCT ASPECTS

ASPECTS

The establishment of the eco-design requirements in the delegated act shall include performance and information requirements (Art. 6 and 7 respectively):

- The performance requirements is a set of qualitative and quantitative technical options to improve the products parameters (durability, maintenance and repair, reuse, remanufacturing, refurbishment, recycling, substances of concern, energy and water consumption, environmental footprint and emission to air, water and soil, etc). They take into account the economic viability, as well as the availability of resources and technologies for the technical options. The performance requirements will be divided into performance classes: the products that don't reach the minimum performance requirements are excluded products from the two highest performance classes are eligible for the EU Green Public Procurement.

- The information requirements refers at a minimum to the information required in the product passport and the tracking of all substances of concern (see paragraph below) throughout the life-cycle of the product. If appropriate, the information requirements can include information on the performance of the product, information to communicate to the user for installation, use, maintenance, repair and disposal in treatment facilities.

Digital product passport

The digital product passport (DPP) is part of the information requirements of the eco-design requirements, and is described in the Art. 9, 10 and 11. The aim is that products can only be placed on the market or put into service if a product passport is available. The DPP will simplify digital access to product-specific information as a decentrized approach for data storage, but is not a track & tracing tool, however it will allow traceability information when appropriate.

The information to be included in a DPP depends on the product group and will be identified in the delegated acts. It is therefore not possible to establish the list of precise information and data the DPP will include, but it may be the following areas, as appropriate for the product group:

- Technical performance and information related to the product parameters
- Environmental and sustainability performance: carbon or environmental footprint, substances of concern (see the following paragraph)
- Circularity aspects: scoring of reparability and durability, how to install, use, maintain and repair the product, how to handle the product at end-of -life, collection and treatment facilities for disassembly, reuse, refurbishment, remanufacturing, recycling and disposal
- Product-related information: user manuals, instructions, warnings, safety information
- Legal compliance documentation: declaration of conformity (CE), technical documentation, certificates, eco-labels
- Identification system: unique product identifier on model, SKU, batch or item level, Global Trade Identification Number, unique operator identifier (the manufacturer or the importer), Unique facility identifier

Among the information contained in the DPP, the delegated act will as well define other requirements, like the manner the DPP shall be made accessible to customers, to what information the actors shall have access, which actor may introduce or update information, or the period for which the DPP will remain available.

Substances of concern

The substances of concern (SoCs) are integrated in the ESPR according to 2 different approaches: tracking and restriction:

- The **tracking** of the SoCs is included in the information requirement and made effective through the DPP. It will enable the information flow (name, location in the product, concentration and safety instructions for use and end-of-life) and facilitate waste management operations (recycling, preparation for reuse, ...). By default, the following SoCs are tracked23:
  - Substances identified as substances of very high concern (SVHCs) in accordance with Art. 59 of REACH (Regulation (EC) No 1907/2006) → ≈ 450
  - Substances with harmonized classification in the following hazard classes or categories under the CLP regulation (classification, labelling and packaging of substances and mixtures regulation, CLP regulation (EC) No 1272/2008): carcinogenicity categories 1 and 2, germ cell mutagenicity categories 1 and 2, reproductive toxicity categories 1 and 2, endocrine disruption for human health categories 1 and 2, endocrine disruption for the environment categories 1 and 2, persistent, mobile and toxic or very persistent, very mobile properties, persistent, bioaccumulative and toxic or very persistent, very bioaccumulative properties, respiratory sensitisation category 1, skin sensitisation category 1, chronic hazard to the aquatic environment categories 1 to 4, hazardous to the ozone layer, specific target organ toxicity –repeated exposure categories 1 and 2, specific target organ toxicity –single exposure categories 1 and 2 → ≈ 5000
  - Persistent organic pollutants regulated under the POPs regulation (EU) 2019/1021 → some hundreds
  - Substances that negatively affects the reuse and recycling of materials in the product. These product-specific substances will be defined in product-specific delegated acts adopted under ESPR.
- The **restriction** of SoCs for sustainability reasons, focusing on the performance requirements and impact on eco-design: durability, resource use, possibility of recycling, reusing or remanufacturing, environmental footprint, ... ESPR will not provide for the restriction of substances based primarily on chemical safety, as it is already done under other legislations.

4.2 HOW THE CIRCULAR DESIGN PRINCIPLES ARE LINKED TO THE EU ESPR?

In Chapter 3 Principles of Circular Design, we explored the similarities and differences between ecodesign and the circular economy, emphasizing that eco-design guidelines are not always aligned with circular design principles. The ESPR outlines its own set of eco-design requirements that furniture, along with other product groups, will need to comply with once the regulation is fully implemented. This section will compare and contrast the circular design principles outlined in this guide with the eco-design requirements of the ESPR, highlighting both their similarities and differences.

- **Circular design principles directly linked to ESPR requirements**

The following ESPR requirements can be directly associated with some circular design principles of this guide, as they have been described in the corresponding circular design principles.

CIRCULAR DESIGN PRINCIPLES

"Reliability" is defined in the adopted ESPR text as "the probability that a product functions as required under given conditions for a given duration without an occurrence which results in a primary or secondary function of the product no longer being performed". In the product parameter annex, parameters of reliability and durability are defined together as "the product's guaranteed lifetime, technical lifetime, mean time between failures, indication of real use information on the product, resistance to stresses or ageing mechanisms". For that reason, we consider that durability and reliability are ESPR requirements that can be associated to the design for physical durability principle. The ESPR requirement "Possibility of recovery of materials" seems close to the "Possibility of recycling", as the recycling is the only circular loop at material level. The adopted ESPR text described further in this way: "Possibility of recovery of strategic and critical raw materials". This ESPR requirement is therefore associated with the Strategic material selection principle.

ESPR REQUIREMENTS

- **ESPR requirements linked to circular loops**

Some ESPR requirements are directly referring to circular loops as defined it in the paragraph Circular economy. The table defined how circular loops can be subdivided into the transversal circular design principles typology presented in this guide.
Therefore, the abovementioned ESPR requirements refer implicitly several circular design principles, e.g. design for disassembly, design for storage and transport, design for flexibility and design for identification and traceability.
On top of that, the ESPR requirement "Generation of waste materials" is referring to the entire circular economy concept, because this concept is led by the drastic reduction of waste.

- **ESPR requirements referring to eco-design principles.**

CIRCULAR DESIGN PRINCIPLES

These ESPR requirements are related to reducing water and energy consumption as well as reducing the greenhouse gas emissions. These aspects are the core principles of the eco-design, which is the reduction of the environmental impacts of a product along its lifecycle. But indirectly, these aspects are also related to the circular economy, because reducing the waste, lengthening the lifetime of the product and the value of the product and material will inevitably generate savings of water and energy, and reduction of greenhouse gas emissions.

4.3 IMPLICATION FOR FURNITURE MANUFACTURERS AND SUPPLIERS

Once the delegated acts are adopted, they will become applicable to economic operators within 18 months, during which time they will be required to comply with certain obligations. The following paragraphs outline the key obligations that may be retained; however, they should not be considered exhaustive, as these obligations may be subject to change prior to the adoption of the delegated acts.

Any actors of the supply chain

Upon request of the market surveillance authorities, the economic operator should provide the name of its product supplier and customer to whom the product is sold (as well as the quantity and model of product), and keep available for at least 10 years.

The economic operator should provide, free of charge and upon request to manufacturers, notified bodies and national authorities, all available relevant information related to their supplies or services. The notified bodies and national authorities are authorized to verify the correctness of the relevant information.

About the premature obsolescence and unsold consumer goods, the economic operator should take necessary measures to prevent the need to destroy unsold consumer goods. If the discard of unsold consumer goods is inevitable, the economic operator should disclose every year on his website the type and quantity of products concerned, the reason of the discarding, the destination of these products (reuse, recycling, energy recovery, ...) and the measures taken to prevent the discarding. On request of the EU commission or national authority, the operator shall provide all necessary detailed information. Micro and small enterprises are exempted from this obligation.

[8] most of the concepts for this paragraph have been taken up since: www.online-learning.tudelft.nl

Product manufacturers and importers

The manufacturers and importers should design the products according to the eco-design requirements. The corresponding information on these products, including technical documentation, should remain up-to-date for minimum 10 years and be provided to national authorities within 15 years upon request.

The manufacturers and importers should make a DPP available via an identifier on the product. They have the choice to run their own DPP platform (as long as it follows the requirements in the delegated acts) or to subcontract it to a DPP service provider.

A back-up of the DPP should be stored with a certified independent third party DPP service provider.

Among the information included in the DPP (according to the delegated act), some information should be available through another ways:

- contact details: (trade)name, postal address and electronic contacts, provided on the product itself, or on its packaging or in a document accompanying
- instructions to assemble, install, operate, store, maintain, repair and dispose the product, provided on paper on request of a consumer for free within 6 months after purchase
- health and safety information provided on paper

The manufacturers and importers should carry out conformity assessment (self-assessment or via certified body) and CE marking is added to the product. They keep as well a register of complaints and concerns for at least 5 years and make available on request to the market surveillance authorities.

The importers have an extra .obligations: they have to ensure that the conformity of the product between departure at manufacturer and arrival in EU remains in place.

Product distributors

The distributors have to make sure that the manufacturers or importers have complied with their obligations, in particular that the product is accompanied by all documents and information requirements and bears the CE marking.

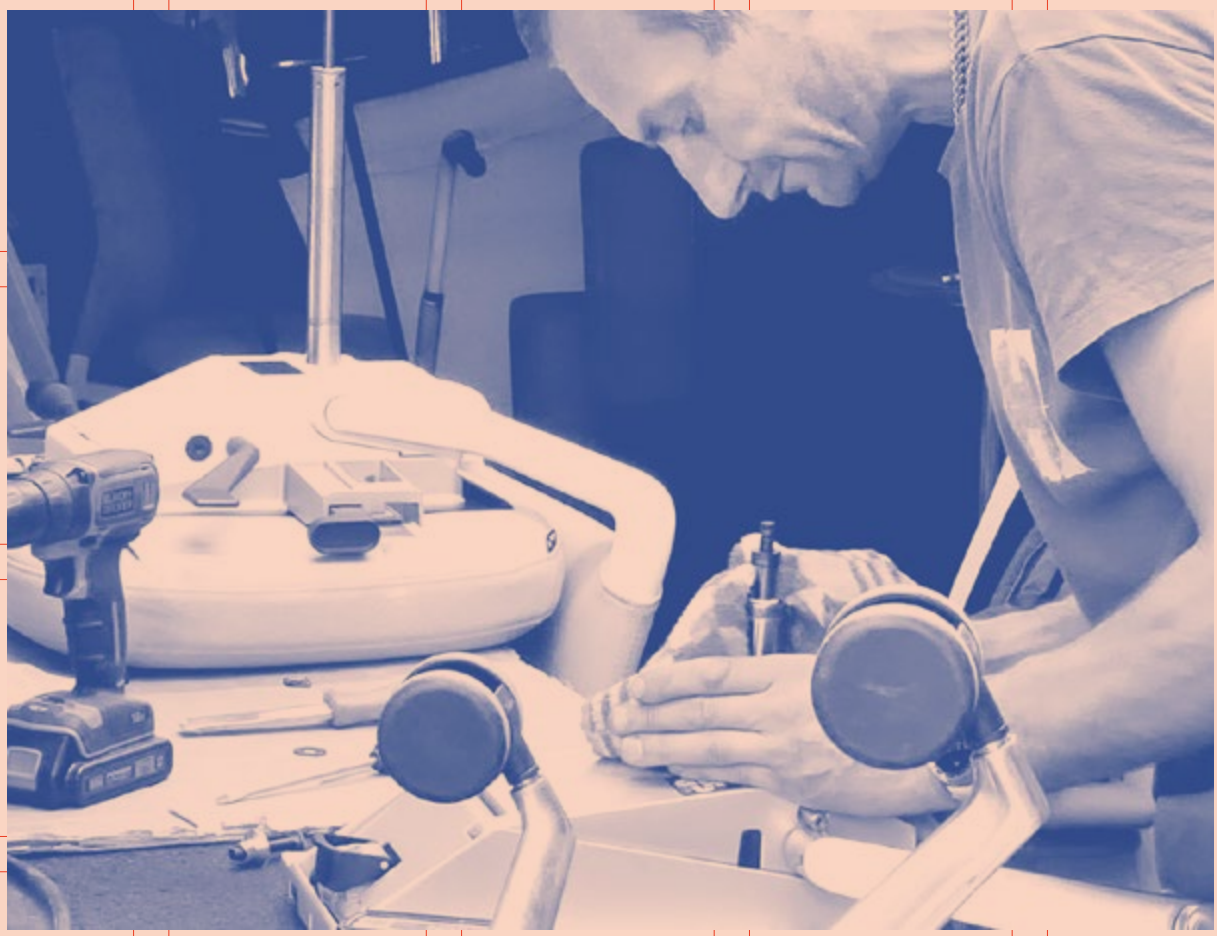
As the manufacturers and importers, the distributors have to keep a register of complaints and concerns for at least 5 years and make available on request to the market surveillance authorities.

Product dealers

The dealers have to make sure that the (potential) customers have access to the relevant information, including an easy access to the DPP. This applies in shops and via ebusiness websites.

5.

TECHNOLOGICAL PROCESSES FOR CIRCULAR MANUFACTURING



Keeping a product, component or material in use for as long as possible with the highest value may require some interventions when the product is damaged or has to change ownership. For this purpose, reuse, maintenance and repair are important circular loops that involve no or few minor interventions (cleaning, small repairs, ..) that can even be carried out by the user itself. Refurbishing (or reconditioning) and remanufacturing on damaged products require more substantial interventions from professional workers and adapted equipment to perform processes that will bring the product back to good conditions. This chapter focuses on existing technological processes for the refurbishing and remanufacturing of office furniture.

5.1 REFURBISHING AND REMANUFACTURING OFFICE FURNITURE: A GENERAL OVERVIEW

The following table gives a precise description of the characteristics of refurbishing and remanufacturing, taken from the definitions of den Hollander et al.[24] According to these definitions, refurbishing processes might be similar for different products, especially the refinishing processes on similar types of surface, while remanufacturing is very product-specific, requiring the original components of the product. The paragraph xxx will give examples of those processes.

Office furniture present some advantages for refurbishing or remanufacturing activities. In contrary to home furniture that are purchased to replace nonfunctional ones, office furniture is often replaced due to aesthetic and corporate branding reasons rather than functionality. Hence items are often replaced on an entire-office basis, rather than individual pieces. These characteristics make office furniture ideal for refurbishing and remanufacturing, because the bulk nature of e.g. reverse logistics means costs are not prohibitive and the

	Refurbishing	Remanufacting
Achieved product performance	Satisfactory working and/or cosmetic condition, that may be inferior to the original specification	New products of a similar type and specification than the original product specifications
Processes	Repairing, replacing or refinishing all major components that are markedly damaged, have failed, or that are on the point of failure.	Disassembling obsolete products into components, to a level as far down as needed to bring back to at least OEM (original equipment manufacturer) original performance specifications, and recombines those components—generally originating from different used products—with as few as possible new parts
Contractor	Companies not necessarily linked to the OEM - often private or social economy companies	An OEM, an OEM contracted third party, or a third party licensed to carry the OEM brand name
Warranty	Generally, any warranty on a refurbished product applies to all major wearing parts, but is less than that of a newly manufactured equivalent	A warranty that is identical to that of an equivalent product manufactured out of all new parts

[24] Marcel C. den Hollander, Conny A. Bakker, and Erik Jan Hultink (2017). Product Design in a Circular Economy - Development of a Typology of Key Concepts and Terms. Journal of Industrial Ecology

high relative cost to remanufacture products compared to the (re-)sale price requires large product batches. Similarly to the rest of the furniture industry, furniture remanufacturers are predominantly SMEs.
In order to stay competitive in the global market, European furniture manufacturers are starting to provide support services (both pre- and post-sales) and allow products to be returned. A model adopted by half of the OEMs (original equipment manufacturers) in the furniture sector is a take-back scheme where third-party subcontractors remove, process and resell old furniture, mainly office furniture[25]. OEMs also offer a refurbishment service to increase their sales of new furniture. In addition, some OEMs offer a scheme whereby an old item is traded either for a newly remanufactured product, or for the same product after a full service and warranty. See the Circular Business Models guide for more information.

Benefits and opportunities

Remanufacturing and refurbishing are part of the circular economy, and the clear benefits is the increase of material efficiency. Additional benefits are that these activities consistently achieve energy savings and cost savings relative to new products[26].

The European furniture supply chain is fragmented by nature, thus there is an opportunity to create new products and reach new markets with remanufactured end-of-life furniture. The biggest motives for remanufacturing in the furniture sector are to secure a supply of spare parts, protect the image of the brand, ad here to government legislation (e.g. green public procurement including circular criteria) and, most importantly, express responsibility to the environment[27].

Challenges and barriers

Even if the greater volume of office furniture gives good conditions to achieve cost savings with refurbishment and remanufacturing, economic performances still fluctuate with a number of variables. Viability relies on a reliable supply chain of virgin and remanufactured products whose durability and characteristics are such that the investment of further time, energy, and materials into their restoration remains both economically and environmentally preferable to virgin production.

According to a survey, the top barriers to remanufacturing in the furniture industry are customer recognition, volume and availability of furniture for remanufacturing, and legislation restrictions[28]. Several OEMs highlighted that remanufactured or refurbished furniture don't offer sufficient value for the costs incurred, and can risk to cannibalize their primary market, possibly reducing the higher profit margin obtained from new furniture. The lack of consumer confidence in the quality lead to a limited market for those furniture, even if there is some evidence to suggest this is changing.

A key issue to develop a robust supply chain is obtaining suitable products for remanufacturing and refurbishing. Trying to process the multitude of low-cost and low-durable furniture, as well as damaged furniture during collection because of a lack of proper handling can lead to further damage consumer perception, but also increase the costs involved to bring these items back up to a warrantable condition.

Another barrier for a robust supply chain is the collection and storage capacity. Transportation of products back to the manufacturing site can pose a difficulty, particularly if the manufacturer is not responsible for direct supply to customers which is often the case.
To address this issue, companies would have to form strategic partnerships with third party subcontractors to collect furniture. Storage capacity at OEMs is limited, which in turn limits the capacity of the industry to take back and store furniture for remanufacturing. Greater investment in larger properties or extensions are required in order to enable greater remanufacturing practices.

Trends in office furniture evolve rapidly with consumer demands and market preferences change rapidly, which means that the original style and/or function of recovered office furniture products by the time of remanufacturing may already be obsolete, and thus noncompetitive. Remanufacturers are therefore challenged to create products that are suitable for the current market.

Ban of chemicals evolve rapidly as well regarding several European legislation (see the Focus on the main EU regulations: in the Chemicals and substances of concern paragraph). When recovering furniture, it is not feasible to accurately list the coatings and other chemicals used in their production. This may present legal issues for the sale of remanufactured products if new legislation has prohibited the sale of chemicals which were used in the original production process. This can be encountered by the use of a digital product passport that contain the information of the product and material composition (see the Design for identification and traceability principle).

[25] European Remanufacturing Network, Remanufacturing Market Study, For Horizon 2020, grant agreement No 645984, November 2015
[26] Krystofik M., Luccitti A., Parnell K. (2018). Adaptive remanufacturing for multiple lifecycles: A case study in office furniture, Resources, Conservation & Recycling 135, 14–23
[27] European Remanufacturing Network, Remanufacturing Market Study, For Horizon 2020, grant agreement No 645984, November 2015
[28] European Remanufacturing Network, Remanufacturing Market Study, For Horizon 2020, grant agreement No 645984, November 2015

5.2 EXPLORING THE CIRCULAR MANUFACTURING MODEL AND PROCESSES

To thoroughly examine the refurbishing and remanufacturing of office furniture, and the potential for these innovative processes to establish new circular business models, interviews were conducted with companies from some countries within the North Sea Region. The range of possible processes goes far beyond simple refurbishing and remanufacturing, encompassing everything from cleaning to upcycling, through repairing and remanufacturing. Multiple circular loops are involved to keep office furniture and its components in use, avoiding the need for recycling. To capture this range of activities, the term "repurposed" has been adopted in the following section.

Type of companies involved

A broad spectrum of companies participates in the repurposing of office furniture. These range from large corporations, such as furniture manufacturers or distributors expanding their service offerings, to social enterprises (which may also be involved in waste collection beyond office furniture). Additionally, small and medium-sized enterprises (SMEs) play a significant role, including professional movers, interior designers, carpenters, and storage facilities, among others.

Office furniture collection

The first step in the repurposing process is securing access to used office furniture for recovery. Collection can be carried out by the company itself, if it forms part of their service offering (e.g., social enterprises that primarily collect waste or professional movers), or if the collection service is directly linked to the repurposing process (where the company collects the furniture from the customer). Alternatively, a third party, such as an eco-organism, may manage the collection process in collaboration with the company.

The quantity and quality of the furniture collected are crucial factors. High-quality office furniture requires fewer repurposing steps, thereby yielding greater economic benefits. A larger volume of collected items also enhances economies of scale, especially for large projects such as office fit-outs.

Variety of processes

Once the used furniture is collected, it is inventoried and undergoes quality control, which primarily determines the type of repurposing work required.

Minimal repurposing for high-quality items : If the furniture is in excellent condition and undamaged, some companies may opt to sell it as second-hand, with only a cleaning step involved. This approach minimizes the time, energy, and resources required, while maximizing both environmental and economic benefits.

Repurposing for damaged furniture: For furniture that is damaged, the extent of the repurposing required depends on the severity of the damage. Minor repairs might involve replacing small components such as chair wheels, screws, locks, resetting code locks, or performing minor touch-ups. In cases of more significant damage, the furniture may require deeper refurbishing or reconditioning. Common processes observed at the interviewed companies include:

- Replacing stained fabric on office chairs with new material.
- Repainting or upholstering the damaged shell of meeting chairs.
- Repainting the damaged metal frame of tables or chairs.
- Replacing or relaminating the damaged tabletop (using wood veneer or laminate).

Upcycling as a creative solution: In some cases, damaged furniture parts can be reimagined for a different function, a process known as "upcycling." For example, an old tabletop might be repurposed into an acoustic panel by resizing and adding acoustic foam and fabric.

Manual processes and labor involvement: Most of these processes are manual, with limited automation, such as CNC cutting machines. The diverse range of office furniture products and the relatively small volumes involved make large-scale automation economically unfeasible. Some processes may be carried out in-house, while others are outsourced to specialized third-party providers, such as powder coating or upholstering services.

Incorporating social employment model: It is also common for repurposing processes to be carried out, either partially or entirely, by workers facing employment barriers, including individuals with disabilities, those in rehabilitation, or the long-term unemployed. This practice, typically supported by government policies in certain countries, offers both social and economic benefits: it provides meaningful employment to

individuals facing challenges in the labor market, while reducing labor costs for the company.

Challenges in the repurposing processes: Challenges encountered during repurposing largely stem from the diversity of office furniture designs and the varying degrees of damage, compounded by the small quantities of products involved. A wide range of specialized skills is often required to perform the manual labor, which may not always be available in-house. This leads to collaborations with third-party specialists. Additionally, the small supply of similar furniture makes investing in automated production lines unfeasible, and the lack of readily available spare parts can complicate the replacement of worn components.

Selling repurposed office furniture

Repurposed office furniture is typically sold through two main models:

- **On Demand:** The company stores the collected used furniture until a customer places an order (through a quote) or a public procurement contract is secured. This "reconditioning on exit" model ensures that the company invests time and effort only for products that are guaranteed to be sold. However, this approach results in longer delivery times (typically 3 to 4 weeks). This model is particularly suitable for large orders, such as outfitting a large office space designed by an interior architect.

- **Direct Sale:** The company immediately repurposes the furniture upon arrival, known as the "reconditioning on input" model. The repurposed items are stored until purchased by a customer. While this approach results in shorter delivery times (a few days), it requires investing time and effort into furniture that may remain unsold for an unknown period. This model is particularly useful for selling small quantities of office furniture, such as for SMEs.

The manual nature of the work significantly impacts the cost of the final repurposed products. Prices can vary widely, ranging from 30% lower than the cost of new products to 30% higher. Despite the price being justified by the actual labor costs, some customers may hesitate to purchase what they perceive as second-hand items. However, some repurposed products feature additional upgrades (e.g., adding upholstery to a chair or incorporating an acoustic panel into a tabletop), which differentiates them from their original form and can be leveraged as a marketing point.
A limitation in sales arises from the availability of certain types of office furniture. Supply shortages can occur, which again reflects the challenges associated with the small quantities involved.

Encouraging Office Furniture Repurposing

A major challenge faced by companies is the lack of traceability for collected products. Without labels, serial numbers, or even brand or manufacturer information, it is difficult to assess the composition of materials and substances, which can hinder compliance with standards (e.g., fire safety regulations for school furniture). The introduction of digital product passports (see Design for identification and traceability principle) or at least serial numbers would greatly enhance the identification process for repurposed items.

Circular design is also critical in facilitating repurposing, particularly through the ease of disassembly and the use of standardized components.

Furthermore, there is a need for the regulatory framework to evolve in support of repurposing. In some countries, such regulations are either non-existent or insufficient, creating a barrier for companies looking to invest in circular business practices.

EXAMPLE

FAIR FURNITURE GROUP

Figure 94: The Fair Furniture Group opened its Circular Center in The Netherlands, a location where all circular operations on second-hand furniture take place, such as refurbishing and repairing. All products are leaving the Circular Center with a Fair Furnished label. This example is the refurbishment of a Vico Duo chair by Fritz Hansen. Main steps involved are: disassembling the shell from the frame, cleaning the metal frame, sanding and repainting the shell with a spray gun, upholstering and inserting it on the shell, reassembling. This refurbishment allows to recover the whole chair's component, and making it more comfortable by adding few upholstery materials (fabric, foam and wooden plate). The painting of the shell is a simple and fast operation to refurbish the shell that shows signs of wear.

www.fairfurnituregroup.de

EXAMPLE

LA RESSOURCERIE NAMUROISE

Figure 98: La Ressourcerie Namuroise, a Belgian waste collector and distributor of reused products, has also an upcycling activity to valorize the recovered furniture that are not suitable for selling: they are cut and transformed into glulam (glued laminated timber), suitable for making new furniture like desks, shelves, or interior design. For now, the manufacturing process of glulam is manual, involving high product price. To reduce the production cost and increase the production volume, an industrial production line is put into place at the time of writing this guide.

www.laressourcerie.be

EXAMPLE

NNOF

Figure 96: NNOF (Nearly New Offices) began its refurbishing activity when the parent removal company was left with a pile of office furniture and was looking for a solution to avoid throwing it away. It their locations in the north of Brussels, the refurbishing takes place in-house and in collaborations with third-party providers. This example is showing how old tabletops or event wall panels are refurbished: the panels go through a delamination machine that remove the laminate, to recover the raw panel (in this case, chipboard). A new laminate is then glued on the panel with a pressing machine. These refurbished panels can be used again as tabletops or wall panels.

www.nnof.be

EXAMPLE

ONBETAALBAAR

Figure 97: ONBETAALBAAR, one of the CEO partners, is an interior designer with a strong experience in using circular materials. This project was the refurbishing of old school chairs, made in collaboration with third-party providers. The chairs are disassembled, the metal frame are powdercoated and the wooden back and seat are reupholstered. In result, the whole chairs are recovered, and some new materials – powdercoat, foam, fabric and plastic caps – are added. This gives a completely new and different aesthetic and added comfort.

www.onbetaalbaar.com

EXAMPLE

EXAMPLE

DURIEZ

Figure 95: the French interior designer Duriez explored a way to refurbish and upcycle old desks. The desk is disassembled between the metal frame, the tabletop and the drawers. The metal frame is kept and lacquered (after sandblasting). A new panel is used as tabletop, the panel is veneered or laminated. On the panel, solid sheetings are glued on the edges and an oblong hatch is cut for cable routing. The whole panel is protected with a varnish finish and reassembled on the metal frame. The old tabletop is upcycle into an acoustic panel: after sizing, it is recovered by acoustic foam and wadding, upholstered with fabric, and finally attached to the refurbished desk.
This refurbishment and upcycling allows to recover most of the used desk (except the drawers). By adding new materials – veneered or laminated panel, solid wood, paint and varnish, acoustic foam, wadding and fabric – it gives to the outdated desk a beautiful and uncluttered aesthetic with the addition of a new functionality thanks to the acoustic panel.

6.

ANNEX

A. MATERIAL SHEETS

This annex is complementary to the Strategic material selection principle. It will give per material good practices for the choice of materials regarding the recyclability and circularity.

Wood and wood-based panels

Wood is the most popular material in the furniture products. When wood is used in products, is can be as massive wood or wood-based panels (i.e. plywood, chipboard, MDF, OSB), which are laminated most of the time.

Challenges for recycling:
Wood waste coming from furniture often belong to the grade B wood category, meaning slightly contaminated massive wood (painted, glued or varnished) and wood-based panels. These chemical contaminations are besides the physical contaminants or material impurities (usually plastic, metal, glass, textiles, concrete or stone) found in wood containers at the collection centers. These contaminants are one of the main challenge of the wood recycling. Grade B wood waste require additional processing and treatment before it can be recycled into particle boards or MDF. These processing include chemical methods to remove paints and coating, and mechanical processes like shredding and sorting (manual sorting, sink-float, gravity, magnetism, electric conductivity) to remove most of the physical contaminants.

However, because proper waste treatment processes are not always present in the sorting and recycling centers, in many locations grade B wood is not recycled into wood-based panels, but used as biofuels. The value of the material is completely lost with the burning.

Good practices for recycling:

- avoid if possible wood surface treatment for massive wood components and the use of other materials like metal components (see the Less (types of) materials guideline)
- Design the product for an easy disassembly into mono-material component (see the Design for disassembly and reassembly principle)
- Find out about the waste collection schemes of furniture and waste treatment of wood in territories where furniture is sold
- Inform the user about the waste collection schemes and the end-of-life actors about the disassembly of the product through a digital product passport (see the Design for identification and traceability principle)

Additional good practices:

- Choose for certified wood (i.e. FSC and PEFC for the sustainable forest management) and favor suppliers with chain-of-custody certification.
- Give preference to local wood species that are suitable for furniture use, i.e. oak, Douglas, larch, fir, beech, ash, birch, chestnut, walnut.
- Choose panels with formaldehyde emission levels that are better than E1 class.

EXAMPLE

UNILIN

Figure 99: Unilin is one of the leader wood-based panel manufacturer. For a number of years, the company has been committed to recycling. For the chipboard production, the wood is sourced at 95% from wood waste, coming from waste and demolition companies or recycling centers. Unilin has set up take-back programs – Wood Loop and Recover -, active in Belgium, The Netherlands and Northern France, to collect wood waste and production waste from furniture industry or interior builders. Unilin is able to recycle wood waste and wood-based panels into new chipboards after a series of treatment processes (magnets, sieves, vibrating conveyors and wind sifters) to end up with a clean wood stream. Nearly all the waste wood in Belgium that is not incinerated ends up at Unilin.

www.unilinpanels.com

Metals

Each type of metal has its own properties, that's why in furniture products they can respond to several needs, like structural elements, hardware components or decorative elements.

Challenges for recycling:

Ferrous and non-ferrous metals are easy to recycle and contain already a significant part of recycled material, but which is hard to estimate because of the complexity of the metal value chain. Finishing layers and post-treatment metal made of other materials complicate (high-value) recycling, or even make it impossible. The challenge is to ensure the qualitative recyclability of metals and to massively increase the amount of waste to be recycled. Indeed, the metal waste stream is insufficient to meet the demand for recycled materials.

Recycling metals and thus, avoiding the use of virgin metals, has a lot of environmental benefits. The pro-

duction of virgin metals contributes to the depletion of mining resources, of which zinc, copper and chromium (for stainless steel) are critical raw materials. Mining and refining metal ores are very energy-consumptive and responsible of soil and water pollution.

Increasing the recycling of metal means as well avoiding that metal components end up in incineration, because the incineration of metals involves significant impacts related to the treatment of bottom ash.

Good practices for recycling:

- Surface treatment of metal should be used only if it extends the lifetime of the product and does not interfere with recycling. For instance, galvanizing steel helps to prevent corrosion on furniture exposed to humidity. But galvanizing only for an aesthetic function should be avoided because it disrupts recycling and require critical raw materials.
- Additives that downgrade the recycling should be avoided. Metal alloys that contain less additives are easier to recycle, they are generally good candidates for recycling.
- Design the product for an easy disassembly into mono-material component (see the Design for disassembly and reassembly principle)
- Inform the user about the waste collection schemes and the end-of-life actors about the disassembly of the product through a digital product passport (see the Design for identification and traceability principle)
- The choice of metal suppliers should be in favor of those that guarantee the traceability of the material to obtain the actual recycled content, and that recycle their production scraps.

Additional good practices:

Like the other materials, but maybe more, the choice of metals has to make the best adequation between the use needs and the environmental and technical issues in terms of specifications and design.

- Use the best suited metal for the intended use. Dimension parts according to requirements. Choose materials and dimensions according to the load to be supported. For instance:
  - If stainless properties are not required, low-alloy steel has to be favored.
  - Metal parts should only be used for mechanisms that are subject to frequent use with very high bending strength requirements.
  - Choose aluminum over steel for weight reduction: if it offers a weight reduction of 55% or more, the choice of aluminum can be advantageous.
- When possible according to the requirements, metal can be substituted by a less impacting material having the same function. For instance, by replacing metal with another material with a metallic appearance, if it is not a structural part.
- Metal components are easy to reuse. They can be chosen for reusable structural elements. Anticipate the possibility of reusing materials as early as the material selection phase.
- Reused metal components should be favored at the design stage, with few reprocessing if possible.
- Zinc and copper are critical raw materials and their choice should be avoided.

Plastics

Plastics are composed of a polymer (thermosets i.e. polyurethane PU; thermoplastics i.e. polyethylene PE, polystyrene PS, polypropylene PP ; elastomer i.e. rubber) and a variety of additives i.e. dyes, fillers, stabilizers, plasticizers. All of them multiply exponentially the number of plastic formulation existing for a variety of use, including furniture components.

Challenges for recycling:

The high number of existing plastics is the main challenge of the recycling. There is no recycling process for each type of polymer, and some additives are recycling disruptors. In the plastics sector, recycling and the integration of recycled materials are becoming more structured, and the ambition is to continue to feed this source and to massively increase the integration of recycled plastic into production processes.

Good practices for recycling:

- Give priority to plastics that are technically recyclable and with existing channels: PET, PP, PE. The following table presents a summary of the conditions on the formulation of plastics to improve the recyclability rate. It shows the additives and other components to avoid.
- Plastic blends are to be avoided because they are not all recyclable (especially for textile, composite fabrics are not recyclable).
- Dyes in plastics should be avoided as much as possible because dyes affect the color of the

secondary material. In particular, dark colors strongly influence the color of the secondary material and pose additional challenges for automated sorting based on near Infrared spectroscopy.

- Plastic fillers are also to be avoided (e.g. glass fiber), because these plastics are not recyclable. If glass fiber would be needed in a plastic components for mechanical requirements, consider using other materials (e.g. wood, metal).
- Identification is the key for recyclers that need to know the chemical composition of the materials they are handling. At a minimum, the plastic resin codes should be molded on the plastic components. These plastic resin codes facilitate that non-packaging components follow the recycling routes that are mostly set up for packaging.

- Access to information on what chemicals ar in plastic products is a necessary condition to improve the recycling rate and the quality of the recycled materials. A digital product passport or other labelling system that contain this information is very helpful. See also the Design for identification and traceability principle.

Additional good practices:

- Give preference to certified plastics, i.e. Certified Responsible Source, Global Recycled Standard, Norme Française Matières premières de recyclage plastique, EuCertPlast, EU Ecolabel, TÜV OK Compost, OK Biobased and OK Biodegradable, Cradle to Cradle, ISCC.
- When choosing bio-based plastics (which are not necessarily biodegradable), there are some points of attention to keep in mind: in the current state of development, bio-based plastics do not systematically ensure a reduction in environmental impact compared than their fossil-based alternatives. The environmental impacts of bio-based plastics is highly dependant on the competitiveness of raw materials with food and on the use of fertilizers or intensive farming to grow the raw materials. Performing a life-cycle assessment (or requesting it from the suppliers) is the only way to make sure that the environmental impacts of bio-based plastics are better than fossil-based alternatives.
- Give preference to bio-based plastics whose raw materials are derived from waste or co-products: lignocellulosic biomass (wood, straw, etc.) or vegetable oils (castor oil, waste, etc.) For example, PA from castor oil or PE from industrial and food oils.

Recyclability	Full compatibility	Limited compatibility	Low compatibility
Thermo-forming mono PET	Additives: Silicone surface coating (on coating area); Antiblocking masterbatch (max 3%) Other components: components which are separated by grinding and float/sink (PE / HDPE / LDPE / PP / TPO, all with a density of < 1 g/cm³)	Additives: UV stabilizers; AA blockers; optical brighteners; antiblocking masterbatch (> 3%); anti-stat agents; antiblocking agents; anti-fogging agents (on coating area)	Additives: Bio/Oxo/Photodegradable additives; Nanocomposites Other components : PVC / PS / EPS / PU / PA; PC/PMMA; Thermoset plastics/metals; Materials with density >1 g/cm³ ; Non detaching or welded components
PP	PP with ≤ 10% TPO (full olefinic or aliphatic structure) Additives that are unavoidable in processing (stabilizers, antioxidants, lubricants, nucleating agents, peroxides) and density < 0.97 g/cm³	PP with ≤ 10% PE Additives: Mineral fillers (CaCO3, talc) not increasing density > 0,97 g/cm³ Other components: PE with density < 1 g/cm³; PET; PETG; PLA; PS all with density > 1 g/cm³	Multilayers PP ; PP with > 10% PE or with TPO containing rubber (e.g. EPDM) Additives changing the material density > 1 g/cm³; Flame-retardant additives, plasticizers; Bio-/oxo-/photodegradable additives Other components: Aluminium; PVC; Glass components; Non-PO and /or foams with density < 1 g/cm³
PS	Additives that are unavoidable in processing (stabilizers, antioxidants, lubricants, nucleating agents, peroxides) and in formulation (SBS copolymer) with density that remains between 1 and 1.07 g/cm³ No other components	Additives: Mineral fillers (CaCO3, talc) not increasing density > 1.07 g/cm³ Other components: Removable PP and/or PE	Additives increasing density > 1.07 g/cm³; Bio/oxo/photodegradable additives Other components: PET, PETG, PVC, PLA, metal, metal foil, paper; Any other material with density >1 g/cm³
EPS container (for packaging)	Monomaterial EPS – can be coated with PS foil White, uncoloured Additives that are unavoidable in processing (stabilizers, antioxidants, lubricants, nucleating agents, peroxides)	Light colours Additives : IR absorbers, Graphite	Any EPS packaging mixed with other polymer types, especially PVC, EPE, EPP, PUR Any other colours Additives : Mineral fillers, Any other additives (flame retardant, plasticizer, bio/oxo/photodegradable)
PE flexible films (for packaging)	Oriented and non-oriented LDPE, LLDPE (including PE-plastomers), HDPE; EVA, EBA, EEA, EMA copolymers with acrylate monomers representing ≤ 5 wt% of the film; EMAA, EAA copolymers & ionomers ≤ 20% Unpigmented; transparent Additives that do not increase the density higher than 0,97 g/cm³ Other components: LDPE, LLDPE (including PE-plastomers), HDPE	Multilayer PE/PP with PP ≤ 5% Light colours; translucent colours Other components : PP	Multilayer PE/PP with PP > 5%; Any other polymer (e.g. PET, PVC, etc.) Dark colours; black; carbon black Bio-/oxo-/photodegradable additives; foaming agents used as expanding chemical agents; Additives that do increase the density higher than 0,97 g/cm³ (CaCO3, talc, glass fibers, etc.) Other components: Metal, aluminum, PVC, PET, PETG, PS, PLA, paper, foams with density < 1 g/cm³

Source: Design for recycling guidelines, RecyClass. See more recycling conditions on this link

Textiles

In furniture, textile is mostly used as upholstery (in the case of carpets, it is a main part of the product). This usage can be solved by different types of textile, from synthetic fibers (i.e. polyester, see as well the Plastics material sheet) to cellulosic fibers (i.e. cotton) and animal fibers (i.e. wool) or even artificial cellulosic fibers (i.e. lyocell).

Challenges for recycling:

In the textile sector, a large source of textile to recycle is available in Europe. There are multiple barriers that hinder large-scale textile recycling:

- Mechanical properties: with mechanical recycling, the textile is shredded and the fibers become shorter, which lower the mechanical properties of the recycled fabric. That's why secondary fibers must be mixed with virgin fibers to spin a resistant enough yarn. Chemical recycling allows to obtain as-new fibers, but most of the existing processes are environmentally impacting.
- The heterogeneity of fabrics: the separation of multilayer fabrics and blended fabrics is very limited, the absence of mechanical solutions leaves only place for chemical solutions.
- Recycling perturbators: there are many types of perturbators: components like zipper, button and rivet, and chemical substances like dyes. For textiles, there is currently a consensus within certain companies that max 2% (by weight) of chemical contamination may be present.

In addition, when recycled, the integration of recycled textiles into products remains to be promoted.

The challenge is therefore to succeed in increasing the recycling of textile and massively integrating recycled textiles.

Good practices for recycling:

- Integrate post-consumer or at least post-industrial recycled materials coming for textile scraps. Nowadays, most of the recycled polyester is coming from plastic bottles. It is also important to incentive the textile recycling sector by creating a demand in the market.
- Limit the use of multilayer fabrics and textile blends, except if a disassembly technique exists. Fabrics and textile parts with different colors should be easy to separate from each other, that will enable the sorting into the 3 categories typically used today: white, light colors and others.
- Several persistent organic pollutants (POPs) are used in textiles for upholstery in furniture and other flame-retarded or surface-treated textiles or carpets (e.g. commercial penta-BDEs, deca-DBE, HBCD, SCCPs, PFOS, and PFOA). These hazardous substances are toxic for the health and the environment, and the risk in recycling is that a plastic waste that contains one of these chemicals will contaminate the whole recycled plastic batch. In addition, the Stockholm Convention's requirement on Persistent Organic Pollutants does not allow recycling of products containing Deca-BDE. See also the paragraph Chemicals and substances of concern.
- Dyes in textiles should be avoided as much as possible because dyes affect the color of the secondary material. In particular, dark colors strongly influence the color of the secondary material and pose additional challenges for automated sorting based on near Infrared spectroscopy. In textiles, the color can be limited to the visible parts. Prefer exemplary dyes: Oeko-Tex certified, natural and vegetable dyes limiting the use of metallic chemical substances.
- Access to information on what chemicals are in plastic products is a necessary condition to improve the recycling rate and the quality of the recycled materials. A digital product passport or other labelling system that contain this information is very helpful. See also the Design for identification and traceability principle.

Additional good practices:

- Prefer textiles with labels or certifications. Some examples: EU Ecolabel, Bluedesign®, Oeko-Tex® Step or Made in Green or Standard 100, Certified Responsible Source, Global Recycled Standard, Global Organic Textile Standard, Biore®, OK-Biobased, Cradle to Cradle, Responsible Wool Standard.
- Check suppliers' reliability with regard to fiber traceability, and if possible ask for a signed certificate of origin. This will allow to know the geographical locations of transformation and the origin of raw materials, and make better choices. For instance, prefer fibers from recycling routes close to production sites and avoid use of cotton from conflict zones or water-stressed areas.Foams

Foams

Foams are used in the upholstered parts of furniture to ensure seating comfort. The vast majority of these foams are made from polyurethane (PU). The common types of PU are the conventional TDI foam, the high-resilience (HR) foam and the viscoelastic foam (or memory foam). Given the complexity of the shapes that a foam can take for the upholstered part of furniture, the fabrication is
a molding process, unlike the slabstock foam which are continuous processed foam blocs usually used in mattresses.

CLIMATEX

PATENT

Figure 100: The patented DUALCYCLE system of Climatex is an innovative structure of textile designed for disassembly of blended textile. Natural and synthetic fibers are not spun into blended fabrics, but are combined in a new and unique way during the weaving process thanks to WAVELOCK, a third and dissolvable yarn. At the end-of-life, the disassembly occurs with heat, water and pressure, but without solvent, and enables to separate the two fabrics, which are suitable for recycling.

www.climatex.com

Challenges for recycling:

Two ways of recycling flexible PU foam exists today: the mechanical and chemical recycling.

- Mechanical recycling: it consist of grinding the foam into flocks and gluing these flocks into a block of rebonded foam. Today it is the main recycling process for PU foam, coming mostly from mattresses. The rebonded foam can serve in several applications like carpet underlays, pet mats and sound insulation in cars and buildings. However, the presence and nature of impurities must be known in order to ensure that the rebonded foam can be placed on the market with the appropriate guarantees, as required, for example, by the Waste Directive 2008/98/CE to comply with end-of-waste criteria.

- Chemical recycling: the foam is depolymerized in a tailor-made mix of chemicals, in order to recover the monomers of the PU foam – isocyanates (TDI or MDI) and polyol. The valuable monomers can serve again in the polymerization of PU foam. To fully exploit the recycling potential of these foams, the waste must be sorted according to the polyol and isocyanate used to make the original foam, otherwise inconsistent mixtures of polyols are produced. In addition, if waste is used in a chemical recycling process, the REACH regulation accepts that the resulting mixture may contain impurities < 0.1% if they are known and evaluated[29] (which is mostly the case, monomers and impurities in PU foam are already registered according to REACH).

In order to be recycled, the foam upholstered in furniture must be separated from the other components – the textile and the plastic, metal or wood frame. This is where the main challenge occurs today: the disassembly of discarded furniture is not a viable operation at the collection and sorting centers and is thus very rarely done (except for mattresses).

Good practices for recycling:

The following table presents some guidelines for the composition of the foam and furniture design with foam components in order to facilitate the recycling. The content has been taken from the report "Design-for-Recycling guidelines"[30] from WOOD.BE and Valumat, which draws up guidelines for the (re)design of polyurethane foams to stimulate a circular economy for mattresses.

But it is to notice that important aspects to increase the recycling are not in the hand of the designers and manufacturers: indeed, the waste sector should be organized in the countries and regions to incentive the dismantling of multi-material (complex) furniture - which for now mostly end up in incineration – i.e. thanks to an Extended producer Responsibility (EPR) scheme for furniture. For mattress products, the EPR schemes implemented in France, Belgium and The Netherlands has enabled a high recycling rate of PU foam in the mattress. Automated dismantling lines allow to separate the materials of a mattress, which is an easy process due to the regular shapes and design of all mattress products.

[29] REACH exemption 2, paragraph 7, point d), see also 'Briefing on REACH Requirements for Recovered Polyol', 10 December 2020, EUROPUR

[30] https://valumat.be/en/about-valumat/design-for-circularity

Category	Guideline	Routed impact	Comment
Product design			
Staples and clips	Ensure that the foam can be easily detachable from the frame and other material	All	
Several types of foams	Choose a single type of foam (conventional TDI, TDI HR, MDI HR, viscoelastic foam) or ensure that the types of foam are easily separable	All	
Adhesives and glues	Avoid gluing different types of foam and with different materials. Or glue only a few points to allow manual removal. Give preference to adhesives that break down during chemical recycling, are water-soluble or lose their adhesion over time.	All Chemical recycling	This would require an industrial standard to guarantee a consistent use. There is the possibility of relying on the requirements for a digital product passport ine the frame of the ESPR (see the Chapter Compliance of the circular design principles with the ESPR)
Foam composition and properties			
Certification CertiPURTM	Choose as much as possible foam suppliers having the CertiPURTM certification	Chemical recycling	CertiPURTM requirements on the composition of foams guarantees that the foams comply with REACH regulatory requirements (impurities after recycling <0.1% and restrictions on the presence of persistent organic pollutants (POP) and substances of concern (SVHC))
Foam density	Prefer higher density foams	Reuse, remanufacturing	Higher density foam extend the lifetime of the foam
Isocyanates	Avoid a mix of different isocyanates (TDI and MDI)	Chemical recycling	This should normally already be the case
Polyols	Prefer the use of an industrial polyol for conventional TDI foam and HR foam	Chemical recycling	Suggested polyols are polyol 3000 MW (molecular weight) with low solids content for TDI foam, and polyol 6000 MW for HRfoam. SAN-based (styrene-acrylonitrile) polymer polyols with high solids content form sticky deposits during chemical recycling and are thus to avoid.
Catalysts	Avoid organic tin catalysts	Chemical recycling	CertiPURTM requirements avoids contamination by tin-based chemicals like TBT (tributyltin)
Dyes and pigments	Prefer dyes and avoid pigments Avoid black and dark colors of foam	All	Pigments, especially dark colors, lower the quality of recycled polyols and interfere with Infrared sorting
Flame retardant	Liquid and solid flame retardants are not compatible with recycling and if they are contained in foams, the foams should be differentiated because they will have to be eliminated	Chemical recycling	Flame retardants are a potential source of persistent organic pollutants (POP) and substances of concern (SVHC) > 0.1% and thus incompatible with chemical recycling
Fillers	Calcium carbonate CaCO3 is to avoid	Chemical recycling	Calcium carbonate is usually used to reduce cost up to 10%. Not only it reduces the durability of the foam, but also the quality of recycled polyols

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Study conducted by **WOOD.BE**
for the CEO project
(Interreg Project under Grant agreement 41-243-22)

THANKS