

Circular Transition in the Furniture Sector

INSIGHTS FROM THE CIRCLER EUROPEAN PROJECT

Edited by

Mauro Attilio Ceconello and Rebecca Squeri

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Introduction

Mauro Attilio Ceconello, Rebecca Squeri

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This publication examines the skills and strategies required to support the circular transition of the European furniture sector. Developed from the results of the CirCLER project, an Erasmus+ initiative bringing together higher education institutions, research and technology centres, sectoral associations and vocational education and training providers, the volume offers an interdisciplinary contribution to understanding how circularity can be embedded into real industrial practice, from regulation and business models to design, technology, and professional training.

Rather than treating these dimensions as separate topics, the book is organised around a systemic perspective: regulatory change, professional competences, business innovation, design strategies, enabling technologies and training methodologies are presented as interdependent parts of a single transition, each shaping and being shaped by the others. At the centre of this transition is the Circular Economy Transition Manager (CETM), a new professional profile developed within CirCLER to bridge strategic sustainability objectives and day-to-day operational decisions across the furniture value chain.

The twelve chapters that follow trace this transition from its broadest framing to its most concrete implementation.

Chapter 1 introduces the CirCLER project and situates the volume within a systemic perspective on the circular transition. It presents the project's origins, partnership and objectives, explains why regulation, competences, business models, design, technology and training need to be read in relation to one another, and provides a map of how the rest of the book is organised.

Chapter 2 analyses the main European policy instruments driving the sector's circular transition, including the Corporate Sustainability Reporting Directive (CSRD), the Ecodesign for Sustainable Products Regulation (ESPR), the Right to Repair, Extended Producer Responsibility (EPR) and the Digital Product Passport. The chapter also addresses the management of chemical substances and the broader regulatory ecosystem shaping transparency and environmental accountability across the value chain.

Chapter 3 defines the CETM profile as a hybrid role connecting strategic objectives with operational implementation. It presents the competence framework developed within CirCLER, structured into six interconnected domains (Values, Interpersonal, Systems, Strategic, Operational and Futures Thinking) in response to the training needs identified through the project's empirical research.

Chapter 4 adopts an ecosystem perspective to examine how circular business models in the furniture industry are enabled and coordinated across networks of interdependent actors. Drawing on ten European case studies, the chapter shows how the viability of these models depends on the alignment between value logics, ecosystem configurations and the concrete realisation of lifecycle loops such as reuse, refurbishment and remanufacturing.

Chapter 5 illustrates the strategic role of design in shaping the environmental impact of furniture products from the earliest stages of development. Through Life Cycle Thinking and the 9R framework, the chapter shows how design decisions concerning materials, disassembly and information systems influence the future recovery of value across the product life cycle.

Chapter 6 examines research and development techniques supporting the creation of innovative, low-impact materials, including

bio-based composites and natural fibres. The Technology Readiness Level (TRL) framework is introduced as a tool for managing innovation processes and guiding the development of more sustainable and higher-performing materials and components.

Chapter 7 explores how digitalisation and key enabling technologies contribute to improving production efficiency and resource traceability. The integration of tools such as Digital Product Passports, digital twins and enterprise resource planning systems is shown to support complex circular strategies, including material recovery and remanufacturing, across fragmented manufacturing value chains.

Chapter 8 focuses on vocational education and training (VET) systems as a key policy lever for anticipating the industrial change generated by the circular transition. The chapter discusses the need to redesign curricula to develop hybrid professional profiles and to build skills ecosystems grounded in collaboration between education providers, companies and public authorities.

Chapter 9 presents the training methodology developed within CirCLER, based on modular, multimedia *learning pills* designed to support flexible and autonomous learning. The chapter emphasises experiential and work-based learning as a way of translating theoretical knowledge into practical solutions applicable to the furniture sector.

Chapter 10 examines the role of distance learning in widening access to professional upskilling across the sector, discussing how digital platforms and online education help overcome geographical, organisational and economic barriers to training while addressing challenges such as learner motivation and digital accessibility.

Chapter 11 explores the role of mentoring and collaborative digital tools in supporting trainers delivering the CETM course online. The Circular Furniture Mentors' Club is presented as a peer-learning environment that facilitates knowledge exchange among trainers while reducing the administrative burden of supporting an asynchronous, multilingual training programme.

Chapter 12 synthesises the project's main results, showing that the circular transition requires a significant cultural and organisational shift in addition to technological change. The CETM emerges as an interdisciplinary profile capable of addressing economic and infrastructural barriers, and the chapter closes by reflecting on the

importance of continuous learning and systemic collaboration among stakeholders for strengthening the resilience and competitiveness of the furniture sector within a circular economy.

1. The CirCLER Project: A Systemic Perspective on the Circular Transition of the Furniture Sector

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ABSTRACT

This opening chapter introduces the CirCLER project and the reasoning behind this volume. It explains why the circular transition of the furniture sector cannot be understood by looking at regulation, business models, design, technology and training separately, and why this book treats them instead as connected parts of a single process. The chapter presents the origins, partnership and goals of CirCLER, a three-year Erasmus+ initiative that developed the Circular Economy Transition Manager (CETM) as a new professional profile for the sector. It shows how the eleven chapters that follow are organised, reflects on the variety of perspectives the volume brings together, briefly describes how CirCLER's results were built and tested, clarifies who the book is written for, and closes with a short, practical summary for furniture companies.

1.1 Introduction

The furniture sector holds a particular place in the European economy. It is a significant manufacturing market, accounting for a substantial share of global furniture production, and at the same time a sector with a heavy environmental footprint: it generates millions of tonnes of waste every year, most of which is still incinerated or landfilled rather than recovered (Pei *et al.*, 2024). These two facts together explain why the sector occupies a prominent place in the European Union's circular economy agenda, as discussed in more detail in Chapter 2.

Knowing that a sector has high circular potential, however, is not the same as realising that potential in practice. Turning regulatory ambition into everyday industrial decisions requires people who can translate strategy into action: professionals able to coordinate design, production, procurement and end-of-life management, and to keep that coordination going over time. This is the gap that motivated the European project behind this volume.

CirCLER: Circular Economy Transition Manager: guiding companies of the furniture value chain to deploy their transition strategy for a more circular economy is a three-year Erasmus+ initiative co-funded by the European Union, with further administrative and implementation details given in Chapter 11, where the project's pilot phase is discussed. Its starting point was a problem stated plainly in the project's own founding documents: "The sector lacks the occupational profile of the Circular Economy Transition Manager (CETM) and the related necessary training" (CirCLER Project, 2024). This chapter, and the volume it introduces, tries to address that gap – not just by describing a new professional profile, but by showing, across eleven chapters and as many disciplinary perspectives, what it actually takes to build the professional, educational and technological groundwork that such a profile needs.

1.2 The CirCLER Project: Origins, Partnership, and Objectives

CirCLER brings together higher education institutions, research and technology centres, sectoral associations and vocational education

and training (VET) providers from across Europe. This kind of partnership matters because no single type of organisation has all the knowledge needed to support a sector-wide transition on its own – a point this chapter returns to in Section 1.5. The project's goal is two-fold: to define the Circular Economy Transition Manager as a recognisable professional profile for the wood-furniture sector, and to build the training infrastructure – curricula, learning materials, an online platform, and a community of practice – needed to prepare this new generation of professionals at scale (CirCLER Project, 2024).

In practice, the project produced a sequence of connected outputs. First, an empirical study of the knowledge, skills and competences required by the CETM role, presented in full in Chapter 3. Second, a joint curriculum spanning three levels of the European Qualifications Framework (EQF 4-6). Third, a multilingual online training toolkit, including a self-assessment tool linked to relevant ESCO occupational profiles. Fourth, a pilot phase in which the curriculum and toolkit were tested with learners from across the European furniture sector, reported in Chapters 10 and 11. As is typical of Erasmus+ partnerships, the value of the project lies as much in this sequence of outputs as in the collaboration itself: the alliance between higher education, VET providers, technology centres and industry associations is meant to function as a lasting mechanism connecting training to the real needs of the labour market, not just as a temporary project consortium (European Commission, 2023).

The furniture sector makes this kind of collaborative structure particularly necessary. Unlike sectors with a more concentrated industrial base, furniture manufacturing in Europe is characterised by a large number of small and medium-sized enterprises, geographically dispersed across different national contexts and design traditions, operating within supply chains that often cross multiple countries and material systems. No single type of organisation holds a complete picture of this complexity. A university research team may understand the regulatory landscape and the theoretical foundations of circular design, but lacks direct access to the shop-floor decisions of a family-run manufacturer. A VET provider knows how adult learners absorb new competences, but may not fully grasp the technological infrastructure needed to track materials across a dismantled product.

A sectoral association understands what companies say they need, but may not know how to translate that into a structured curriculum. The consortium model of CirCLER was designed precisely to bring these partial views together, not just administratively, but as a genuine epistemological choice: the knowledge produced in this volume is stronger because it was built by people who see the problem from different sides.

The chapters that follow document, from different disciplinary angles, how this general ambition became a regulatory analysis, a competence framework, a set of business and design strategies, a set of technologies, and, ultimately, a training methodology tested with real learners. The rest of this chapter explains how to read the volume as a whole.

1.3 Why a Systemic Perspective?

It would have been possible to organise this volume as a list of separate topics: policy in one section, business models in another, design strategies elsewhere, technology in its own chapter, and training as a final, loosely connected addition. This is not the approach we have taken. Research on sustainability transitions has repeatedly shown that such transitions cannot be reduced to the sum of their parts: they involve regulation, business practices, technology, organisational routines and professional skills changing together, not one at a time (Markard *et al.*, 2020).

Figure 1 summarises this idea for the specific case of CirCLER. Five dimensions of the circular transition (policy and regulation, business and design, technology, training and skills, and the everyday practice of people inside organisations) are shown as connected rather than separate. The CETM sits at the centre of the figure because this is precisely the role's purpose: to connect what happens in each of these areas to what happens in the others, inside a real company.

This way of thinking also explains why sustainability transitions cannot be left entirely to technology or to regulation alone. Research on how such transitions actually unfold has shown that workers and professionals are not passive recipients of strategies decided

elsewhere: their day-to-day decisions determine whether a strategy is actually implemented or not (Moilanen & Alasoini, 2023). Even small, local initiatives at the level of individual roles and routines can grow into organisation-wide change, provided the right skills and the right organisational support are in place (Ivory & MacKay, 2020). The CETM, discussed at length in Chapter 3, is designed to be exactly this kind of professional: someone positioned to turn external pressure (regulatory, market, or technological) into concrete, everyday operational decisions.

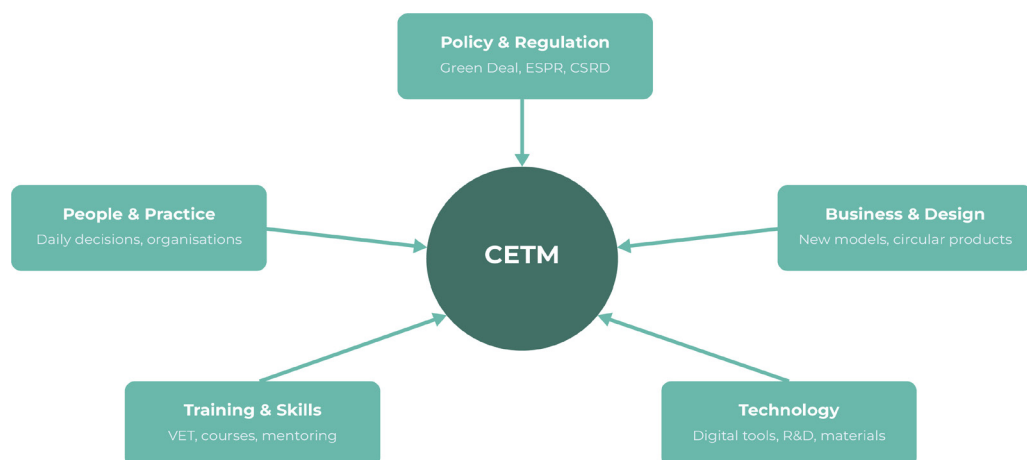


Figure 1.
Five connected
dimensions of the
circular transition of the
furniture sector.
Source: authors'
elaboration.

A systemic perspective, in other words, is not an abstract preference. It is the most accurate way of describing why a volume on the circular transition of the furniture sector needs chapters on policy, competences, business models, design, technology and training; and why these chapters are meant to be read in relation to one another, not as separate units.

1.4 How This Book Is Organised: Connecting the Chapters

The eleven chapters that follow this one are grouped into five thematic areas that reflect the five dimensions of the circular transition introduced in Section 1.3. Figure 2 summarises this structure.



The first area concerns the regulatory and professional context. It examines the European policy instruments that are reshaping the rules of the game for furniture manufacturers, from product design requirements to transparency obligations, and translates this regulatory pressure into the competence framework that defines what a professional capable of navigating this landscape actually needs to know and be able to do. Regulation and competence are treated together because one without the other produces little: rules without the people to implement them remain on paper, and competences without a regulatory context to anchor them lack direction.

The second area moves from context to practice, examining how circular principles are currently enacted within real companies and real products. This includes both the business models through which companies are reinventing their relationship with materials, clients and supply chains, and the design strategies through which products are conceived from the outset to last longer, be maintained more easily, and return to use rather than becoming waste. These two dimensions (business and design) are adjacent in the book because they are adjacent in practice: a furniture product can only be truly circular if the business model surrounding it is designed to recover it, and a circular business model can only work if the products it handles are designed to be recoverable.

The third area addresses the tools and technologies that make circular strategies operationally feasible at scale. This covers both the

Figure 2.
How this book is organised: six blocks, from policy and foundations to final reflection.
Source: authors' elaboration.

research and development techniques used to create more sustainable and innovative materials, and the digital and enabling technologies, from product passports to enterprise data systems, that allow companies to track, manage and act on material information across complex value chains. Technology is treated not as an end in itself, but as an enabler: it is only useful insofar as it supports the business decisions and design intentions described in the previous area.

The fourth area turns to the human infrastructure of the transition: the vocational education and training systems that must prepare a new generation of professionals, the pedagogical methodologies developed to make complex sustainability concepts accessible to diverse adult learners, and the distance-learning and digital tools that allow this training to reach people across different countries, languages and organisational contexts. The underlying question here is not only what professionals need to learn, but how they can learn it in ways that are realistic given the constraints of working life in a small enterprise.

The fifth area, finally, documents how all of this was tested in practice. The pilot implementation of the CETM course, with its learner numbers, its multilingual delivery, its community of practice and its feedback, provides the empirical grounding that turns the rest of the volume from a theoretical proposition into a tested framework.

A concluding chapter then draws together what the project as a whole revealed: where the framework held up, where it needed adjustment, and what remains to be explored.

Throughout all five areas, the Circular Economy Transition Manager profile functions as a connective thread. The chapter dedicated to this profile explains explicitly how the competence domains it defines connect to each of the five thematic areas, providing readers with a direct map between professional skills and the knowledge developed across the rest of the volume.

1.5 A Plurality of Perspectives

One of the first things readers will notice about this volume is how different its chapters are from one another. They are written by universi-

ty researchers, applied technology centres, sectoral associations and vocational training providers. Some chapters read like academic literature reviews, others like practical implementation reports; some rely mainly on regulatory analysis, others on laboratory work, others again on data collected directly from hundreds of learners across more than a dozen European countries. This variety is not something to smooth over. It is, we think, one of the volume's main strengths.

The reasoning behind this is fairly simple. Models used to study how different organisations jointly produce innovation, originally developed to describe relationships between universities, industry and government, have gradually been extended to include civil society and, more recently, the environment itself, as distinct contributors to the process (Carayannis *et al.*, 2021). Applied to a project like CirCLER, this means that no single type of organisation could have produced, on its own, the knowledge needed to support a sector-wide transition. Academic research brings conceptual rigour; technology centres bring applied, industry-tested expertise; sectoral associations bring direct knowledge of company needs; VET providers bring pedagogical experience built over decades of vocational practice. Put together, this knowledge is more complete than what any one of these actors could have produced alone.

Readers should therefore expect, and we would suggest welcome, a certain unevenness of style across chapters. A chapter analysing European regulation reads differently from one documenting laboratory work on bio-based materials, which in turn reads differently from a chapter reporting survey results from a training pilot. What ties these different styles together is not uniformity, but the shared object of study, the circular transition of one sector, and the way each chapter's contribution connects to every other, as described in Section 1.3.

1.6 Narrating the CirCLER Experience

Behind the conceptual architecture presented in this chapter lies a concrete, multi-year process of collaborative research, structured expert validation and real-world pilot testing. Describing it briefly here is not a formality: it matters because the legitimacy of the framework

developed within CirCLER rests not only on the quality of the ideas it contains, but on the process through which those ideas were built, challenged and refined. This volume is not a collection of independent expert opinions assembled between covers; it is the record of a process in which different disciplines, professional traditions and national contexts worked together on a shared problem, disagreed productively, and produced something that none of them could have produced alone. Understanding how that process worked helps the reader interpret what follows, and to appreciate, in particular, the difference between knowledge that has been tested against real learners and real companies, and knowledge that has merely been theorised.

The work began with a survey-based study of the competence gaps affecting the furniture sector's transition to circularity, which underpins the framework presented in Chapter 3. This was followed by a structured validation process involving circular economy specialists, VET and higher education professionals, furniture manufacturers and other industry consultants, who assessed how important each competence is, how well current training covers it, and, where relevant, how proficient professionals currently are (see Chapter 3 for the full methodology and results). The resulting framework then shaped a joint curriculum and a multilingual online toolkit, organised into modules and *learning pills*, as discussed in Chapter 9.

The final stage was a pilot course delivered to learners from across the European furniture sector and beyond, supported by a dedicated community of trainers organised through the Circular Furniture Mentors' Club. Chapters 10 and 11 report the results of this pilot in detail, and Chapter 12 reflects on what the consortium learned from the experience as a whole. Readers interested in the pilot's main figures (learners, countries, languages and satisfaction levels) should go to Chapter 11.

1.7 Who Should Read This Book

This volume is written for several audiences, and different readers may reasonably choose to read it in a different order.

Furniture companies, particularly small and medium-sized enterprises already working on, or considering, a circular transition, will likely find the most direct relevance in the chapters on business models, design and enabling technologies, and in the summary in Section 1.8 of this chapter. Vocational training providers and higher education institutions wanting to integrate circular economy competences into their own programmes will find the most direct relevance in the chapters on the CETM competence framework, VET systems and training methodology, and may also find the pilot results useful. Policymakers and sectoral associations working on the regulatory environment for the furniture industry will find the opening policy chapter most relevant, while researchers interested in sustainability transitions, circular design or vocational education are likely to engage with the whole volume, since its main contribution lies in connecting these usually separate strands of work around one sector.

No prior knowledge of the furniture sector, circular economy theory, or vocational education research is assumed. Each chapter introduces its own key concepts and points to related discussions elsewhere in the book, so readers can start wherever is most useful to them while still being able to follow the connections to other chapters.

1.8 Key Takeaways for Companies

For readers who want a short, practical summary, here are five points that capture the volume's main messages for furniture companies considering, or already working on, a circular transition:

1. the circular transition is not one technical fix, but a coordinated change across regulation, business models, design, technology and people. Changing only one of these – adopting a new material without rethinking the business model, for example – rarely produces lasting results.
2. Regulatory pressure is not going away, and companies that move early tend to face lower compliance costs than those that wait. The Ecodesign for Sustainable Products Regulation and the Digital Product Passport are likely to become binding requirements, not just good practice, within this decade.

3. Circular business models already exist in the furniture sector and offer a realistic starting point. Companies do not need to invent circularity from scratch: approaches such as product-as-a-service, take-back schemes and remanufacturing have already been implemented successfully by European peers.
4. Skills gaps, not technology gaps, are often the real obstacle. Research conducted within CirCLER found that the biggest mismatch between how important a competence is and how available training for it is concerns exactly the kind of systemic, forward-looking thinking that circular transitions require – a gap that no piece of equipment can close on its own.
5. A dedicated professional role: the Circular Economy Transition Manager, described throughout this volume, can provide the coordination that most companies currently lack, connecting strategic intent to day-to-day decisions across design, production, procurement and end-of-life management.

1.9 Conclusion

This chapter has introduced the CirCLER project and explained why this volume treats the circular transition as a connected whole rather than a set of separate topics, and has shown how the rest of the book is organised around five thematic areas that mirror the five dimensions of the transition itself.

What this chapter has also tried to suggest, more quietly, is that the circular transition of the furniture sector is not only a technical or regulatory challenge. It is a cultural one. It requires companies to change not just what they make and how, but what they value, how they think about time, and how they understand their relationships with materials, clients and ecosystems. It requires training systems to move beyond transmitting information and begin cultivating the kind of systemic, forward-looking thinking that no checklist can replace. And it requires research to stay close enough to practice to remain useful, while remaining rigorous enough to be trustworthy.

This volume does not resolve any of these challenges. What it does is map them honestly, from multiple angles and with multiple lev-

els of concreteness, and offer a framework, centred on the CETM profile, through which companies, trainers, policymakers and researchers can begin to work on them together. The next chapter turns to the first building block of this picture: the European policy framework that, in many respects, sets the whole transition in motion.

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2. European Policies Driving the Circular Transition of the Furniture Sector

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Chiara Terraneo
FederlegnoArredo

ABSTRACT

This chapter examines the European policy framework driving the circular transition of the furniture sector, highlighting how EU regulations are reshaping business models, supply chains, and product design. It outlines the European Green Deal and climate objectives, showing why furniture is a strategic sector for the circular economy. It discusses the Corporate Sustainability Reporting Directive (CSRD), emphasising transparency as both a reporting obligation and a governance tool supporting comparability, sustainability targets, and value-chain accountability. The chapter then analyses the Ecodesign for Sustainable Products Regulation (ESPR), which promotes durability, reparability, and environmental performance, together with coordination mechanisms. It also reviews circular economy instruments, including the Right to Repair, Extended Producer Responsibility, the Waste Framework Directive, the Digital Product Passport, the EU Deforestation Regulation, and measures against greenwashing.

2.1 The Policy Framework for Circular Transition

The transition toward circularity within the European furniture sector is progressively shaped by a combination of regulatory developments, market expectations, technological innovation, and evolving value chain dynamics. For furniture manufacturers, circularity is progressively becoming part of a broader industrial strategy connected to competitiveness, resource efficiency, product quality, and long-term resilience (European Furniture Industries Confederation [EFIC], 2020). Over the last few years, the European Union has progressively redefined circularity as a structural pillar of industrial policy, climate governance, and strategic competitiveness (European Commission, 2019). In this context, furniture manufacturing has emerged as a particularly relevant sector because it combines intensive material use, globalised supply chains, chemical complexity, and growing waste generation (European Environmental Bureau & Eunomia, 2018).

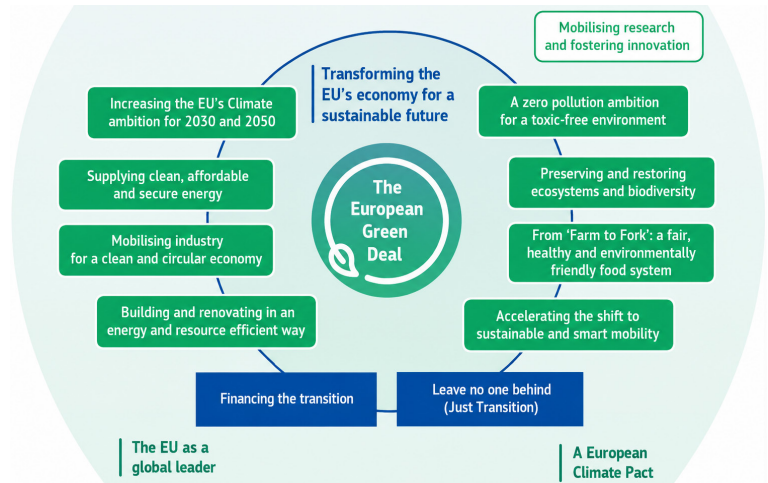
Unlike sectors traditionally associated with heavy industrial emissions, furniture production impacts are distributed across multiple lifecycle stages. While embodied energy incorporated into furniture components plays a prominent role, a complex mix of raw material extraction, wood sourcing, chemical treatments, logistics, product durability, indoor emissions, and end-of-life management all contribute to the sector's environmental footprint and interact with global sustainability goals (European Environment Agency, 2024). Consequently, European policymaking progressively approaches furniture not simply as a consumer good but as part of a broader ecosystem connecting construction, forestry, retail, digital traceability, and sustainable finance.

What distinguishes the current regulatory phase from previous environmental initiatives is the shift from isolated obligations toward integrated systemic governance. Circularity is no longer confined to waste management targets; instead, it influences product design, corporate reporting, financial access, consumer information, procurement practices, and material traceability (European Commission, 2022). The furniture industry therefore represents an important case study for understanding how European sustainability governance is

evolving from sector-specific regulation toward a multidimensional transition model.

2.1.1 The European Green Deal and EU Climate Objectives

Figure 1.
Elements of
the Green Deal.
Source: European
Commission (2019).



The European Green Deal, presented by the European Commission in 2019 and progressively reinforced through the Fit for 55 packages, the Circular Economy Action Plan, and the Net-Zero Industry Act, represents the main strategic framework guiding Europe toward climate neutrality by 2050 (European Commission, 2019). Recent policy developments progressively connect industrial competitiveness with decarbonisation and circularity, positioning resource efficiency as a strategic component of European industrial resilience (European Environment Agency, 2024). The initiative combines climate policy, industrial transformation, biodiversity protection, energy transition, and circular economy principles into a single integrated strategy.

Within this framework, the circular economy is considered essential for reducing greenhouse gas emissions and decoupling economic growth from resource consumption. The furniture industry plays a significant role because it relies heavily on raw materials such as wood, plastics, metals, textiles, foams, adhesives, and chemicals. The sector also generates substantial waste streams connected to production scraps, packaging, short product lifecycles, and end-of-life disposal.

The Circular Economy Action Plan adopted in 2020 further strengthened the European Green Deal by identifying sectors with

high resource intensity and strong potential for circularity. In recent years, European institutions have also emphasised the strategic importance of reducing dependency on virgin raw materials and strengthening secondary material markets, particularly after supply-chain disruptions and rising geopolitical risks (European Environment Agency, 2024). The European Union progressively considers furniture not only as a consumer product but also as a component of a wider industrial ecosystem connected to construction, interior design, hospitality, retail, and public procurement.

The climate goals of the European Union are also linked to the reduction of embodied emissions in products. Furniture manufacturing contributes to emissions through material extraction, transportation, production processes, and waste treatment. Therefore, improving durability, repairability, reuse, and recyclability becomes part of the broader decarbonisation strategy.

2.1.2 Why the Furniture Sector Is Under Increasing Scrutiny

The furniture sector has historically operated according to relatively linear production models characterised by resource extraction, manufacturing, consumption, and disposal (Furn360 Consortium, 2018). However, several structural challenges have increased political and regulatory attention toward the industry.

First, furniture consumption has accelerated due to globalisation, e-commerce, and fast-furniture business models inspired by trends in the fashion industry. Low-cost products with shorter lifespans have contributed to increase waste generation and reduced the case for repair.

Second, the sector depends heavily on forest resources. Sustainable forest management, traceability of timber, and biodiversity preservation are now central policy concerns, particularly in the context of global deforestation and illegal logging (European Parliament and Council of the European Union, 2023).

Third, furniture products often contain complex combinations of materials that could complicate recycling processes. Adhesives, coatings, foams, laminates, and composite panels create technical barriers to material recovery (European Environmental Bureau [EEB] & Eunomia, 2018).

Fourth, growing attention is being devoted to chemical safety and indoor environmental quality within the furniture sector. Manufacturers are progressively investing in low-emission materials, safer chemical solutions, and innovative production technologies in response to evolving regulatory standards and consumer expectations regarding health, durability, and product quality.

Finally, consumers and institutional investors increasingly expect companies to demonstrate environmental responsibility and transparency. Sustainability performance is progressively influencing market access, financing conditions, procurement decisions, and corporate reputation (European Parliament and Council of the European Union, 2022).

2.1.3 From Regulatory Pressure to System Transformation

European policy is gradually moving from isolated environmental obligations toward a systemic transformation of production and consumption models. This transition increasingly addresses product design, information systems, financial disclosure, and value chain accountability.

For the furniture sector, this means that sustainability is no longer limited to voluntary corporate initiatives. Circularity is becoming embedded in regulatory frameworks that influence every stage of the product lifecycle. Manufacturers are expected to design products that last longer, can be repaired more easily, contain safer materials, and generate fewer environmental impacts.

At the same time, financial institutions, public authorities, retailers, and consumers are becoming active participants in the transition.

As a result, the circular transition of the furniture sector should not be interpreted merely as compliance with environmental regulation. Rather, it represents a broader industrial transformation involving innovation, governance, digitalisation, material science, and changes in consumer behaviour.

2.2 Corporate Transparency and Sustainable Finance

2.2.1 Corporate Sustainability Reporting Directive (CSRD)

The strengthening of sustainability reporting obligations reflects a broader transformation in the relationship between industrial production, financial markets, and environmental governance. European institutions progressively consider transparency not merely as a disclosure exercise but as an instrument capable of influencing investment decisions, corporate strategies, and value-chain coordination. Within this framework, the furniture sector occupies a complex position because sustainability impacts often emerge indirectly through sourcing practices, outsourced production, logistics networks, and downstream product management.

The Corporate Sustainability Reporting Directive (CSRD) represents one of the most important European measures for strengthening corporate sustainability transparency (European Parliament and Council of the European Union, 2022). It replaces and expands the previous Non-Financial Reporting Directive (NFRD), increasing the number of companies required to disclose environmental, social, and governance information.

The CSRD introduces the principle of double materiality, according to which big companies must report both how sustainability issues affect financial performance and how corporate activities impact society and the environment (European Parliament and Council of the European Union, 2022).

Companies subject to the CSRD must report according to the European Sustainability Reporting Standards (ESRS). These standards require detailed information on climate change, pollution, biodiversity, resource use, circular economy practices, workforce issues, and governance structures.

Stop-the-Clock and Omnibus I: New Approach and Revised Thresholds

Recent European discussions surrounding the *Stop-the-clock* mechanism and the Omnibus I simplification package have substantially revised the expected scope and timing of the Corporate Sustainability Reporting Directive (CSRD). The current direction of the European

debate reflects the intention to maintain transparency objectives while reducing disproportionate administrative burdens, especially for small and medium-sized enterprises (SMEs).

Under the revised framework, mandatory sustainability reporting requirements are expected to remain focused primarily on large companies exceeding specific thresholds related to employees, turnover, and balance-sheet criteria. This clarification is particularly relevant for the furniture sector, which across Europe is characterised mainly by SMEs, family-owned businesses, and highly specialised manufacturing districts. Therefore, only a relatively limited number of furniture companies are expected to fall directly within the mandatory CSRD reporting perimeter.

At the same time, sustainability reporting practices are progressively extending throughout supply chains. Large retailers, multinational groups, financial institutions, and public procurement systems increasingly request ESG-related information from suppliers and subcontractors to comply with their own reporting obligations and risk assessment procedures (CirCLER Project, 2025).

Within this evolving context, the Voluntary Sustainability Reporting Standard for non-listed SMEs (VSME), developed by EFRAG, is gaining relevance. The VSME framework is designed specifically for SMEs that are not directly subject to the CSRD but nevertheless need to respond to sustainability information requests from customers, banks, investors, or business partners.

For many companies in the furniture sector, the VSME may therefore represent a practical and proportionate tool for organising sustainability-related information without the complexity associated with full CSRD compliance. The framework can support SMEs in structuring data collection processes, improving comparability, facilitating access to finance, and strengthening relationships within increasingly sustainability-oriented value chains.

Transparency as a Driver of Comparability and Performance Improvement

One of the most important functions of sustainability reporting is the creation of comparable and standardised information. Before the CSRD, sustainability reporting often relied on voluntary methodologies and inconsistent metrics, making comparisons difficult.

The harmonisation introduced by European reporting standards improves transparency for investors, regulators, customers, and civil society. Comparable data allows stakeholders to evaluate corporate performance more effectively and identify best practices.

Transparency also acts as a governance mechanism inside companies. The process of measuring emissions, waste streams, energy use, or resource efficiency often reveals operational inefficiencies and opportunities for innovation. Reporting therefore becomes a strategic management tool rather than a purely administrative obligation.

Target-Setting for Companies and Spillover Effects along the Value Chain

The CSRD encourages companies to establish measurable sustainability targets linked to climate neutrality, circular economy objectives, and biodiversity protection. Target-setting is becoming progressively important for access to finance and investor confidence.

Financial institutions are also integrating sustainability considerations into lending and investment decisions through the broader framework of sustainable finance regulations and taxonomy for sustainability criteria. Furniture companies able to demonstrate credible transition strategies may therefore benefit from improved access to capital.

In parallel, large corporations are transmitting sustainability expectations throughout their supply chains. Suppliers are progressively requested to disclose environmental data, adopt climate targets, and implement responsible sourcing policies.

This creates both opportunities and challenges for the furniture industry. Companies investing early in circular business models may strengthen competitiveness, while those unable to adapt risk losing market access or facing higher compliance costs.

2.3 Ecodesign and Sustainable Product Policy

2.3.1 Ecodesign for Sustainable Products Regulation (ESPR)

Among recent European policy initiatives, the ESPR represents perhaps the clearest attempt to operationalise circular economy

principles directly at product level. While earlier environmental policies frequently focused on waste treatment or energy efficiency, the new regulatory approach intervenes upstream, targeting design decisions capable of determining environmental impacts throughout the entire product lifecycle.

For the furniture sector, this shift is particularly significant because design choices strongly influence consumer behaviour. Circular policy objectives promote longer lifespans, modularity, ease of maintenance, and compatibility with secondary material flows.

Figure 2.
Young hands working
with wood to create
unique pieces.
Credit: Francesco Rucci;
Courtesy:
FederlegnoArredo.



The ESPR represents one of the most ambitious pillars of European product policy (European Commission, 2022). It expands the logic of the previous Ecodesign Directive beyond energy-related products and introduces sustainability requirements applicable to a broad range of goods.

The ESPR seeks to improve product durability, repairability, recyclability, energy efficiency, and resource efficiency while reducing environmental impacts across product lifecycles. Recent discussions

at European level increasingly connect the ESPR with digital traceability systems, secondary raw material markets, and carbon reduction strategies, reinforcing the role of product policy in achieving climate neutrality objectives. It also aims to reduce premature obsolescence and promote the use of secondary raw materials.

For the furniture sector, the regulation marks a fundamental shift because sustainability requirements will become mandatory rather than voluntary. Product design choices are expected to integrate circular economy principles from the earliest development stages.

Potential ecodesign requirements for furniture may include:

- minimum durability performance;
- disassembly requirements;
- availability of spare parts;
- limitations on hazardous substances;
- recycled material content;
- material traceability;
- repairability criteria;
- recyclability performance.

In the furniture sector, particular attention will likely be devoted to requirements related to product lifetime extension, especially regarding technical reliability and durability over time, as well as to the role of commercial and legal guarantees in supporting consumer confidence and longer product use cycles.

Furniture as a Priority Product Category

The European Commission has identified furniture as a priority product category due to high waste generation volume and strong circularity potential. Furniture products often involve large material volumes and long value chains, making them suitable candidates for circular policy interventions (FurnCircle Project, 2025).

In addition, the sector presents opportunities for extending product lifetimes through repair, refurbishment, remanufacturing, reuse, and modular design. Public procurement policies may also support circular furniture markets by favoring durable and repairable products.

According to the current indicative timeline, ESPR requirements are expected to apply to furniture products from 2028, while mat-

tresses, which have been also identified as a priority, are currently expected to follow in 2029.

The Ecodesign Forum

The ESPR also establishes governance mechanisms such as the Ecodesign Forum, which brings together stakeholders including industry representatives, civil society organisations, technical experts, and public authorities.

The Forum supports dialogue regarding technical requirements, implementation priorities, and methodological approaches. For the furniture sector, stakeholder engagement is essential because product categories are highly diverse, ranging from office furniture and mattresses to kitchen systems and upholstered products.

Collaboration within the Forum may contribute to balancing environmental ambition with technical feasibility and economic competitiveness. It also facilitates knowledge sharing regarding innovative materials, circular business models, and digital traceability solutions.

2.4 Circular Economy Regulatory Framework

2.4.1 Right to Repair

The Right to Repair initiative represents a major European effort to extend product lifetimes and reduce waste generation (European Parliament and Council of the European Union, 2024). The policy seeks to strengthen consumer rights and encourage manufacturers to make products more repairable.

In the furniture sector, repairability may involve the replacement of damaged components, availability of spare parts, modular design, and access to repair information. Extending furniture lifetimes can significantly reduce resource consumption and environmental impacts.

The Right to Repair also promotes the development of local repair ecosystems, including independent repair services and refurbishment businesses. This may create new employment opportunities while supporting more sustainable consumption patterns. At the moment, it is mainly dedicated to electronic products and household appliances.

For manufacturers, however, the initiative may require changes in design philosophy and business strategy. Companies increasingly need to consider durability and repairability as central product characteristics rather than optional features.



2.4.2 Extended Producer Responsibility (EPR)

Extended Producer Responsibility (EPR) is another important instrument supporting circular economy goals. Under EPR schemes, producers become financially responsible for managing products at the end of their lifecycle.

In the furniture sector, EPR systems may support collection, reuse, recycling, and waste treatment infrastructures. Producers may be required to contribute financially to waste management systems or organise take-back schemes.

EPR policies aim to create economic incentives for better product design. When producers bear end-of-life costs, they are encouraged to develop products that are easier to disassemble, repair, reuse, or recycle (European Environmental Bureau & Eunomia, 2018).

Different Member States have adopted their own approaches to furniture EPR systems (e.g., Ecomaison in France, which operates under French law since 2013, or Riqualta in Italy, which advocates for establishing an Italian EPR scheme for furniture), and harmonisation remains an ongoing challenge. Nevertheless, the overall policy

Figure 3.
A young woman
woodworking in a
professional school
workshop, carefully
shaping a piece of
wood using tools while
learning traditional and
modern craftsmanship
techniques. Credit:
Blossom; Courtesy:
Artwood Academy
Lentate sul Seveso.

direction clearly supports greater producer responsibility and lifecycle accountability.

Figure 4.
Preventing waste is the preferred option, and sending waste to landfill should be the last resort.
Source: European Commission (n.d.).



2.4.3 Waste Framework Directive

The Waste Framework Directive provides the general legal foundation for European waste policy and establishes key principles such as the waste hierarchy, prevention, reuse, recycling, and recovery.

For the furniture sector, the Directive encourages a shift away from landfill disposal toward higher-value circular strategies (European Environment Agency, 2024). Waste prevention and reuse are prioritised over recycling, reflecting the environmental benefits of extending product lifetimes.

The Directive also supports separate collection systems and improved waste management infrastructure. Better collection systems may facilitate the recovery of materials and increase opportunities for refurbishment and reuse.

In practice, implementing circular waste strategies for furniture remains challenging due to bulky waste logistics, mixed material compositions, and varying local infrastructure capacities. Also, waste legislation doesn't fully recognise the idea of waste as a resource, and could sometimes hinder innovative efforts to build circular business models.

Nevertheless, the Waste Framework Directive establishes the overarching policy orientation toward circular resource management.

2.5 Building Trust on Environmental Information

2.5.1 EU Deforestation Regulation (EUDR)

The EU Deforestation Regulation (EUDR) represents a major step toward improving supply chain accountability for forest-related commodities and products (European Parliament and Council of the European Union, 2023). The regulation aims to ensure that products placed on the European market are not associated with deforestation or forest degradation.

Because furniture production relies extensively on timber and wood-based materials, the EUDR has significant implications for the sector. Companies must demonstrate due diligence regarding the origin of wood products and verify compliance with sustainability requirements.

The regulation strengthens traceability obligations and requires the collection of geolocation data linked to production areas. Businesses must assess and mitigate deforestation risks within their supply chains.

For furniture companies, compliance may require stronger supplier engagement, improved documentation systems, and investment in digital traceability technologies. While implementation may generate additional administrative complexity, the regulation also supports more sustainable forest governance and responsible sourcing practices.

It has to be noted that among the *commodities* regulated under EUDR, wood was the only one already covered by specific legislation, the EU Timber Regulation (EUTR).

European industry organisations advocated for a simplification of the requirements of the new regulation. These actions ended up in a postponement of the entry into force of the legislation and a different focus between the first operator that introduces the wood on the market and the following ones.

2.5.2 Digital Product Passport (DPP)

The Digital Product Passport (DPP) is considered one of the most transformative tools supporting the circular transition (European Commission, 2022). Current pilot projects within the furniture and

wood sectors demonstrate how digital traceability systems may facilitate lifecycle assessment, repair operations, waste sorting, reuse markets, and material recovery. Introduced within the ESPR framework, the DPP aims to provide accessible digital information regarding product characteristics and sustainability performance.

The DPP is intended to improve transparency for consumers, repair operators, recyclers, regulators, and market surveillance authorities. It may also facilitate secondary markets and circular business models by improving information availability.

The DPP will be deployed according to the working plan of the Commission based on ESPR priorities, so the content and requirements for furniture DPP will be set up together with furniture ecode-sign criteria.

Digitalisation therefore becomes a central component of circular policy implementation. Reliable product data can improve resource efficiency, support recycling processes, and reduce information asymmetries across value chains (WoodCircle Project, 2025; FurnCircle Project, 2025).

However, important challenges remain regarding interoperability, information and data, confidentiality, and implementation costs, particularly for SMEs.

2.5.3 Greenwashing

As sustainability claims become increasingly important in marketing and investment decisions, European institutions are intensifying efforts to combat greenwashing (European Commission, 2020). Greenwashing refers to misleading or unsubstantiated environmental claims that create false impressions regarding the sustainability performance of products or companies. In the furniture sector, claims related to *eco-friendly*, *green*, *natural*, or *sustainable* products may sometimes lack sufficient scientific evidence.

Within the European framework addressing greenwashing, particular relevance should be attributed to the Empowering Consumers for the Green Transition Directive and to the proposed Green Claims Directive. The first entered into force in 2024 and is currently in the transposition phase across Member States, introducing stricter rules on environmental claims, durability information, and misleading sus-

tainability communication toward consumers. The proposed Green Claims Directive, on the other hand, remains subject to political debate and uncertainty within the legislative process, with discussions concerning its future scope and implementation timeline. Together, these initiatives reflect the European objective of improving the credibility, comparability, and reliability of sustainability-related information within the internal market.

2.6 Chemicals in Furniture

The growing focus on circularity within the furniture sector is also encouraging further innovation in material quality, chemical safety, and indoor environmental performance (European Chemicals Agency, 2023). In recent years, European manufacturers have progressively invested in low-emission materials, improved production technologies, and safer chemical solutions in response to evolving regulatory standards, customer expectations, and sustainability objectives.

This topic is particularly relevant for furniture products because they combine a wide variety of materials, including engineered wood, textiles, coatings, laminates, foams, adhesives, and composite components.

Within this context, European policies are progressively promoting the use of safer substances and lower-emission solutions, while supporting innovation in product performance, durability, and circular design. Chemical safety therefore represents not only a regulatory issue but also an important driver for product quality, technological development, and consumer confidence.

Attention has been devoted to formaldehyde emissions, mainly due to the large use of formaldehyde in resins used in the wood-based panels sector. Over the last decade, the furniture industry has significantly reduced emission levels through technological innovation, improved resin formulations, and stricter manufacturing controls. The European regulatory framework has progressively reinforced these efforts: under the updated EU rules aligned with REACH restrictions, from August 2026 the emission limit for formaldehyde from furniture and wood-based products placed on the European market has been substantially reduced, effectively halving the previous threshold

values for indoor environments. This regulatory evolution is expected to further accelerate the adoption of ultra-low-emission materials and alternative binder technologies across the sector.

The European regulatory framework addressing chemicals includes instruments such as REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) and CLP (Classification, Labelling and Packaging) (European Chemicals Agency, 2023). These regulations aim to improve chemical safety, restrict hazardous substances, and promote safer alternatives.

For furniture manufacturers, chemical compliance is becoming increasingly complex due to evolving restrictions, customer expectations, and international market requirements. Companies are investing in research and innovation aimed at developing low-emission materials, bio-based adhesives, water-based coatings, and safer production technologies (WoodCircle Project, 2025). Innovation in material science may play a decisive role in the circular transition of the furniture sector. Safer materials not only improve health protection but may also facilitate recycling and material recovery.

2.7 Conclusion

The evolution of European circular economy policy illustrates a gradual but decisive shift from fragmented environmental measures toward an integrated framework of industrial transformation. Within this evolving architecture, circularity is increasingly embedded across multiple policy domains, including product regulation, corporate reporting, chemical safety, digital traceability, and sustainable finance. For the furniture sector, this convergence of policy instruments is particularly significant. The industry operates within complex and fragmented value chains, characterised by the high prevalence of micro-enterprises and SMEs, strong reliance on natural and engineered materials, and increasing exposure to global market dynamics. As a result, regulatory developments at European level are not only shaping compliance requirements but also influencing strategic decisions related to design, sourcing, production processes, and market positioning.

Rather than functioning as isolated obligations, recent initiatives such as the CSRD framework, the ESPR, the Digital Product Passport, EPR schemes, and emerging rules on environmental claims are progressively forming a coherent regulatory ecosystem. This system encourages a lifecycle-oriented approach in which product durability, reparability, material efficiency, and transparency become central determinants of competitiveness.

At the same time, the transition remains uneven and characterised by different levels of readiness across companies and Member States. While larger organisations are better positioned to integrate reporting systems and digital tools, many SMEs in the furniture sector face challenges related to administrative capacity, data availability, and investment requirements. In this context, proportionality instruments such as simplified reporting standards and voluntary frameworks (e.g., VSME) play an important role in facilitating inclusion within the broader sustainability transition.

Overall, the circular transition of the furniture sector should be understood not only as a regulatory pathway but also as an industrial modernisation process. Its success will depend on the capacity of policy frameworks and market actors to align environmental objectives with innovation, competitiveness, and long-term value creation across European manufacturing systems.



Figure 5.
A male student engaged in woodworking at a professional training school, demonstrating focus, precision, and craftsmanship while developing practical skills in a modern workshop environment. Credit: Blossom; Courtesy: Artwood Academy Lentate sul Seveso.

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3. Skills and Competences for Circular Economy Transition Managers in the Furniture Sector

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ABSTRACT

The transition to a circular economy in the furniture sector requires new professional profiles able to manage complex, cross-functional processes. This chapter defines the Circular Economy Transition Manager (CETM) as a key role bridging strategic objectives and practical implementation of circular strategies. Drawing on research from the CirCLER project, it presents a competence framework integrating operational, strategic, green, digital, and transversal skills tailored to the furniture industry and aligned with real business needs. The chapter also identifies current skills gaps, highlighting challenges related to coordination, systems thinking, and digital capabilities. Finally, it discusses implications for education and training, stressing interdisciplinary and practice-oriented approaches. By linking competence development with implementation needs, the chapter provides practical guidance for companies, educators, policymakers, and industry stakeholders supporting the circular transition of the furniture sector.

3.1 Introduction

The transition towards a circular economy has become a strategic priority for the European furniture sector. Environmental pressures, resource scarcity, evolving consumer expectations, and expanding national and European regulations – including the ESPR and Digital Product Passport (DPP) future requirements – are pushing companies to rethink traditional production and business models.

However, circular transition involves far more than the adoption of greener materials or recycling practices. Furniture companies are increasingly expected to redesign products according to lifecycle principles, integrate digital traceability systems, collaborate across fragmented supply chains, adopt circular business models, and monitor environmental impacts through measurable indicators. These processes require the integration of technical, strategic, organisational, and relational capabilities that are rarely concentrated within existing professional profiles.

For many companies, particularly SMEs, one of the main barriers to circular transition is therefore not only technological or financial, but organisational and cultural. Sustainability initiatives often remain fragmented across departments, while companies frequently lack professionals capable of translating circular principles into operational practices, coordinating stakeholders, interpreting and adapting to regulations, and supporting organisational change.

Within this context, the CETM emerges as a key professional figure bridging sustainability objectives and practical implementation. Rather than acting solely as a technical sustainability specialist, the CETM functions as an interdisciplinary coordinator supporting the integration of circular principles across products, processes, business models, and value networks.

Building on empirical research conducted within the CirCLER project, this chapter defines and conceptualises the CETM as an emerging professional profile for the furniture sector. It analyses the competences required for this emerging role and presents a structured framework specific to the furniture sector integrating operational, strategic, green, digital, and transversal future-oriented skills. It also examines current skills gaps, related challenges, and reflects

on the implications for vocational education, training systems, and organisational capacity building.

Within the overall structure of this book, the chapter provides the competence-based foundation connecting the regulatory framework discussed in Chapter 2 with the business models, design approaches, technologies, and educational methodologies explored in the following chapters. By positioning competences at the centre of circular transition processes, the chapter highlights the human and organisational dimensions necessary to operationalise circular economy strategies in the furniture sector.

3.2 The Role of the Circular Economy Transition Manager (CETM)

Within the CirCLER project, the CETM is defined as a professional figure responsible for guiding furniture sector companies towards more circular practices and business models across the entire value chain while supporting their long-term sustainability and competitiveness.

More specifically, Furniture sector Circular Economy Transition Managers (CETMs) are responsible for leading the transition of sector companies towards more circular practices and business models along their whole value chain and ensuring their sustainability. They provide assistance in the design and implementation of plans and measures along different company departments in order to ensure that products, processes and organisation comply with current and future environmental regulations; they promote the adoption of circular strategies, practices and voluntary standards/certificates at all levels; they foster circular design approaches and the adoption of circular business models; they inspire the company's environmental communication and employees training; and they monitor and report on the implementation of circular strategies within the company supply chain and business processes. They analyse and re-address issues linked

to manufacturing processes, including materials, waste, energy and product traceability and end-of-life.

This definition highlights the interdisciplinary and cross-functional nature of the CETM profile. Unlike traditional sustainability roles mainly focused on compliance and reporting, the CETM operates at the intersection of strategy, operations, innovation, and organisational transformation. The role combines technical, managerial, digital, and relational competences reflecting the complexity of circular economy implementation in the furniture sector.

The CETM bridges sustainability objectives and operational practice by coordinating circular initiatives across departments and value chains. One of the key added values lies in adopting a systemic perspective capable of linking environmental performance, operational efficiency, economic viability, and long-term resilience. The role therefore reflects the shift from fragmented sustainability initiatives towards integrated circular transition strategies.

The breadth of these responsibilities demonstrates that a successful circular transition cannot rely on isolated technical expertise or individual initiative alone. For this reason, the CirCLER project developed a structured competences framework identifying the knowledge, skills, and transversal capabilities required to support the effective implementation of circular economy strategies in the furniture sector.

3.3 The CirCLER Competences Framework

To translate the CETM occupational profile into concrete learning and professional requirements, the CirCLER project developed a structured competences framework (Figure 1) defining the key knowledge areas, skills, and transversal capabilities necessary to support circular transition processes in the furniture sector. The framework functions both as an analytical model for understanding the complexity of the CETM role and as a practical reference for the development of curricula, training programmes, and competence-based learning pathways.

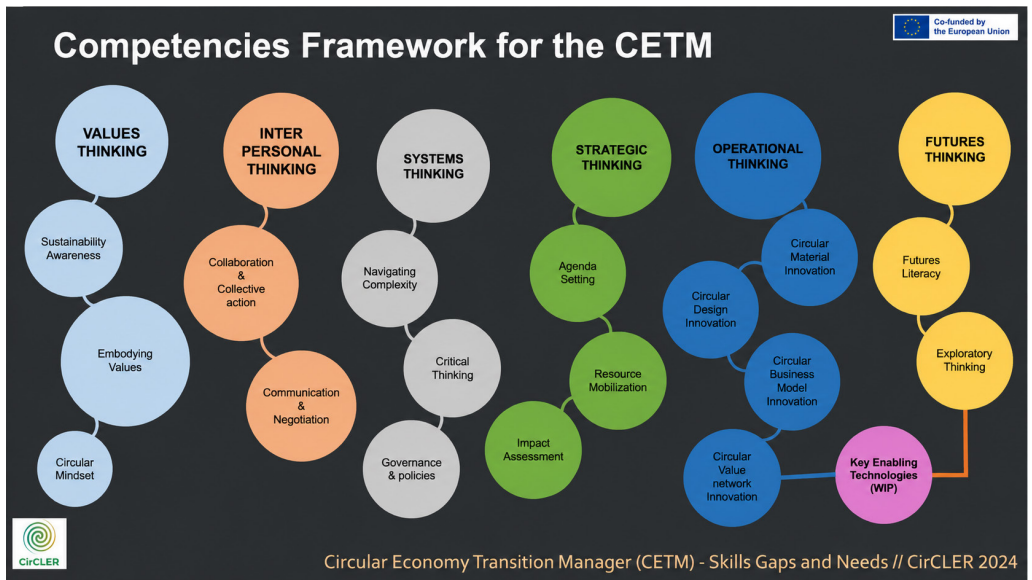


Figure 1.
CirCLER Competences
Framework for CETM.
Source: CirCLER Project
D3.1 (2024).

Rather than focusing exclusively on technical sustainability expertise, the framework adopts a holistic approach reflecting the interdisciplinary nature of circular economy implementation. It recognises that effective transition management requires the integration of operational, strategic, relational, and future-oriented competences capable of supporting organisational transformation across the entire value chain.

The competences framework developed within the CirCLER project structures CETM competences into six interconnected domains: Values Thinking, Interpersonal Thinking, Systems Thinking, Strategic Thinking, Operational Thinking, and Futures Thinking. As illustrated in Figure 2, the framework combines competence domains, indicative knowledge areas, practical applications within the furniture sector, and enabling attitudes and mindsets necessary to support circular transition processes.

The framework was initially developed by the CirCLER consortium and was then improved and validated through a two-stage validation process involving stakeholders from across the circular economy and furniture ecosystem. The first validation stage consisted of an international survey involving 153 experts from 10 countries, including higher education teachers and researchers, managers and CEOs from furniture companies, circular economy consultants, cluster repre-

sentatives, designers, environmental managers, innovation managers, and project managers. The second stage involved validation workshops attended by 22 internal and 10 external experts.

The results demonstrated strong consensus regarding the importance of all six competence domains. Operational Thinking and Systems Thinking received the highest importance ratings, reflecting the need for practical implementation capacities combined with the ability to understand complex interdependencies across the value chain.

At the same time, respondents identified significant gaps between the importance of these competences and the current availability of relevant training. Futures Thinking and Systems Thinking were considered particularly underdeveloped within existing education and training provision.

The framework confirms that circular economy implementation requires more than technical expertise alone. Instead, it demands the integration of transversal competences related to communication, governance, critical thinking, collaboration, and organisational transformation.

Figure 2.
Proposed Competence Framework for CETM.
Source: CirCLER Project (2024).



- Values Thinking represents the cultural and ethical foundation of the CETM profile. It includes sustainability awareness, embodying values, and the development of a circular mindset. Stakeholders participating in the CirCLER validation activities repeatedly emphasised that circular transition requires a shift away from linear production and consumption assumptions. CETMs therefore need the capacity to promote long-term thinking, resource responsibility, and regenerative approaches inside organisations. Respondents also stressed the importance of organisational culture in supporting circular transformation. Resistance to change was frequently identified as a barrier, particularly when companies are required to modify established production processes or business models. Consequently, CETMs require competences related to behavioural change, stakeholder engagement, and value communication.
- Closely connected to this domain is Interpersonal Thinking, which focuses on collaboration, communication, negotiation, and collective action. Circular economy implementation depends on cooperation across departments, companies, and value chains. CETMs therefore need the ability to coordinate actors with different priorities and levels of expertise. Communication competences were considered particularly important. Experts highlighted the need for professionals capable of translating complex sustainability concepts into practical organisational actions while creating shared ownership around circular objectives. The findings also revealed that although generic soft-skills training is often available, it is rarely adapted to the specific challenges of circular economy implementation in the furniture sector.
- Systems Thinking emerged as one of the most important competence domains within the framework. Circular economy implementation requires understanding relationships between materials, products, users, supply chains, regulations, and environmental impacts. Respondents emphasised the importance of *seeing the big picture* and recognising how decisions in one area influence other parts of the system. CETMs therefore require competences related to navigating

complexity, critical thinking, and governance understanding. Critical thinking was considered particularly relevant in order to distinguish between genuinely circular solutions and superficial sustainability claims. Experts also stressed the importance of understanding rapidly evolving regulations related to ecodesign, waste management, environmental reporting, and traceability.

At the same time, Systems Thinking was identified as one of the most difficult areas to teach effectively. Existing training provision was often considered too theoretical and insufficiently connected to operational realities.

- Strategic Thinking complements this systemic perspective by focusing on agenda setting, resource mobilisation, and circular impact assessment. CETMs are expected to support the integration of sustainability objectives into organisational strategies and business transformation processes. Stakeholders repeatedly highlighted the importance of lifecycle assessment, sustainability reporting, circularity monitoring, and environmental performance indicators. These competences are becoming increasingly important due to both regulatory obligations and market expectations. However, respondents also noted that many companies, especially SMEs, lack the internal resources and expertise necessary to develop long-term circular strategies. CETMs therefore need the ability to connect sustainability initiatives with business priorities while mobilising organisational support for transformation processes.
- Operational Thinking received the highest importance ratings among all competence domains. This reflects the practical nature of circular transition in the furniture sector.

The domain includes competences related to circular material innovation, circular design innovation, circular business model innovation, circular value network innovation, and Key Enabling Technologies (KETs). Stakeholders stressed the importance of sustainable materials, lifecycle thinking, product-service systems, reverse logistics, remanufacturing, and waste valorisation. Circular design competences were considered particularly important because design decisions strongly

influence product durability, repairability, disassembly, and recyclability. Respondents also highlighted the growing relevance of circular business models based on leasing, take-back systems, repair services, and reuse strategies.

Digitalisation and Key Enabling Technologies are increasingly important drivers of operational circularity. Digital Product Passports, artificial intelligence, blockchain traceability systems, Internet of Things (IoT) solutions, and data-driven lifecycle monitoring tools were recognised as essential for improving traceability, resource efficiency, transparency, and decision-making across the value chain.

Nevertheless, stakeholders repeatedly warned against overly theoretical approaches disconnected from industrial realities. There was strong demand for practical training focused on real business cases, operational challenges, and sector-specific applications.

- Futures Thinking completes the competence framework by introducing competences related to futures literacy, exploratory thinking, and the anticipation of emerging technological and regulatory developments. Although this domain received slightly lower importance scores, experts recognised its growing relevance in a context characterised by rapid technological, regulatory, and market change. CETMs must be able to anticipate future trends, explore alternative scenarios, and support adaptive organisational strategies. In particular, respondents highlighted the importance of understanding how Key Enabling Technologies, including artificial intelligence, advanced data analytics, smart traceability systems, and digital manufacturing technologies, may reshape circular business models, resource management practices, and value chain coordination in the future.

However, respondents also acknowledged that future-oriented and technology-related competences remain insufficiently represented in existing training systems, particularly regarding foresight, innovation management, and the strategic integration of emerging technologies into circular transition pathways.

3.4 Skills Gaps, Implementation Challenges and Educational Implications

One of the most important findings emerging from the CirCLER skills research concerns the growing mismatch between the importance of circular economy competences and the limited availability of specialised training and organisational capacities within the furniture sector. Although companies increasingly recognise the strategic relevance of circular transition, many still struggle to translate circular economy principles into concrete operational practices.

The challenges identified go beyond technical implementation and highlight the systemic nature of the transition process. In particular, stakeholders emphasised difficulties related to organisational coordination, systems thinking, digitalisation, and the integration of sustainability objectives into everyday business operations. Circular initiatives often remain fragmented across departments, while many organisations lack professionals capable of connecting environmental goals with operational decision-making and long-term business strategies.

Stakeholders also highlighted a persistent gap between theory and practice within existing training provision. Current programmes are often perceived as overly academic and insufficiently connected to the operational realities of furniture companies, especially SMEs. For this reason, respondents strongly supported more practice-oriented and flexible learning approaches integrating case studies, simulations, collaborative exercises, work-based projects, and modular learning pathways adapted to different professional profiles and experience levels.

Another recurring theme concerned interdisciplinarity. Circular transition requires the integration of environmental science, product design, manufacturing systems, governance, business management, and digital technologies. Consequently, CETM education cannot remain confined within traditional disciplinary boundaries, but must support the development of hybrid professional profiles capable of navigating complexity and facilitating collaboration across multiple domains.

The relationship between competence development and implementation needs identified through the CirCLER project is summarised in Table 1.

Competence Area	Main Skills Gaps Identified	Implementation Need in Companies	Educational Implications
Interpersonal and Coordination Skills	Weak communication and change management capabilities.	Cross-functional collaboration and stakeholder engagement.	Collaborative learning, facilitation exercises, and stakeholder simulations.
Systems Thinking	Limited holistic understanding of circular systems.	Managing lifecycle impacts and value chain interdependencies.	Greater integration of lifecycle thinking, systems mapping, and governance analysis.
Strategic Thinking	Difficulty connecting environmental goals with operational decision-making.	Integration of sustainability into business strategy.	More business-oriented and transformation-focused training approaches.
Operational Thinking	Gap between theory and industrial realities.	Practical implementation of circular solutions.	Work-based learning, case studies, and practical industry projects.
Futures Thinking	Limited foresight and innovation capacity.	Anticipating regulatory and market evolution.	Inclusion of scenario building, trend analysis, and exploratory methodologies.
Digital Competences	Limited knowledge of digital tools and data management.	Product traceability, monitoring, and data-driven circularity.	Inclusion of Digital Product Passports, AI, traceability, and digital manufacturing tools.

Table 1.
Linking CETM
competences with
circular economy
implementation needs in
the furniture sector.

In response to these findings, the CirCLER research identified several priorities for the development of future education and training initiatives: Modular and flexible learning approaches adapted to different professional profiles and organisational contexts, particularly for SMEs and professionals already working in industry.

Experiential and work-based learning methodologies (including case studies, simulations, practical assignments, mentoring, and company-based projects) as essential tools for bridging the gap between theory and implementation.

Interdisciplinary training programmes integrating environmental, technological, managerial, and operational perspectives in order to develop hybrid professional profiles capable of managing the complexity of circular transition processes.

Lifelong learning and continuous upskilling approaches capable of responding to evolving regulations, technological innovation, changing market expectations, and emerging circular business models. Competence development therefore needs to be understood as a continuous and adaptive learning process rather than a one-time educational pathway.

From a broader perspective, the findings of the CirCLER project demonstrate that competence development and circular economy implementation are deeply interconnected. The successful implementation of circular strategies depends not only on the availability of technologies or regulatory frameworks, but also on the presence of professionals capable of translating sustainability objectives into coordinated organisational action.

3.5 Positioning the CETM within the CirCLER Knowledge Framework

Within the overall structure of this publication, the CETM profile functions as a connecting element between the different dimensions of circular transition explored throughout the book. As illustrated in Figure 3, the CETM operates across the entire furniture value chain, linking strategic sustainability objectives with operational implementation processes and coordinating actions among multiple organisational and external actors.

The role extends from raw material sourcing and manufacturing processes to distribution, product use, maintenance, and end-of-life recovery activities. In this context, the CETM supports the integration of circular strategies related to sustainable sourcing, traceability, resource efficiency, circular design, reverse logistics, remanufacturing, and waste recovery. At the same time, the profile requires continuous interaction with internal company departments – including design, production, procurement, quality, marketing, and management – as well as with suppliers, logistics providers, certification bodies, policy-makers, and customers.

This cross-functional positioning reflects the interdisciplinary nature of circular transition itself. The regulatory instruments analysed in Chapter 2 require professionals capable of translating policy obligations into operational practices. Similarly, the circular business models discussed in Chapter 4 depend on systems thinking, stakeholder coordination, and value-network management competences. The circular design approaches presented in Chapter 5 require lifecycle thinking and environmental assessment capabilities, while

the technological innovations explored in Chapters 6 and 7 depend on organisational actors able to integrate sustainability and digitalisation into strategic and operational decision-making. The educational and training methodologies discussed in Chapters 8, 9, and 10 directly respond to the competence gaps identified in this chapter, particularly regarding interdisciplinary collaboration, digitalisation, and practice-oriented capacity building. Together, these contributions demonstrate that circular transition in the furniture sector depends not only on technologies and regulations, but also on the development of integrated skills ecosystems capable of supporting organisational transformation and continuous learning.

THE CETM: COORDINATING CIRCULAR TRANSITION ACROSS THE FURNITURE VALUE CHAIN

Connecting strategy with action. People with processes. Sustainability with business.

The CETM leads, coordinates and monitors the implementation of circular strategies across all stages of the furniture value chain, ensuring environmental, economic and social value.

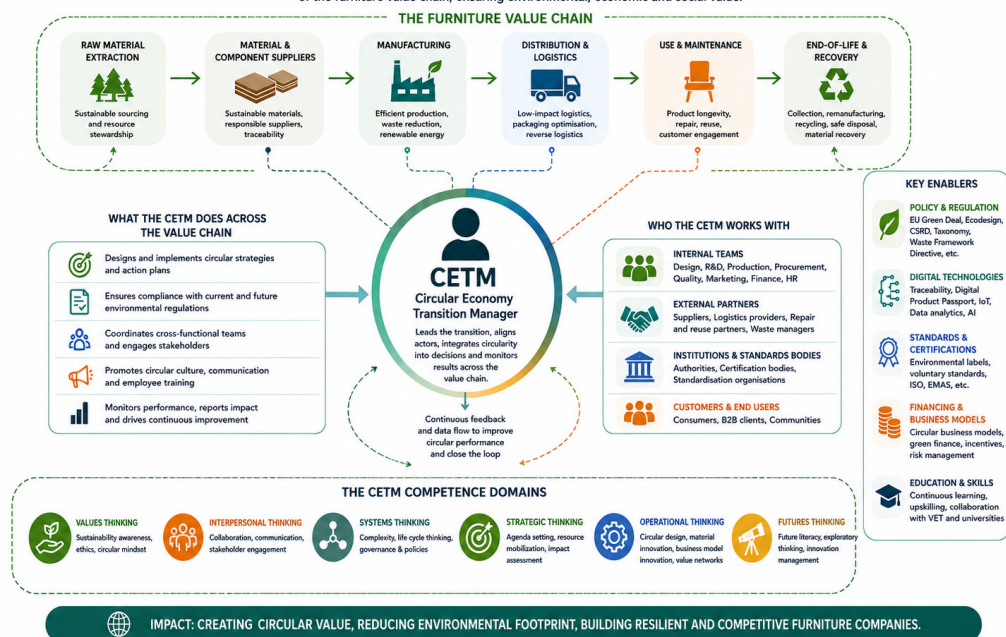


Figure 3.
Infographic illustrating
CETM coordination
across the value chain.
Source: CirCLER Project
(2024).

The CETM therefore represents more than a new professional role. It embodies the systemic and interdisciplinary logic underpinning the circular transition by connecting sustainability objectives, operational processes, stakeholder collaboration, and long-term organisational resilience across the furniture value chain.

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4. Circular Business Models in the Furniture Industry: An Ecosystem Perspective

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ABSTRACT

The transition to a circular economy requires changes in how furniture is designed, produced, used, and recovered. Circular strategies such as refurbishment, reuse, remanufacturing, and furniture-as-a-service extend product lifetimes and reduce resource consumption. This chapter adopts an ecosystem perspective, arguing that circular business models depend on coordinated networks of manufacturers, refurbishment operators, logistics providers, digital platforms, recyclers, and institutional buyers rather than on individual firms alone. It examines the roles, partnerships, and value flows that enable product life extension and resource recovery across interconnected value chains. Building on current literature and emerging industry practices, the chapter proposes a conceptual framework identifying key actors, coordination mechanisms, and value creation processes, contributing to a more systemic understanding of circular business models in the furniture sector.

4.1 Introduction

The transition to a circular economy has become a priority across industries seeking to reduce resource use and environmental impact. Yet, despite growing attention and policy momentum, many sectors remain structurally anchored in linear production and consumption patterns. The furniture industry exemplifies this tension. While circular strategies such as refurbishment, reuse, and service-based offerings promise to extend product lifecycles and retain value, their large-scale implementation remains uneven and limited.

A key explanation lies in the way circular business models (CBMs) have been conceptualised and operationalised. Existing research has made significant progress in identifying CBM archetypes, such as product-as-a-service, lifetime extension, and resource recovery (Bocken *et al.*, 2014, 2016). However, these archetypes are typically framed as firm-level configurations, implicitly assuming that circular value creation can be designed and implemented within organisational boundaries. In practice, however, circularity in sectors such as furniture depends on the coordination of multiple interdependent actors, including manufacturers, service providers, refurbishers, logistics partners, digital platforms, and users (Kulakovskaya *et al.*, 2024). As a result, the challenge is not only to design CBMs, but to enact and sustain them across complex ecosystems.

Recent research has begun to acknowledge this limitation by emphasising the role of ecosystems, networks, and inter-organisational collaboration in enabling circular economy transitions (Kanda *et al.*, 2021; Reim *et al.*, 2025). However, this perspective remains only partially integrated into CBM research, with limited understanding of how CBMs are configured, coordinated, and realised across sector-specific ecosystems. This chapter addresses this gap by examining CBMs in the furniture industry through an ecosystem lens, highlighting the coordination mechanisms required to align actors, resources, and activities in circular value creation (Adner, 2017; Jacobides *et al.*, 2018).

Drawing on qualitative analysis of nine European cases, we argue that CBMs are not implemented as discrete archetypes, but as hybrid configurations of value logics enacted through ecosystems of interdependent actors. Furthermore, we show that the viability and

scalability of these configurations depend on the alignment between value logic, ecosystem configuration, and lifecycle loop realisation.

4.2 Circular Business Models: From Archetypes to Ecosystem Configurations

Circular business models (CBMs) have been widely conceptualised through a set of recurring archetypes that describe alternative ways of creating, delivering, and capturing value while reducing resource use. Foundational work identifies key configurations such as product-as-a-service, lifetime extension, resource recovery, circular supply, and sharing platforms (Bocken *et al.*, 2014, 2016; Brown *et al.*, 2021; Tukker, 2004). These archetypes correspond to different circular strategies, including slowing, closing, and narrowing resource loops, and have provided an important vocabulary for understanding how firms can move beyond linear *take-make-dispose* models. Table 1 summarizes these dominant CBM archetypes and their associated value logics, serving as an entry point for the analysis.

Archetype	Loop logic (closing/slowing/narrowing)	Value proposition examples
Product-as-a-Service (PSS)	Slowing (extends use via access over ownership)	Pay-per-use; reduced upfront cost.
Lifetime extension	Slowing (repair, refurbish, upgrade)	Longer product life; customisation.
Resource recovery	Closing (reuse materials/products)	Closed loops; zero waste.
Circular supply	Closing/narrowing	Sustainable material, recycled content.
Sharing platform	Slowing (access over ownership)	On-demand access; utilisation.

Table 1.
Circular business model archetypes.

Despite their analytical usefulness, these archetypes are typically framed as firm-level configurations, implicitly assuming that circular value creation can be designed and implemented within organisational boundaries. This assumption is increasingly problematic. Beyond requiring multiple actors, circularity in furniture is not limited to end-of-life recovery but involves the reconfiguration of value across multiple lifecycle stages. As a result, CBMs cannot be fully understood as isolated organisational choices, but must be examined in relation

to the broader systems in which they are enacted. To address this limitation, this chapter reconceptualises CBMs as ecosystem-enacted value logics. From this perspective, CBM archetypes define how circular value is intended to be created, but their realisation depends on how they are embedded within broader systems of actors and processes. This shift is particularly relevant in the furniture sector, where circularity depends on the activation and coordination of lifecycle loops. Furniture products often retain functional, aesthetic, and material value beyond their initial use, enabling multiple circular pathways such as reuse, refurbishment, remanufacturing, resale, and recycling (Pei *et al.*, 2024; Wulf *et al.*, 2024). However, to enact these pathways, coordination across actors, infrastructures, and market mechanisms is necessary.

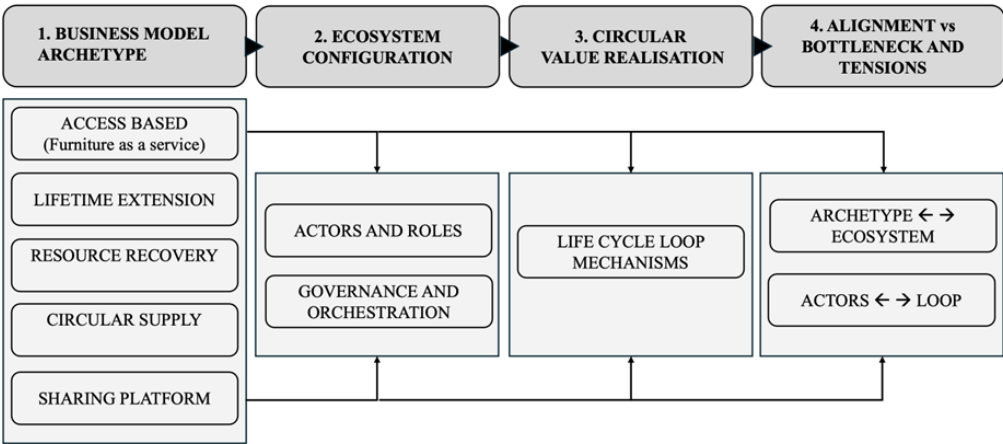


Figure 1.
Framework overview.

Building on this perspective, the analysis focuses on three interrelated dimensions that structure circular value creation. First, value logic refers to the dominant circular mechanism underpinning the CBM archetype (e.g., access-based use or lifetime extension). Second, ecosystem configuration captures how actors, roles, and governance arrangements are structured to support this value logic (Adner, 2017; Jacobides *et al.*, 2018). Third, lifecycle loop realisation refers to how circular value is operationalised through concrete processes such as reuse, refurbishment, remanufacturing, and recycling (Geissdoerfer *et al.*, 2017). These dimensions are analytically distinct but empirically interdependent. These elements are brought togeth-

er in the analytical framework presented in Figure 1. The framework further incorporates a fourth dimension – alignment, bottlenecks, and tensions – capturing the conditions under which circular configurations succeed or fail. Misalignments across dimensions give rise to coordination challenges, economic constraints, and scaling barriers, underscoring the need for a systemic rather than firm-centric understanding of CBMs.

4.3 Methodological Note

This chapter draws on a qualitative analysis of nine illustrative cases of circular business models in the EU furniture sector, as listed in Table 2.

Cases were purposefully selected to capture variation across key CBM archetypes. Data were collected from multiple secondary sources, including company reports, websites, industry publications, and prior case documentation, allowing for triangulation of business model characteristics, ecosystem arrangements, and lifecycle practices. The analysis followed a systematic combining approach (Dubois & Gadde, 2002), iterating between empirical observations and conceptual lenses from CBM and ecosystem literature. Coding focused on identifying value logics, ecosystem configurations, lifecycle loop mechanisms, and alignment conditions across cases.

Table 2.
Overview of case studies.

Case	Country	Primary archetype
Martela	Finland	Access-based (Furniture-as-a-Service)
Vepa	Netherlands	Lifetime extension
Lammhults	Sweden	Circular supply
System 180	Germany	Lifetime extension
Arper	Italy	Circular supply
Relieve Furniture	Belgium	Lifetime extension
Stooping Milano	Italy	Sharing Platform
WIVRE	Italy	Sharing Platform
DEESUP	Italy	Sharing Platform

4.4 Hybrid Configurations: How Circular Models Combine Value Logics

4.4.1 Access-Based Models Meet Lifetime Extension

Across the cases, CBMs rarely operate as pure access-based systems. Instead, models such as furniture-as-a-service are consistently combined with lifetime extension mechanisms, including refurbishment, repair, and resale. For instance, service-led models such as the one implemented by Martela rely not only on leasing arrangements but on the ability to recover, restore, and redeploy furniture across multiple use cycles. Without these capabilities, access-based offerings would struggle to retain asset value and maintain economic viability over time.

This combination reflects a deeper structural requirement: access models shift ownership but do not, in themselves, ensure circularity. Circular value emerges only when products are effectively circulated through reuse and refurbishment loops. This, in turn, requires an ecosystem of actors capable of supporting reverse logistics, quality assessment, repair operations, and secondary market channels. In these configurations, circularity is not embedded in the contract alone but enacted through coordinated lifecycle operations across the ecosystem.

4.4.2 Resource Recovery through Platform Coordination

A second dominant configuration is organised around platform-mediated resource recovery and recirculation. In these cases, digital platforms act as orchestrators that connect supply and demand while enabling the circulation of used or surplus furniture. Actors such as Relieve Furniture, DEESUP, and VVIVRE illustrate how circular value can be generated through multi-sided coordination rather than direct production control.

Here, circularity is achieved primarily through reuse and redistribution loops, often with limited physical transformation of products. Platforms facilitate this process by enabling inventory visibility, quality verification, transaction management, and logistics coordination. Importantly, value creation is distributed across multiple actors, including suppliers, refurbishers, logistics providers, and end users. The

platform thus becomes a central mechanism through which lifecycle loops are activated and sustained.

However, these models depend critically on coordination mechanisms that ensure trust, quality consistency, and timely flows. Without such mechanisms, the system risks fragmentation, uneven product quality, and inefficiencies that undermine circular performance.

4.5 Alignment Conditions: When Circular Configurations Succeed

4.5.1 The Alignment Framework

While hybrid configurations are necessary, our analysis shows that they are not sufficient. CBM performance depends on the degree of alignment between three core dimensions: value logic, ecosystem configuration, and lifecycle loop realisation.

Misalignment across these dimensions leads to persistent bottlenecks. For example, access-based models without adequate refurbishment infrastructure fail to sustain reuse cycles, while platform-based systems without reliable logistics and quality control struggle to maintain user trust. Similarly, design strategies aimed at durability or recyclability often fail to translate into circular outcomes when not supported by take-back systems or market channels for recovered products.

Alignment, therefore, emerges as a central condition for circular viability. It requires that business model intent, ecosystem structure, and operational mechanisms reinforce rather than contradict each other.

4.5.2 Orchestration Mechanisms

Achieving alignment depends on effective ecosystem orchestration. Across the cases, two broad coordination patterns can be observed. In focal-firm-orchestrated systems, manufacturers or service providers coordinate lifecycle activities, including design, take-back, refurbishment, and redistribution. This approach enables tighter control over quality and value retention but requires significant organisational capabilities and investment.

In contrast, platform-based systems rely on distributed coordination, where orchestration is achieved through digital infrastructures that connect multiple actors. Here, governance is embedded in platform rules, standards, and data flows rather than hierarchical control. Both approaches demonstrate that circular business models depend not only on strategic intent but on the ability to coordinate interdependent actors and activities across the ecosystem.

4.5.3 Scaling Implications

The importance of alignment becomes particularly evident when considering scaling. CBMs often fail to scale not because of flawed value propositions, but due to ecosystem constraints. These include limitations in reverse logistics infrastructure, variability in product quality, lack of standardisation, and insufficient user participation.

As a result, scaling circular models requires a shift from focusing solely on business model design to assessing ecosystem readiness. Firms must consider whether the necessary actors, infrastructures, and coordination mechanisms are in place to support circular flows at scale.

4.6 Implications for Circular Furniture Systems

4.6.1 Theoretical Contributions

First, this chapter advances CBM research by moving beyond the treatment of archetypes as discrete, firm-level strategies. The findings show that CBMs are more accurately understood as hybrid configurations of value logics, where access-based, lifetime extension, resource recovery, and platform mechanisms are combined rather than adopted in isolation. This shifts the analytical focus from selecting archetypes to understanding how different value logics interact and reinforce one another in practice.

Second, the chapter contributes by positioning circular value creation as an ecosystem-level phenomenon. Rather than being contained within individual firms, CBMs are enacted through configurations of interdependent actors whose roles, complementarities, and

coordination mechanisms determine whether circular value can be realised. This perspective extends emerging ecosystem approaches in CBM literature by demonstrating how value logics are operationalised through concrete actor arrangements and lifecycle processes.

Third, the chapter introduces alignment between value logic, ecosystem configuration, and lifecycle loop realisation as a central mechanism for assessing CBM viability. This provides a more integrative framework for understanding why some circular configurations remain experimental while others scale, shifting attention from isolated design features to systemic coherence.

4.6.2 Managerial Insights

For managers, the findings suggest that implementing CBMs requires moving beyond the selection of individual archetypes toward the design of integrated configurations. Access-based offerings, for example, must be supported by refurbishment, logistics, and resale capabilities to sustain value over time. Treating archetypes as standalone solutions risks creating incomplete systems that fail to deliver circular outcomes.

A second implication concerns the need to assess ecosystem capabilities prior to implementation. Successful CBMs depend on the availability of complementary actors, including refurbishers, logistics providers, and digital intermediaries. Managers must therefore evaluate whether the necessary infrastructure and partnerships exist, or whether they need to be actively developed.

Third, the findings highlight the importance of ecosystem orchestration. Firms must take an active role in coordinating actors, aligning incentives, and establishing governance mechanisms that enable circular flows. This may involve internalising key activities, developing platform-based coordination, or forming strategic partnerships to fill ecosystem gaps.

4.6.3 Policy and Infrastructure Implications

The results also point to the importance of moving beyond firm-level incentives toward policies that enable ecosystem coordination. Circular transitions in the furniture sector depend on infrastructures such as reverse logistics systems, refurbishment facilities, and stand-

ardised quality assessment mechanisms, which individual firms are unlikely to develop independently.

Finally, regulatory frameworks play a critical role in shaping the conditions under which CBMs can scale. Policies that align economic incentives with lifecycle extension, reuse, and material recovery can strengthen ecosystem viability, while fragmented or inconsistent regulations may reinforce existing linear structures. The findings therefore suggest that advancing circularity requires not only business model innovation but also the development of institutional conditions that support multi-actor circular systems.

4.7 Conclusion

This chapter has argued that CBMs in the furniture industry are best understood not as discrete firm-level archetypes, but as ecosystem configurations in which multiple value logics are combined and enacted across interdependent actors. The findings show that circular value creation depends on the alignment between value logic, ecosystem configuration, and lifecycle loop realisation, rather than on the adoption of any single business model approach. Where such alignment is achieved, CBMs are more likely to move beyond experimentation toward scalable circular systems.

The analysis is limited by its focus on European furniture cases, which may reflect specific institutional and market conditions. Future research could extend this perspective to other sectors, examine alignment dynamics quantitatively, and explore how ecosystem configurations evolve over time through longitudinal studies.

Ultimately, the transition to a circular economy is not simply a matter of redesigning business models, but of building coordinated ecosystems capable of sustaining circular flows under real-world constraints.

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5. Circular Design Strategies: A Life Cycle Approach for the Furniture Sector

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ABSTRACT

Design plays a strategic role in enabling the circular transition of the furniture sector by influencing how products are conceived, produced, used, and recovered. As most environmental impacts are determined during the design phase, circular design is a key lever for improving resource efficiency and reducing impacts throughout the product life cycle. This chapter examines the evolution of sustainability-oriented design approaches, showing how circular design integrates ecodesign, systemic design, product-service systems, and Life Cycle Thinking (LCT). It also discusses the use of Life Cycle Assessment (LCA) to evaluate environmental impacts and avoid burden shifting. Finally, the chapter presents the 9R framework, covering design, life extension, and waste optimisation strategies, highlighting how design choices foster innovation, competitiveness, and environmental, economic, and social value across the furniture value chain.

5.1 Introduction

Circular design in the furniture sector can be understood as an evolution of sustainability-oriented approaches, including ecodesign, expanding their field of intervention from the single product to the entire life cycle. It is therefore not limited to the choice of lower-impact materials or to the reduction of environmental impacts in specific production phases, but considers the set of relationships that allow products, components and materials to remain in use over time. In this way, the unit of design expands from the isolated artefact to the life cycle, and from the life cycle to the system of actors, processes and infrastructures that enable its maintenance, reuse, repair and recovery. This shift is the central topic of CirCLER, since the furniture sector combines industrial production, material complexity, long lifetimes, emotional value and end-of-life challenges.

This perspective is consistent with the orientation of European policies, which emphasise the need to integrate sustainability from the earliest design stages. The European Commission highlights that up to 80% of a product's environmental impacts are determined during the design phase, making design a decisive moment for guiding durability, repairability, resource efficiency and end-of-life recovery potential (European Commission, 2020).

The urgency of this transition is not abstract. The Circularity Gap Report indicates that the share of secondary materials, understood as recovered or recycled materials that re-enter the economy in place of virgin raw materials, decreased from 9.1% in 2018 to 7.2% in 2023, while global material consumption continued to increase (CGR 2024, 2024). For furniture companies, this implies that incremental improvements in production efficiency must be accompanied by design strategies capable of reducing dependence on virgin raw materials, extending product lifetimes, facilitating assembly and disassembly, and enhancing end-of-life recovery options. Circular design therefore intervenes before waste is even generated: in the design brief, the bill of materials, the product's joinery, the maintenance strategy, the packaging system and the information that enables future actors to repair, reuse or recover the product (Ellen MacArthur Foundation, 2016; Pei *et al.*, 2024).

5.2 From Sustainable Product to Circular System

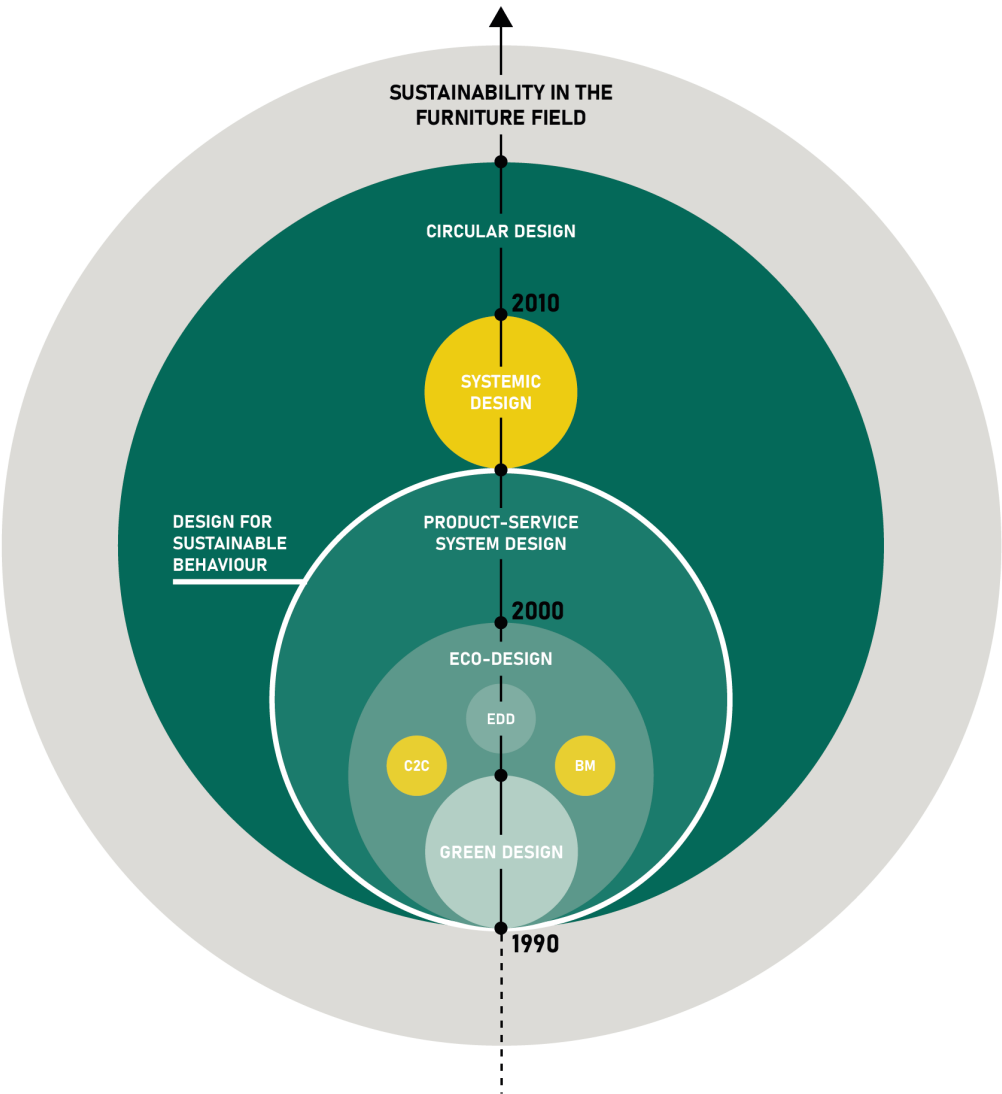
The emergence of circular design in the furniture sector can be read as the result of a progressive expansion of the designer's responsibility. Papanek's critique of design made visible the ethical consequences of products and their contribution to consumerism, social inequality and environmental degradation (Papanek, 1985). Subsequently, Design for Environment translated environmental concern into product development criteria, focusing on eco-efficient materials and processes (Fiksel, 1996). Green design introduced reduction, reuse and recycling as practical strategies, but it was criticised when it remained too close to green consumerism without truly transforming production and consumption systems (Madge, 1997). Ecodesign further broadened the field by adopting a life cycle perspective and integrating environmental criteria from raw material extraction to end-of-life management (Ecodesign Circle, 2021; Vezzoli, 2018).

Circular design builds on this genealogy but changes its ambition. It aims not only to reduce damage, but to preserve and regenerate value. The principles of the circular economy, such as reducing waste and pollution, keeping products and materials in circulation and regenerating natural systems, provide a strategic framework for this ambition (Ellen MacArthur Foundation, 2022). In the furniture sector, these principles translate into decisions concerning material sourcing, safety, durability, repairability, adaptability, disassembly, service models and future recovery. A product is circular only if it can maintain value through successive cycles of use, maintenance, refurbishment and material reintegration.

Several design traditions contribute to this approach. The Cradle to Cradle model introduced the idea that materials should be designed as biological or technical nutrients rather than as future waste (McDonough & Braungart, 2002). Biomimicry invited designers to learn from natural forms, processes and ecosystems (Benyus, 2002). Emotionally Durable Design (EDD) seeks to strengthen and prolong the emotional bond between users and products, thereby postponing replacement. Systemic design showed how production chains can connect the outputs of one process to the inputs of another (Barbero

& Toso, 2010). Research on design for sustainability has also demonstrated that lasting change requires a shift from product improvement to product-service systems and socio-technical transitions (Ceschin & Gaziulusoy, 2016, 2019). Circular design represents a convergence of material, product, service and system innovation. This convergence is synthesised in the framework developed in the CirCLER training materials, which represents circular design as the outcome of the integration of product-, service-, behaviour- and system-oriented approaches, as shown in Figure 1.

Figure 1.
Sustainable Furniture
Design Framework:
Circular Design.
Source: CirCLER, Pill 5.2.



However, circular design must avoid simplified narratives. Biological materials are not automatically harmless, since residues and nutrients may cause ecological damage if their chemical composition, concentration or disposal conditions are unsuitable (Reijnders, 2008). Technical materials cannot circulate indefinitely without energy consumption, losses or quality degradation (Bjørn & Hauschild, 2012). These limits are important because they prevent circularity from becoming a label simply attached to a preferred material. The designer's task is to understand whether the entire material-product-service system actually reduces environmental pressure while maintaining functional, social and economic value.

Furniture has specific potential in this transition. Unlike many short-lived products, furniture can remain in use for decades and acquire cultural and emotional value over time. The Danish design tradition demonstrates how quality materials, repairable construction and formal restraint can support long-lasting use and intergenerational value (Ellen MacArthur Foundation, 2021). Yet contemporary furniture also uses composite panels, foams, adhesives, surface treatments, plastics, metals and upholstery systems that may be difficult to separate. Circular design must therefore combine a culture of durability, life cycle-based evidence and industrial feasibility.

5.3 Life Cycle Thinking as a Design and Assessment Framework

Life Cycle Thinking represents an analytical and systemic approach that enables the integration of sustainability into decision-making processes related to furniture design and production. In the furniture sector, this approach makes it possible to consider the product not only as a finished object, but as a set of phases, flows and relationships that span the entire life cycle: from raw material acquisition to production, distribution, use, maintenance and end-of-life management. In this sense, Life Cycle Thinking broadens the field of design evaluation, shifting attention from the purchased object to the function it provides over time (Vezzoli, 2018). This perspective makes it possible to visualise the product as a dynamic system, composed of

interdependent phases that generate inputs and outputs throughout the life cycle, as synthesised in Figure 2.

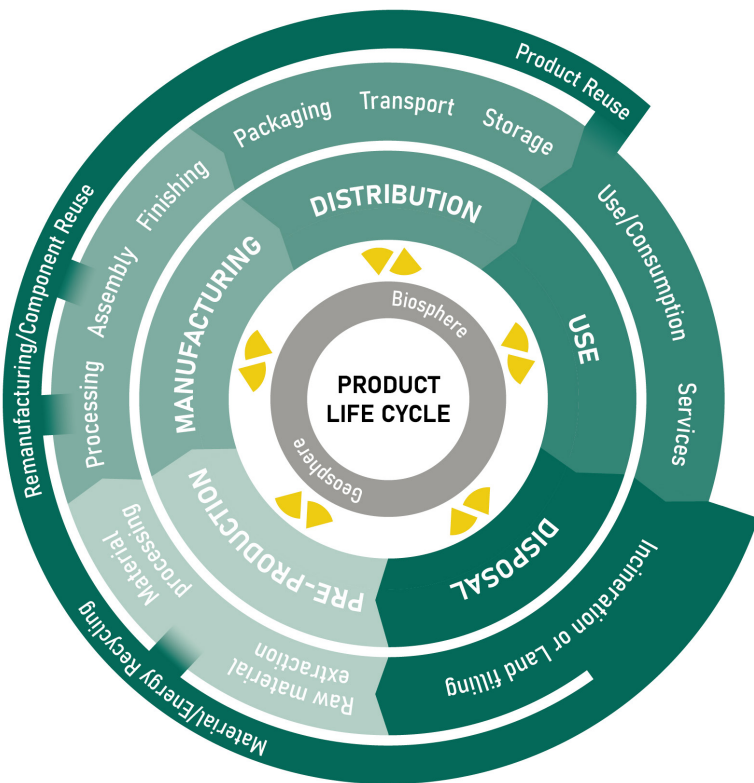


Figure 2.
Product life cycle and
main phases.
Source: CirCLER, Pill 5.3,
adapted from Vezzoli
(2018).

A table, for example, should not be evaluated exclusively as a quantity of material used, but as the provision of a work or dining surface for a given period and in a specific context of use. Similarly, a chair should be assessed in terms of seating performance over an anticipated lifetime, including aspects such as maintenance, repair and recovery potential. The role of the functional unit is to avoid misleading comparisons between products with different dimensions, lifetimes or performances, and instead evaluate them in relation to the function they provide over time (Vezzoli, 2018; Yang & Vezzoli, 2023). In the CirCLER training material, the functional unit is presented as an essential criterion for evaluating and rethinking products from a sustainability perspective, especially in the furniture sector.

Life Cycle Assessment (LCA) is the most established tool for quantifying the environmental impacts associated with these

relationships. Standardised through the ISO 14040 and ISO 14044 framework, LCA defines goal and scope, life cycle inventory, impact assessment and interpretation of results (International Organization for Standardization, 2023). Its value for designers does not lie only in producing a final environmental result, but in the possibility of identifying the most critical phases of the life cycle, testing design assumptions and avoiding the transfer of impacts from one phase to another. In the furniture sector, for example, LCA can help understand whether impacts are concentrated in material extraction, panel production, metal finishing, foam production, packaging, distribution, maintenance, replacement or disposal.

A life cycle-based approach can be expanded to include economic and social dimensions. Life Cycle Costing considers the costs associated with purchase, use, maintenance, repair, end-of-life management and residual value, while Social Life Cycle Assessment considers the social effects on workers, consumers, local communities and value chain actors. The integration of these perspectives makes it possible to go beyond an exclusively environmental reading of sustainability and to consider broader perspectives of economic feasibility and social implications in design strategies. This perspective is particularly relevant because a solution may reduce some environmental impacts but prove ineffective if it makes repair economically unsustainable, transfers costs to users or fails to consider the conditions of the actors involved along the supply chain (Vezzoli, 2018; Yang, 2024).

European policies further reinforce the relevance of life cycle-based methods. Over the last three decades, references to LCA and related methods have increased significantly in European environmental policies, indicating a progressive orientation toward measurable and verifiable product performance (Sala *et al.*, 2021). The Ecodesign for Sustainable Products Regulation strengthens this direction by introducing requirements related to durability, reparability, recyclability, recycled content, information provision and digital product data for priority product groups, including sectors relevant to furniture (European Commission, 2024; Faraca *et al.*, 2024). For the full regulatory context of the ESPR and its implications for the furniture sector, see Chapter 2, Section 2.3. Studies on Product

Environmental Footprint and Environmental Product Declarations also contribute to making environmental claims more transparent, comparable and grounded in life cycle evidence (Publications Office of the European Union, 2019).

The most important implication for design practice concerns the moment at which these tools are used. If LCA is conducted only after the product has been completed, it mainly documents the impacts generated; if, instead, it enters the early stages of the process, it can guide decisions relating to product architecture, materials, joinery, packaging, maintenance and end of life. As highlighted in the CirCLER material, LCA is particularly effective in the early design phases, when it can guide design choices while working with less complete data. The accuracy of the analysis progressively increases as more detailed information becomes available. Life cycle evaluation should not be a subsequent verification or technical requirement, but a supportive tool capable of guiding more conscious choices coherent with the objectives of the circular transition.

5.4 Circular Strategies across the Furniture Life Cycle

The 9R hierarchy helps organise circular design strategies according to the depth of intervention and the length of the cycles. Short-cycle strategies such as Refuse, Rethink and Reduce prevent the unnecessary use of resources at the beginning of the process. Medium-cycle strategies such as Reuse, Repair, Refurbish, Remanufacture and Repurpose extend the life of products and components. Long-cycle strategies such as Recycle and Recover intervene on materials and energy when higher-value options have been exhausted (Potting *et al.*, 2017; Pei *et al.*, 2024). This hierarchy is essential because it prevents recycling from being treated as the first circular solution, instead of one of the last strategies to be adopted after prevention, reduction and the extension of product lifetime (Charter, 2018; Pei *et al.*, 2024). Figure 3 synthesises this hierarchical logic, showing how the strategies closest to waste prevention are associated with shorter cycles and a greater capacity to preserve value.

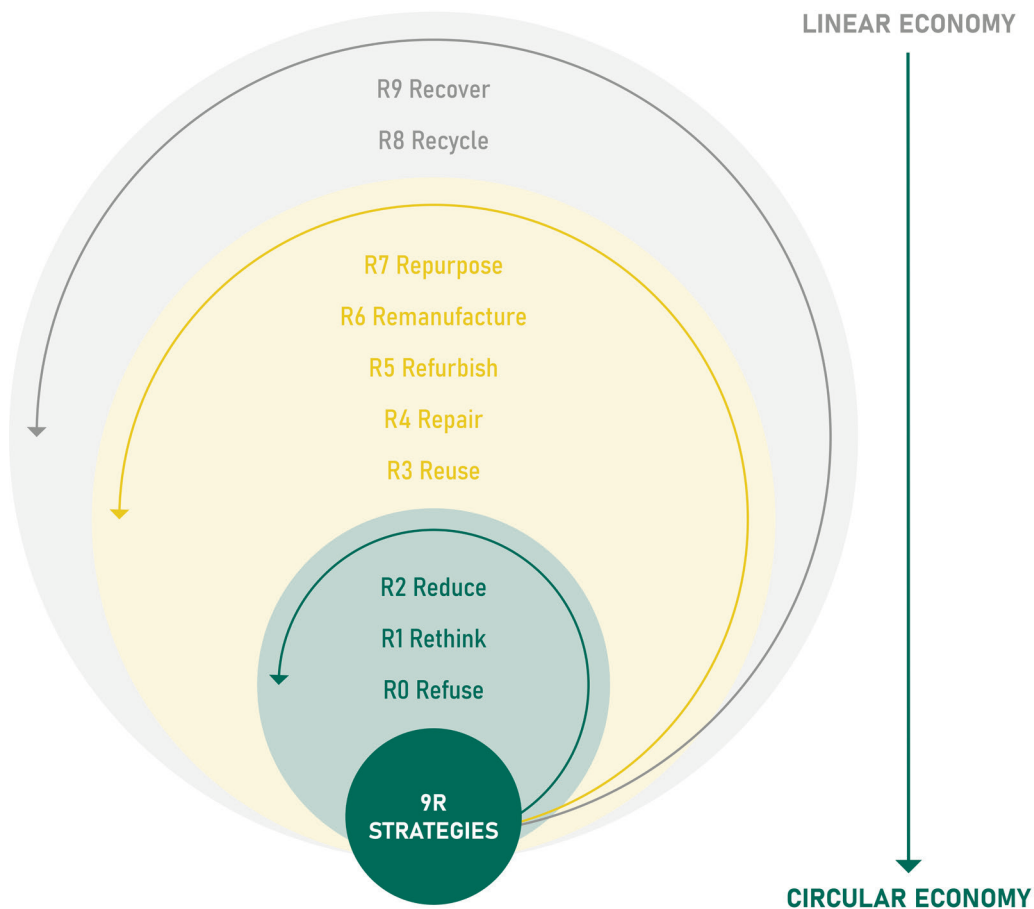


Figure 3.
9R strategies model for
circular design.
Source: CirCLER, Pill 5.4,
adapted from Potting *et al.* (2017).

Refuse asks what should not enter the system. Examples include toxic substances, unnecessary components, redundant finishes, fragile details, single-use packaging or material combinations that make recovery impossible. Rethink concerns the role of the product within a broader system. Examples include shared use, leasing, rental, modular configurations or take-back services. Reduce addresses the quantity of material, energy, process steps, transport volume and waste, without compromising comfort, stability, durability or repairability. A lighter product is not circular if it breaks quickly or cannot be maintained over time (Pei *et al.*, 2024).

Medium-cycle strategies are particularly relevant for furniture, since many products retain value after their first use. Reuse depends on the durability of the furniture's construction, ease of cleaning,

timeless aesthetics and functioning second-hand markets. Repair requires accessible components, reversible fasteners, spare parts, instructions and service networks. Refurbishment renews function and desirability through the replacement of upholstery, finishes, panels or hardware. Remanufacturing requires industrial systems for take-back, disassembly and reassembly, while Repurposing creates new functions for products or components when the original function is no longer suitable. These strategies show that circularity cannot be designed by product designers alone; it requires coordination among companies, users, logistics operators, repair networks and recyclers (Ceschin & Gaziulusoy, 2019; Pei *et al.*, 2024).

Long-cycle strategies remain necessary, but they should be designed as high-quality outcomes. Design for recycling requires material compatibility, clear identification, limited material diversity, avoidance of irreversible contamination and feasible disassembly. Recovery should be considered only after higher-value options have been assessed. The 9R model is therefore not a checklist, but a decision-making framework for selecting the appropriate cycles in relation to product, context and supply chain (Potting *et al.*, 2017; Pei *et al.*, 2024).

Several operational guidelines translate this hierarchy into practice: minimising material and energy consumption, reducing toxicity, optimising renewability and biocompatibility, extending the lifespan of products and materials and facilitating disassembly (Pei *et al.*, 2024). These guidelines are interconnected. Reversible joinery supports repair, refurbishment and recycling; a non-toxic finish affects production, indoor air quality and recovery. A modular system can reduce replacements and improve logistics. Circular strategy depends on the coherence of many design, production and organisational decisions.

5.5 Materials and Manufacturing: From Material Claims to Material Systems

Material choice is one of the most visible dimensions of circular design in the furniture sector, but also one of the most complex to evaluate. A material cannot be considered sustainable in absolute terms: its environmental quality depends on availability, renewability, em-

bodied energy, recycled content, emissions, toxicity, proximity to the production site, processing requirements, durability, maintenance, recyclability and end-of-life pathway (Pollini, 2020). As highlighted in CirCLER Pill 5.5, material selection must therefore be evaluated in relation to the entire product life cycle, and not only to the characteristics of the material in the production phase. A renewable material may involve chemical treatments or high-impact processes; a recycled material may be difficult to recycle again if combined with incompatible substances; a biodegradable material may not degrade correctly in the actual disposal context. The design question is therefore not which material appears *greener*, but which relationship between material, function, production process and end of life can preserve value and reduce overall impacts.

A rigorous methodology for material selection begins with a detailed bill of materials. Designers should identify material families, origin, recycled or renewable content, chemical composition, functional role, compatibility, expected wear and future recovery pathway. The material selection approach proposed by the Ellen MacArthur Foundation emphasises material classification, the distinction between biological and technical cycles, chemical screening, safe sourcing and the definition of post-use scenarios (Ellen MacArthur Foundation, 2016). For furniture companies, this requires collaboration with suppliers and the availability of reliable technical and environmental data.

Distinctions between biological and technical cycles are relevant when translated into concrete design choices, from material composition to end-of-life scenarios. Biological materials must be able to return to the biosphere under safe conditions, also considering additives, coatings and adhesives; technical materials must be recoverable with limited quality loss and without excessive energy or economic costs (Ellen MacArthur Foundation, 2016). In many furniture products, the decisive issue is not only the material itself, but the way in which different materials are combined. Irreversible bonding, laminated composites, complex upholstery and non-separable fasteners can transform valuable materials into low-value waste. For this reason, reversible joinery and connectors, replaceable covers and modular interfaces can determine whether a product can be repaired, refurbished or recycled.

Manufacturing processes are fundamental to a product's circularity. CNC optimisation can reduce panel waste when geometries are designed for efficient cutting; additive manufacturing can reduce material use in specific components when it avoids overproduction and supports repair or customisation; digital simulation can reduce physical prototyping and optimise structures before production. Closed-loop processes, low-emission finishes, water-based coatings and non-toxic treatments can improve environmental performance and indoor air quality. However, these solutions must be integrated with choices oriented toward durability, repairability, disassembly and recovery: low-impact production does not depend only on process efficiency, but also on the product's capacity to maintain value over time (Fiksel, 1996; Wever & Vogtländer, 2014).

Digital tools support these decisions by connecting design, material data and environmental assessment. LCA software, material databases, circularity assessment tools, CAD-integrated simulations and platforms such as MATREC help designers compare materials, technologies and end-of-life scenarios (MATREC, n.d.). Their usefulness, however, depends on data quality, the correct definition of system boundaries and the designer's ability to interpret aspects and considerations in relation to performance, ergonomics, aesthetics, maintenance and recovery.

5.6 A CirCLER Methodology for Designers

CirCLER's methodological contribution can be understood as the formation of a circular design mindset that integrates evidence, strategy and implementation. The circular designer is not only a form-giver or material selector, but a system integrator who coordinates environmental data, product architecture, production constraints, business models, use practices and post-use infrastructures. This role requires the ability to foresee LCA results, understand material behaviour, imagine service models, negotiate with suppliers and translate circular principles into manufacturable products.

A life cycle-based methodology for furniture can begin with considerations of function and duration. It can then follow with question-

ing what service does the product provide, under which conditions and for how long? The process can then include:

- the mapping of materials and processes;
- hotspot identification;
- selection of 9R strategies;
- architecture for repair and disassembly;
- service design;
- validation and communication.

The sequence and process outlined above are iterative. Choosing a material influences production, aesthetics, repair and end of life. Choosing a service model influences robustness, logistics and ownership. Designing for disassembly influences joinery, costs and visual language.

For the furniture sector, robust circular strategies combine long life with transformability. Durability reduces replacements, but adaptability prevents durable products from becoming unsuitable. Repair preserves function, while refurbishment renews desirability. Recycled content reduces primary extraction, but designing for a product's disassembly may protect the future quality of materials. Local materials can reduce transportation costs but are circular only if they meet performance and responsible sourcing criteria. Bio-based materials can support regeneration, but only if they are safe and if a real end-of-life pathway exists. Circular quality is relational, emerging from coherence across life cycle phases.

Ultimately, a life cycle-based approach transforms the very meaning of design quality. A high-quality furniture product is not only beautiful but also functional and well made. It is also legible to future actors, maintainable, adaptable, materially coherent, safe in use, and recoverable after use. It carries information as well as form and creates relationships of care rather than mere moments of purchase. From the CirCLER perspective, circular design is not less ambitious than traditional furniture design; it is more demanding. It asks designers and companies to create products that are desirable today and recoverable tomorrow, efficient in production and generous in use, materially responsible and culturally durable.

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6. R&D Techniques for Circular Product Development

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ABSTRACT

Research and development (R&D) is essential for advancing sustainable materials and supporting the circular transition of the furniture sector. This chapter examines how innovation promotes recyclability, low-impact sourcing, bio-based materials, green chemistry, and carbon-negative processes within the Technology Readiness Levels (TRLs) framework. It discusses the replacement of conventional materials with renewable, recycled, and low-impact alternatives, alongside advances in lightweight composites, low-emission adhesives and finishes, and modular solutions for repair, reuse, and recycling. Particular attention is given to material selection, processing methods, and lifecycle strategies that improve environmental performance while preserving functionality, durability, and aesthetic quality. The chapter shows how material science and R&D can accelerate circular manufacturing practices and turn sustainability challenges into opportunities for technological innovation.

6.1 Introduction

Despite promising developments, sustainable innovation in furniture manufacturing faces several challenges. These include the limited availability of reliable eco-materials, uncertainties in long-term performance, cost barriers, and a lack of standardised testing protocols for novel composites. Additionally, consumer acceptance and scalability remain key hurdles.

However, these challenges also bring opportunities. Companies that invest in material R&D can differentiate their products in a competitive market, align with green building certifications, and contribute to carbon-neutral manufacturing goals. Furthermore, collaborative R&D models, linking academia, industry, and policymakers, can accelerate innovation and drive widespread adoption of sustainable furniture solutions.

The transition from a linear take-make-dispose economy toward a circular economy has become a major objective in sustainable industrial development. Circular product development aims to minimise waste generation, extend product lifecycles, improve resource efficiency, and maintain the value of materials and products for as long as possible. In this context, research and development (R&D) techniques play a critical role in enabling companies to design products that are durable, repairable, reusable, recyclable, and environmentally sustainable (den Hollander *et al.*, 2017).

Recent literature highlights that product design decisions made in the early stages of development strongly influence a product's environmental performance and circularity potential throughout its lifecycle. Therefore, integrating circular economy principles into the new product development (NPD) process has become an important research direction in engineering, industrial design, and manufacturing (Rotondo *et al.*, 2025).

A wide range of R&D techniques has emerged to support circular product development, including eco-design, design for disassembly (DfD), design for recycling (DfR), life cycle assessment (LCA), material flow analysis, biomimicry, TRIZ-based innovation methods, digital twins, and artificial intelligence-assisted optimisation (Bocken *et al.*, 2016; Moreno *et al.*, 2016; Vinuesa *et al.*, 2020; Rotondo *et al.*, 2025).

For the 9R framework and the related circular design strategies referenced throughout this section, see Chapter 5, Section 5.4.

Furthermore, modern circular design methodologies increasingly rely on interdisciplinary knowledge bases and digital databases that contain scientific findings, engineering principles, patents, and cross-industry examples of innovation. Such tools support designers and engineers in identifying alternative materials, improving product performance, and transferring solutions from other industrial sectors into new applications. This cross-sectoral innovation capability is particularly valuable for solving complex sustainability challenges in manufacturing industries, including furniture production, construction materials, automotive systems, and consumer products (Cascini, 2012; Ghane *et al.*, 2022).

Several studies also emphasise that the successful implementation of circular product development requires not only technical innovation but also organisational transformation, new business models, and cross-supply-chain collaboration. Circular strategies such as re-manufacturing, modularity, product-service systems, and closed-loop material cycles require companies to rethink conventional product development processes and adopt more integrated sustainability-oriented R&D frameworks (Ladewig, 2008; Paulista *et al.*, 2026).

In manufacturing sectors such as furniture production, circular product development can involve recycled materials, lightweight composite structures, modular assemblies, low-impact adhesives, and multifunctional acoustic or thermal panels. R&D techniques enable manufacturers to optimise material properties, reduce environmental impact, and improve product functionality while supporting circular economy objectives. Emerging technologies such as AI-driven optimisation, smart materials, and advanced manufacturing systems further accelerate the development of sustainable and resource-efficient products (Pigosso *et al.*, 2015; Ceschin & Gaziulusoy, 2019; Ghane *et al.*, 2022).

This chapter presents an overview of key R&D techniques for circular product development, focusing on innovation methods, sustainable design approaches, and technological tools that support the transition to circular manufacturing systems and sustainable industrial practices.

6.2 Stages of R&D for New Products

The stages of R&D for new materials and products extend beyond simply creating a functional item: they must be designed to be sustainable and circular from the outset. In the context of materials and composites applicable to the furniture industry, R&D involves a combination of computational tools, laboratory-scale experimentation, and sustainability-oriented design. The R&D process for new sustainable products can be described through ten successive stages, presented below.

Ideation and Concept Development

This is the starting point of the innovation process, in which researchers identify problems and generate ideas with sustainability as a guiding criterion. At this stage, particular attention is given to how the future product can be reused, repaired, or recycled, with the overall goal of designing products that fit within a circular economy, in which materials retain value beyond their first use.

Material Selection and Innovation

Once the concept has been defined, the next step is the selection of appropriate materials. Rather than relying on virgin materials, researchers prioritise recycled, recyclable, biodegradable, or renewable alternatives. This stage also allows for experimentation with converting waste streams into usable resources, provided that the resulting materials remain safe, durable, and compatible with circular design requirements.

Prototyping and Testing for Circularity

At this stage, prototypes are built and tested. In addition to verifying functional performance, researchers assess ease of disassembly, separability of materials, and potential for repair, reuse, or recycling. Testing also includes mechanical performance, safety, and user feedback.

Evaluation and Improvement Loops

After testing, improvements are made. This process may happen several times. Researchers learn from what did not work and improve the

design to make it more circular and efficient. Tools like life cycle assessments (LCA) and sustainability checklists help evaluate impacts and identify better alternatives.

Final Design Optimisation

With all improvements made, the product is finalised. Researchers prepare it for production by making sure it is efficient to manufacture, uses minimal resources, and has the smallest possible environmental footprint. The design should still allow for easy reuse, repair, or recycling in the future.

Circular Business Model Development

The success of a circular product also depends on how it is delivered to, and used by, the end customer. Rather than relying solely on conventional sale-and-disposal models, researchers explore alternative approaches such as take-back schemes, repair services, and recycling pathways.

Production and Supply Chain Setup

The next stage is about how the product will be made and what resources are needed. The goal is to reduce waste, energy use, and emissions during production. This includes working with suppliers who follow sustainable practices and planning for efficient, low-impact transportation and packaging.

Market Launch and Communication

When the product reaches market readiness, its environmental and circular benefits must be clearly and accurately communicated. Effective communication helps users understand the product's distinguishing features and encourages responsible use.

Monitoring and Circular Impact Assessment

After launch, the work isn't over. That phase involves tracking how the product performs, how long it lasts, and what happens at the end of its life. In this phase, user data is collected, and the environmental impact is calculated using tools such as carbon footprint calculators or material flow analysis.

In the final stage, the focus shifts to scaling the circular approach across the wider production system, with the aim of ensuring that materials are continuously reused or repurposed and that waste generation is minimised even as production volumes increase.

6.3 R&D Techniques

When it comes to R&D techniques for new products, particularly in materials and composites, the state of the art involves a blend of computational tools, lab-scale experimentation, and sustainability-oriented design (Figure 1).

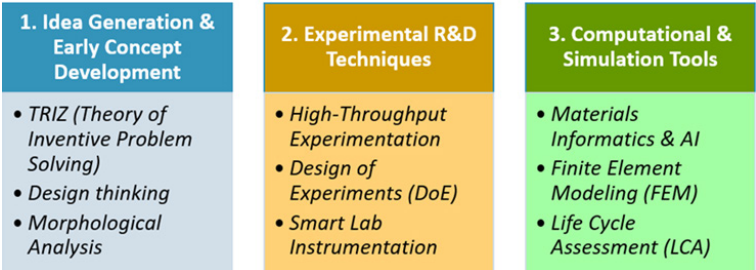


Figure 1. Advanced R&D techniques for new products, particularly in the context of materials. Source: Original material created by C. Cosereanu.

6.3.1 Idea Generation & Early Concept Development

TRIZ (Theory of Inventive Problem Solving)

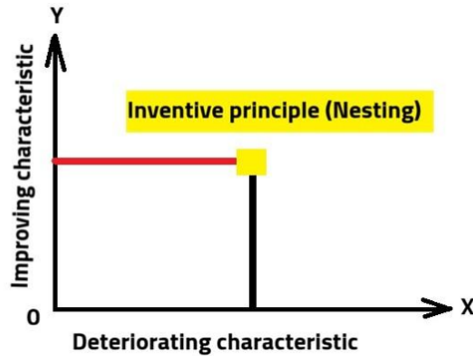
This is a systematic method for solving innovation problems by analysing patterns of invention. It identifies and solves engineering problems by analysing how similar issues were solved in other industries. This theory has several key principles, such as: (I) innovation is not random, it follows patterns that have worked elsewhere; (II) it encourages *out-of-the-box* thinking without relying on brainstorming alone; (III) it helps invent patentable solutions or disrupt conventional product design.

Ladewig (2008) defines seven inventive techniques:

- formulate the contradiction;
- formulate the ideal final result and define the ideal machine;
- solve the problem using functional diagrams;
- solve using *physical separation* techniques by separating the conflicting requirements acting on the same object;

- solve the contradiction by using the invention matrix; any technological system, no matter its complexity, is defined with only 39 characteristics, such as size, strength, weight, density, reliability, etc. There are deteriorating characteristics and improving ones. They can be represented in an invention matrix in an XOY coordinate system, as shown in Figure 2. The intersection between the two attributes being in contradiction gives the solution of resolving the conflict, and it is named *nesting*;

Figure 2.
Invention matrix,
according to Ladewig
(2008).



- solve with the trends of system evolution, which defines six major directions of system evolution, as shown in Table 1.
- solve the problem using the physical effects database. Software-based databases containing scientific findings, patents, technical references, animations, and cross-industry examples enable users to search for functional solutions for product innovation, system improvement, and problem-solving. These knowledge bases help generate new product features, restore performance after design simplifications, and provide solutions drawn from other industries and expertise beyond the user's field.

For example, in furniture manufacturing, a physical effects database can be used to identify the cellular-structure effect, where internal air cavities reduce weight while preserving stiffness. By introducing a honeycomb or foam-like internal structure into a furniture panel, weight is reduced without significantly compromising mechanical performance, lowering transportation costs and improving overall material efficiency.

Nr.	Definition (Ladewig, 2008)	Explanation with examples in furniture manufacturing systems
1	Transition to a higher level, or multi-object system	A system evolves from a single, independent object into a coordinated, multi-component, or integrated system. Example: a simple office desk evolving into a modular workstation system equipped with interconnected desks, integrated cable management, shared power/data hubs, movable partitions, ergonomic lighting, and IoT occupancy sensors.
2	Non-uniform rate of sub-system evolution	Different parts of a system evolve at different speeds, creating contradictions that drive innovation. Example: a contradiction between high-speed manufacturing and slow manual upholstery operations in upholstered furniture, creating bottlenecks. CNC cutting improved precision, but manual upholstery assembly remained labor-intensive; innovation introduced robotic fabric handling, automated sewing, and digital pattern matching.
3	Shortening of the energy path	Energy transfer becomes more direct and efficient with fewer intermediates. Example: traditional furniture manufacturing relies on manual transportation of materials between separate machines; modern smart factories use automated conveyor systems, CNC centers, and robotic transfer arms, so material moves continuously through production with minimal handling and energy loss.
4	Increasing flexibility, from rigid mechanical to pliable to electrical	Systems evolve from rigid, fixed mechanisms toward adaptable, controllable solutions. Example: adjustable office chairs evolved from fixed wooden chairs to mechanically adjustable chairs, and then to modern ergonomic ones, including electric height adjustment and posture monitoring.
5	Transition from macro to micro-level	Innovation moves from large-scale structural changes to micro- or nano-scale control of material properties. Example: acoustic furniture panels evolved from large, thick, high-density designs toward micro-perforated surfaces, engineered fibre structures, and microcellular foams.
6	Increasing ideality	Systems deliver more useful functions at lower cost, material use, energy use, complexity, or harm. Example: traditional fixed furniture evolved into knock-down furniture, reducing shipping volume, simplifying assembly, lowering transportation costs, and enabling recycling.

Another example that illustrates the TRIZ theory could be the innovation of new sustainable materials designed for furniture manufacturing applications. Particleboard is the most used wood-based material for furniture manufacturing. It is made of wood particles bonded with formaldehyde resins. A new method is to replace the wood particles with those derived from agro-waste, since their chemical composition is similar: lignin, cellulose, and hemicellulose. In this case, the researchers are facing a technical contradiction: to increase strength – a desired improvement, without increasing weight – an undesired outcome. Applying TRIZ, several solutions can be identified:

- use mixed particle sizes: fine particles fill the gaps between larger ones, leading to a denser structure and stronger bonding with little added mass;

Table 1.
Trends of any system evolution.

- mix agro-waste with lightweight reinforcing fibres (e.g., jute, kenaf, hemp) or binders that offer strength without much weight;
- densify the outer layer while keeping the core lighter;
- modify agro-waste treatment (e.g., alkaline treatment of fibres) to improve adhesion and mechanical properties at the microscopic level;
- modify an object's structure in specific areas to improve performance.

A real example that illustrates innovation in materials science along these lines is the work by Barta *et al.* (2024), who developed mycelium-based composites using waste materials – spent coffee grounds, coffee chaff, hay straw, hemp dust and a cereal mixture – as the substrate for mycelium growth. The result is a light, porous material that can be used as a core for sandwich structures.

Design Thinking

It represents a human-centered process for solving complex problems, popularised by Stanford University. This method keeps the end-user at the center, reduces risk by catching flaws early, and encourages iterative experimentation, with five phases: (I) empathise and understand user needs and important points (e.g., who's using the furniture and what materials are required?); (II) define the real problem, not just the symptoms; (III) generate a wide range of solutions; (IV) build simple, testable prototypes quickly; (V) test and gather feedback, iterate, and refine.

Morphological Analysis

This creativity technique uses a multi-parameter matrix to explore possible configurations of a material, product, or system by combining key parameters, such as composition, adhesive, additives, thickness, and surface quality. It is useful in early-stage R&D, when the solution space is still open. The process involves: (I) identify the key parameters of the system; (II) list possible variants for each parameter; (III) create a morphological matrix with all possibilities; (IV) explore combinations for viable and novel solutions.

A real example of applying morphological analysis in research work comes from the study by Zawawi *et al.* (2022). The morphological analysis was applied to design particleboard panels made from agro-waste materials (specifically rice husk, kenaf core, and oil palm biomass) for sustainable furniture applications. They identified the following key parameters:

- core material (rice husk, kenaf, oil palm fibres);
- resin type (urea-formaldehyde, melamine-urea-formaldehyde, bio-resin);
- additives (fire retardant, water repellent, none);
- panel thickness (10 mm, 15 mm, 20 mm);
- surface treatment (laminated, veneered, plain).

The morphological matrix that combined these possibilities into hundreds of different configurations was organised into three options per parameter (Table 2).

Parameter	Option 1	Option 2	Option 3
Core Material	Rice husk	Kenaf core	Oil palm biomass
Resin Type	Urea-formaldehyde	Melamine-urea-formaldehyde	Bio-resin
Additives	Fire retardant	Water repellent	None
Panel Thickness	10 mm	15 mm	20 mm
Surface Treatment	Laminated	Veneered	Plain

The total number of combinations for this case was $3^5 = 243$ possible panel designs. Researchers applied several filters to reduce the number of possibilities, as follows:

- only bio-resin was acceptable for *eco-friendly* furniture;
- low mechanical strength: rice husk combinations were eliminated (poor bonding strength);
- panels without fire retardant were excluded for furniture applications needing fire resistance;
- a thickness of 15 mm was prioritised because 10 mm was too fragile, and 20 mm was too heavy for furniture.

Using this method, Tests showed that a 15 mm kenaf core with bio-resin and a laminated surface worked best for indoor furniture.

Table 2.
Morphological matrix.

6.3.2 Experimental R&D Techniques

High-Throughput Experimentation (HTE)

HTE involves testing systems that can screen dozens or hundreds of formulations or conditions at once. Originally popularised in the pharmaceutical industry, it's now widely used in materials science.

It rapidly explores multiple variables (e.g., binder types, additives, fibre ratios) and generates large datasets for statistical modeling. It also reduces human error and speeds up R&D cycles. It measures physical properties (density, swelling, bonding) across all samples using automated instruments.

In furniture manufacturing, High-Throughput Experimentation (HTE) has been applied to accelerate the development of coatings and lamination adhesives for wood-based panels (Gomez *et al.*, 2019). Automated formulation and rapid screening techniques enable simultaneous evaluation of properties such as scratch resistance, curing behaviour, adhesion strength, and surface quality, significantly reducing product development time. Using HTE, researchers can automatically prepare and test hundreds of coating or adhesive formulations in parallel rather than evaluating them individually.

As an example, researchers at The Dow Chemical Company developed automated high-throughput workflows for industrial coatings. Their system uses robotic formulation, parallel sample preparation, miniaturised testing, and automated property screening. The method enabled rapid evaluation of properties such as hardness, scratch resistance, cure speed, impact toughness, and surface defects – properties that are critical for furniture coatings and laminated wood panels (Kuo *et al.*, 2016).

A practical case in the furniture industry is Covestro's development of water-based polyurethane adhesives for 3D-laminated furniture fronts, using a real-time formulation configurator. HTE principles are useful here because many adhesive compositions can be screened rapidly to identify the best formulation for a given application (Covestro, 2025).

Design of Experiments (DoE)

DoE is a statistical approach that strategically plans experiments to understand how input variables affect outcomes. Unlike random

testing, DoE optimises the test plan for maximum information with fewer trials. Common methods used in DoE are as follows: (I) Full factorial, which tests all combinations of variables, being used for small systems; (II) Fractional factorial, which reduces the number of tests while maintaining accuracy; (III) Taguchi method, which focuses on robustness against noise and variability.

Tools used to build the experimental matrices and analyse results include Minitab, JMP software, and Statsmodels.

Design of Experiments (DoE) is widely applied in furniture manufacturing to optimise production parameters of wood-based composite panels. In particleboard and MDF production, factorial experimental designs are used to evaluate the combined influence of variables such as pressing temperature, pressing time, and adhesive content on mechanical and physical properties, including modulus of rupture, internal bonding strength, and thickness swelling.

When studying wood-based and innovative materials, researchers need to identify processing conditions that provide the desired mechanical and physical properties and surface quality. Design of Experiments (DoE) examines several factors simultaneously, rather than one at a time, and reveals interactions between them. Ayilmis (2007) applied DoE to MDF panels for furniture, studying how density affects the dimensional stability of medium- and high-density fibreboards. Response Surface Methodology, discussed by Khuri and Mukhopadhyay (2010), helps optimise wood-composite manufacturing variables such as adhesive content, press pressure, and temperature. It assesses their effects on bonding strength, water resistance, and surface smoothness, helping identify the most influential factors, interactions between temperature and pressure, and optimal settings for durable furniture panels.

The results show how manufacturing conditions influence the final properties of the panels.

Smart Lab Instrumentation

Smart Lab Instrumentation uses advanced analytical instruments to gain deep insights into material structure, composition, and performance, complementing the design-stage techniques described in the previous section.

Instrument	Use
FTIR (Fourier Transform Infrared Spectroscopy)	Identifies chemical bonds (e.g., cross-linking, starch modification).
SEM (Scanning Electron Microscope)	Visualises surface and internal structure at micro level (e.g., fibre distribution, pore size, adhesion).
XRD (X-ray Diffraction)	Determines crystalline structures (e.g., filler phase, additives).
TGA/DSC (Thermogravimetric/Calorimetric Analysis)	Measures thermal stability, decomposition, phase changes.
Acoustic Impedance Tube	Measures sound absorption coefficient across frequencies – essential for evaluating acoustic panel performance.
Heat Flow Meter	Measures the thermal resistance and thermal conductivity of insulation materials.

Table 3.
Smart Lab
Instrumentation.

A good example of experimental R&D techniques comes from IKEA, which sought to create sustainable, lightweight, and affordable furniture panels to reduce material use, shipping costs, and environmental impact. The material innovation involved collaboration with materials developers to use bio-composite cores made from recycled wood fibres mixed with bio-based or recycled plastics (e.g., PLA and recycled PP). In particular, *Board-on-Frame* (BOF) construction, a lightweight honeycomb structure within panels, was enhanced by experimenting with different core composites, including variations in natural fibre content, bio-resin type, foaming additives, and pressing parameters. Production and mechanical testing (bending strength, impact resistance) were partly automated to screen composites more quickly, with statistical analysis used to optimise material combinations and environmental impact data (LCA) collected in parallel to guide sustainable choices. The result was the development of lightweight panels with densities of 200-300 kg/m³, using minimal material while maintaining adequate strength. For IKEA's use of artificial intelligence and supply-chain technologies, see Chapter 7, Section 7.6.1.

6.3.3 Computational & Simulation Tools

Materials Informatics & AI

It combines data science, machine learning (ML), and materials science to predict properties, discover new materials, and optimise formulations faster than lab-only approaches.

- Predict mechanical, thermal, or acoustic properties based on existing datasets.

- Use ML algorithms to identify relationships between composition and performance, ML uses algorithms that learn from data to make predictions.
- Enable inverse design: define desired properties, and artificial intelligence (AI) suggests possible formulations.

Several tools are presented in Table 4.

Table 4.
Tools for material informatics. Tool websites accessed June 2026.

Tool	Description	Website
Materials Project	Open-access database with calculated material properties.	materialsproject.org
Matminer	Python library for materials data mining; includes featurizers and datasets.	hackingmaterials.lbl.gov/matminer
PyMatGen	Python Materials Genomics – used to analyse and manipulate crystal structures.	pymatgen.org
AFLOW	Integrated infrastructure for computational materials discovery; rich databases for property prediction.	afflowlib.org
OQMD	Database of calculated thermodynamic and structural properties of one million materials.	oqmd.org

Finite Element Modeling (FEM)

This is a computational technique used to simulate how a material or structure responds to physical forces (e.g., stress, heat, vibration). This method helps simulate stress–strain distribution, thermal gradients, and acoustic wave propagation in 2D or 3D, and analyses deformation, failure, or insulating performance under various loading conditions. Several tools are presented in Table 5.

Table 5.
Tools for FEM. Tool websites accessed June 2026.

Software	Key Focus	Website
COMSOL Multiphysics	Multiphysics simulation (e.g., structural + acoustic + thermal).	comsol.com
ANSYS	Industry-standard for mechanical, thermal, and acoustic simulations.	ansys.com
Abaqus	Powerful for non-linear material modelling (e.g., porous or fibre-reinforced composites).	3ds.com/simulia/abacus
Elmer FEM (open source)	Free alternative with good flexibility.	elmerfem.org

Finite Element Modeling (FEM) is increasingly applied in furniture manufacturing to evaluate the structural behaviour of chairs, upholstered frames, and wood-based furniture components under static

and cyclic loading conditions. FEM enables the prediction of stress distribution, deformation, and joint performance, allowing manufacturers to optimise furniture structures and reduce the need for costly physical prototypes (Matwiej *et al.*, 2025). These researchers at Poznań University of Life Sciences applied FEM to analyse upholstered furniture frames made of pine and spruce. The study created 3D numerical models of furniture frames and simulated real loading conditions using Autodesk Inventor Nastran. The FEM model evaluated stress concentrations, displacement, equivalent strain, and stiffness of glued and stapled joints. The results helped optimise the frame geometry and reinforcement strategy, improving structural durability while reducing unnecessary material use.

Another furniture-industry application involved FEM analysis of wooden office chairs (Ceylan *et al.*, 2021). Researchers designed 30 chairs made of beech and pine wood. They were tested under three cyclic loading directions and analysed as structures to obtain the axial, shear, and bending stresses acting on each member under the loading, and to compare these values with the design stresses.

Life Cycle Assessment (LCA) Software

LCA evaluates the environmental impact of a product or process throughout its entire life cycle, from raw material extraction to disposal or recycling. Its key capabilities are as follows: quantify CO₂ emissions, energy use, water footprint, and toxicity; compare environmental trade-offs between different materials or manufacturing methods; support eco-labeling, green product development, and regulatory compliance. Several tools are presented in Table 6. For the methodological framework underpinning LCA (ISO 14040/14044, functional unit definition, and impact category selection), see Chapter 5, Section 5.3.

Table 6.
Tools for LCA. Tool
websites accessed June
2026.

Tool	Highlights	Website
SimaPro	Industry-standard, user-friendly with built-in impact methods.	simapro.com
GaBi	Widely used in academia and industry, with strong databases.	sphera.com/gabi
OpenLCA	Free, open-source tool with good database compatibility (e.g., ecoinvent).	openlca.org
One Click LCA	Focuses on construction and building materials.	oneclicklca.com

Life Cycle Assessment (LCA) software, such as SimaPro, GaBi, and OpenLCA, is widely applied in furniture manufacturing to quantify the environmental impacts of wood-based products throughout their life cycle. These tools enable assessment of processes, including raw material extraction, panel production, furniture assembly, transportation, use, and end-of-life management. In furniture applications, LCA software has been used to identify environmental hotspots in products such as chairs and wardrobes, supporting the development of more sustainable furniture designs (Iritani *et al.*, 2015; Dingil, 2024).

The recent study by Dingil (2024) conducted a cradle-to-grave LCA of a dining chair using SimaPro and the ecoinvent database. The researcher evaluated raw material extraction, veneer production, upholstery, packaging, transportation, use phase, and end-of-life disposal. The study identified the manufacturing stage as the main environmental hotspot, particularly in the use of urea-formaldehyde resin, woven textile production, and packaging materials. The software enabled the calculation of environmental indicators such as Global Warming Potential (GWP), human toxicity, acidification, and ecotoxicity. The results showed that recycling scenarios and alternative textile materials could reduce the chair's environmental impact by up to 48%.

Another research work used GaBi to assess a medium-density particleboard (MDP) wardrobe. The researchers modeled wood extraction, MDP/particleboard production, furniture manufacturing, transportation, and distribution. The study found that raw material supply, resin production, and transport distance were the largest contributors to environmental impact. Scenario analysis demonstrated that replacing virgin wood with recycled wood waste significantly reduced environmental burdens (Iritani *et al.*, 2015).

6.4 Using the TRL Framework to Guide Circular Product Innovation

In the transition toward a circular economy, developing innovative products that minimise waste and maximise resource efficiency is essential. The Technology Readiness Level (TRL) framework offers a structured approach to assess and advance technologies from

concept to market. By applying the TRL framework to circular product innovation, stakeholders can better navigate the complexities of integrating sustainability into product development, ensuring that environmental goals align with technical feasibility and market readiness. Table 7 provides a brief description of the TRLs, with examples for furniture panels.

Table 7.
Technology Readiness
Levels (TRLs).

TRL	Description	Example (Furniture Panels)
TRL 1	Basic principles observed.	Chemical interaction of adhesives and wood particles.
TRL 2	Concept formulated.	Concept for low-emission, high-strength particleboard.
TRL 3	Experimental proof of concept.	Lab-scale tests for bonding, mechanical strength.
TRL 4	Lab validation in the relevant environment.	Pilot-scale panel pressing and testing.
TRL 5	Technology validated in an industrial environment.	Industrial press trials; QC checks; compatibility analysis.
TRL 6-7	Prototype and system demonstration in an operational environment.	Pilot-line and commercial-line production runs; certification.
TRL 8-9	System qualified and proven in operational use.	Full-scale commercial launch and post-market monitoring.

6.4.1 Design and Develop New Products (TRL 1 and TRL 2)

In sustainable product innovation, especially in furniture manufacturing, early-stage R&D (TRL 1 and TRL 2) focuses on fundamental research and concept formulation. This phase is critical for generating viable ideas and aligning them with performance, sustainability, and market expectations.

TRL 1 - Basic Principles Observed

At this level, the fundamental principles underlying new materials or technologies are studied, including literature reviews, laboratory observations, and assessments of material behaviour.

Research focuses on:

- identification of raw materials to be used: natural fibres, bio-binders, waste materials, and agricultural residues, all of which help reduce pollution, conserve resources, and create sustainable alternatives to traditional composites;

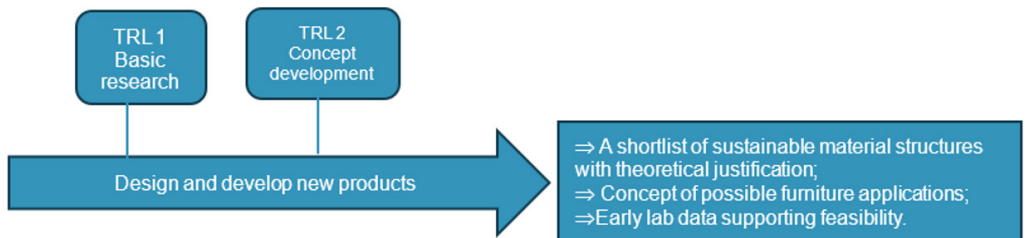
- properties evaluation (moisture content, fibre morphology, biodegradability potential, LCA), which indicate how the material will perform under real-world conditions and how eco-friendly it is;
- theoretical modeling (e.g., using FEM) to simulate mechanical performance and identify stress distribution, weak points, and failure zones before physical testing;
- formulation of material-structure interaction hypotheses, describing how the material is expected to behave within the structure in which it will be used.

TRL 2 - Technology Concept Formulated

At this stage, design ideas are aligned with functional needs and translated into early technology concepts. Materials begin to be combined into early prototypes, sketches are tested against real-life application scenarios, and preliminary feedback, including from unsuccessful tests, informs subsequent refinement. The following activities are typically carried out at this stage:

- prototypes of composite material structures are proposed, with different formulations created to explore how they perform together;
- functional design scenarios are sketched with potential applications;
- preliminary validation is carried out: laboratory-scale specimens are tested for integrity, strength, and fibre adhesion, in order to determine whether the concept warrants further development;
- the output of TRL1 and TRL2 in furniture development is presented in Figure 3.

Figure 3.
TRL 1 and TRL 2 in short.



6.4.2 From Laboratory Validation to Market Launch (TRL 3–TRL 9):

Summary

Between TRL 3 and TRL 5, particleboard and panel concepts move from laboratory proof of concept to validation in an industrial environment. At TRL 3, physical and mechanical properties are characterised against recognised standards (e.g., EN 312) under controlled laboratory conditions. At TRL 4, the product is validated under simulated or small-scale production conditions and benchmarked against existing commercial products and regulatory minimums. At TRL 5, the technology is transferred to a real industrial environment, with independent certification bodies verifying compliance with safety and performance standards (e.g., CE marking, formaldehyde emission limits).

Between TRL 6 and TRL 9, the focus shifts from process validation to market deployment: the prototype is demonstrated in an operational environment (TRL 6–7), the system is fully qualified and certified for commercial production (TRL 8), and the product is proven in real-world use through post-market monitoring and continuous improvement (TRL 9).

6.5 Examples of Good Practice

6.5.1 Lignin-based Particleboards

A study conducted by Paul *et al.* (2021) explored the feasibility of using lignin-based adhesives for particleboard manufacturing to achieve low formaldehyde content in the board. Formaldehyde emission is associated with urea-formaldehyde resin, a dominant adhesive used in particleboard manufacturing.

In Europe, the European Chemicals Agency (ECHA) classified formaldehyde as a *presumed human carcinogen* (category 1B) and of *acute toxicity*. The limit on formaldehyde emissions set by CARB (California Air Resources Board) is 0.09 ppm for particleboard. These limits are 10 to 20 times lower than those in force 30 years ago, which has forced producers to adopt alternative methods.

The selection and preparation of raw materials were based on previous attempts in this research topic. They were selected as follows:

- raw materials: mixed beech (30%) and spruce (70%) wood particles at a moisture content of around 10%, with a bark percentage of 5% of the total amount.
- Adhesive: bio-adhesive based on magnesium lignosulfonate (LIGNEX MG F, supplied by SAPPI BIOTECH GmbH – Düsseldorf, Germany), oxidised with 30% hydrogen peroxide (H_2O_2) in an aqueous alkaline solution.
- Additives: crosslinkers (glucose 1% and diphenylmethane diisocyanate 1%-3%).

The manufacturing process was based on the following parameters: boards were hot-pressed at 180°C for 16 min under a pressure of 2.5 N/mm². The final product is shown in Figure 4.



Figure 4. Eco-friendly particleboard bonded with lignin-based adhesive (Paul *et al.*, 2021).

The results of this study on formaldehyde emissions have shown that for panels with 15%-20% adhesive in their composition, formaldehyde emissions were 6.3 to 10.9 times lower than the acceptable value for emission class E1. The study concluded that particleboards produced with magnesium lignosulfonate met the requirements for use in dry environments as specified by EN 312.

6.5.2 Lightweight Panels for Thermal Insulation Applications

Another study by Mazaherifar *et al.* (2024) explored the potential of recycled cardboard for manufacturing lightweight panels for thermal insulation applications (Figure 5).

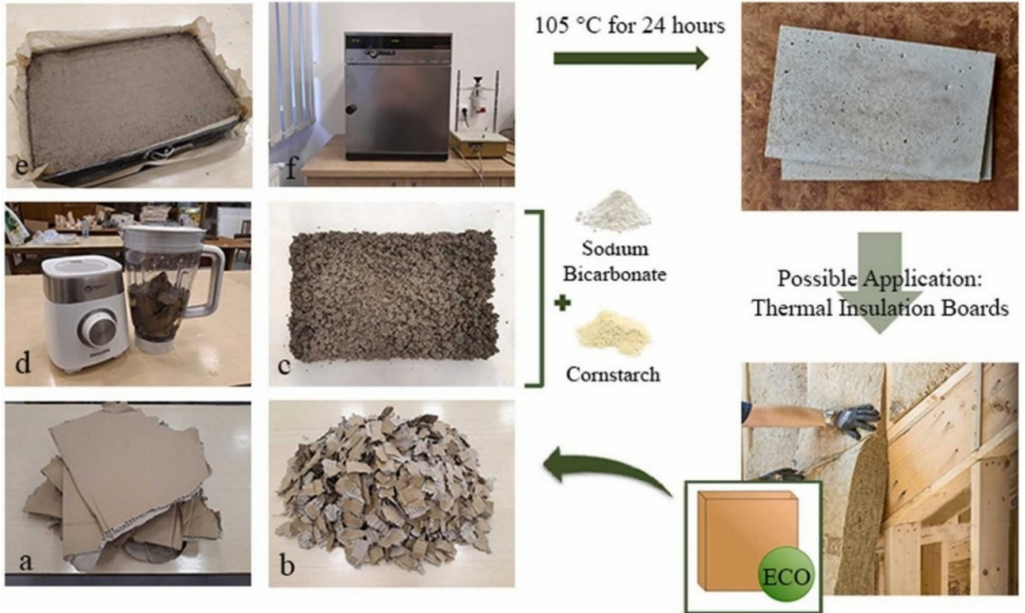
The following materials were used for the preparation of composites:

- raw materials: recycled cardboard.
- Adhesive: cornstarch.
- Additives: sodium bicarbonate.

The manufacturing process was innovative and based on baking at 105°C for 24 h in the oven, followed by cooling at room temperature. Lightweight composites were obtained with this technology, having densities in the range 237-284 kg/m³ and thermal conductivity

coefficient values between 0.048 W/mK and 0.049 W/mK, indicating composites well suited to wall paneling for thermal insulation purposes. The study concluded that there is potential to use recycled corrugated cardboard in the manufacture of foam composites and to extend its life cycle in this way, thereby reducing the environmental burden associated with cardboard waste disposal in landfills.

Figure 5.
Low-density panels made
from recycled cardboard.
(Mazaherifar *et al.*,
2024).



6.6 Conclusions

1. Research and development (R&D) for new products follows a structured and progressive sequence that begins with idea generation and early concept development, followed by the integration of experimental investigations and computational evaluation methods. This phased approach ensures that innovation is not only creative but also grounded in technical feasibility, systematic testing, and practical applicability.
2. The Technology Readiness Level (TRL) framework plays a fundamental role in guiding circular product innovation, particularly in industries such as furniture manufacturing, where sustainability, material efficiency, and product durability are

increasingly important. Through its staged progression, the framework enables developers to evaluate technological maturity, identify limitations, and systematically improve product performance before commercialisation.

3. The initial phases of R&D, Idea Generation and Concept Development, represent highly creative and exploratory stages that establish the foundation for subsequent scientific, engineering, and technological evaluations. Decisions made during concept development strongly influence the product's future environmental footprint, economic feasibility, and functional performance.
4. Modern R&D practices increasingly integrate experimental testing with computational simulations in order to optimise product designs, reduce material waste, and improve functional performance. The combination of these approaches significantly enhances the efficiency of product development by reducing the number of physical prototypes required and shortening the overall innovation cycle.
5. Sustainability and circularity considerations should not be treated as secondary aspects of product development but rather as central design criteria integrated throughout the entire R&D process. In the furniture sector, the use of recycled and bio-based materials, modular design principles, and repairability strategies can significantly reduce environmental impacts while maintaining product quality and consumer acceptance.
6. Finally, the evolution of modern R&D demonstrates the increasing importance of interdisciplinary collaboration and continuous innovation in achieving sustainable industrial development. Future R&D activities should continue to focus on integrating creativity, scientific validation, and sustainability-oriented methodologies to support the transition toward a more circular and resource-efficient economy.

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7. Key Enabling Technologies for Circular Transition in the Furniture Sector

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ABSTRACT

The digital and green transformation is reshaping the furniture and wood sector, creating opportunities to improve production efficiency, reduce environmental impacts, and accelerate the transition toward circular economy models. This chapter examines the role of key enabling technologies (KETs), focusing on digitalisation and advanced manufacturing solutions for resource optimisation, waste reduction, and extended product lifecycles. Particular attention is given to Digital Product Passports, enterprise resource planning systems, and digital twins for lifecycle monitoring, which improve data availability, traceability, and supply chain transparency. The chapter also explores the integration of connected and data-driven technologies throughout the product lifecycle, from design and manufacturing to use and end-of-life management. These solutions improve quality control and product customisation while supporting repair, refurbishment, remanufacturing, material recovery, and better coordination across the furniture value chain.

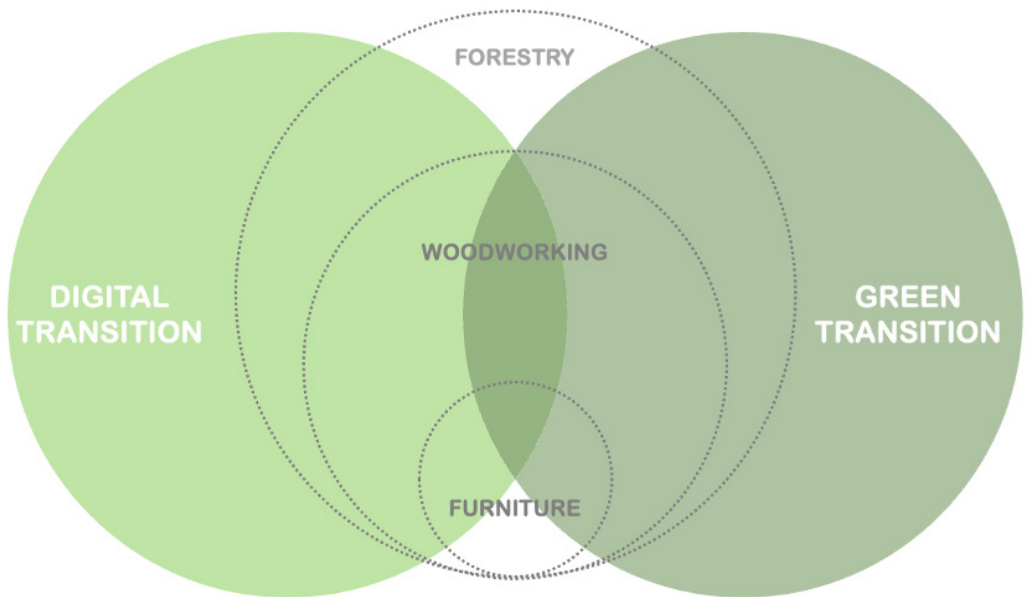
The furniture and wood sector is undergoing a profound transformation driven by the convergence of two major strategic imperatives: the digital transition and the green transition. On one side, the integration of advanced digital technologies is reshaping production systems, supply chains, and business models. On the other, growing environmental pressures, resource scarcity, and increasingly demanding regulatory frameworks are pushing the industry to adopt more sustainable and resource-efficient approaches. As analysed in Chapter 2, the European Green Deal and the new European Industrial Strategy have reinforced this direction by positioning sustainability, climate neutrality, and digitalisation as central pillars of future industrial competitiveness (European Commission, 2019, 2020).

These two transitions are deeply interconnected. Digital technologies provide the infrastructure, data, connectivity, and intelligence needed to implement circular economy (CE) strategies at scale, while sustainability goals give direction and purpose to technological investments. In this context, the concept of the *twin transition* has emerged to describe the simultaneous advancement of digitalisation and sustainability within industrial systems. Recent research highlights that Industry 4.0 technologies are increasingly recognised not only as drivers of productivity and competitiveness, but also as essential enablers of circularity and environmental sustainability (Rosa *et al.*, 2019; Jamwal *et al.*, 2021; Ortega-Gras *et al.*, 2021a).

The CE represents a systemic shift from the traditional linear *take-make-dispose* model toward one in which products, components, and materials are maintained in use for as long as possible through reuse, repair, refurbishment, remanufacturing, and recycling (Ellen MacArthur Foundation, 2015). In the furniture sector, this transition implies significant changes across the entire value chain, from product design and material selection to manufacturing, logistics, use phase, and end-of-life management. Furniture products must increasingly be designed for durability, modularity, disassembly, repairability, and recyclability, while manufacturers are expected to reduce waste generation, energy consumption, and environmental impacts throughout production processes. At the same time, new circular business models, such as product-service systems, leasing, take-back schemes, refurbishment services, and secondary material markets, are gaining

The implementation of these circular strategies is strongly supported by a set of KETs associated with Industry 4.0. These include the Internet of Things (IoT), Artificial Intelligence (AI), robotics, additive manufacturing, big data analytics, blockchain, cloud computing, simulation, and extended reality technologies. KETs are recognised as foundational technologies capable of accelerating industrial innovation and supporting both economic growth and sustainability objectives. Research has shown that these technologies can improve resource efficiency, optimise manufacturing operations, enable real-time monitoring, facilitate predictive maintenance, support traceability, and enhance lifecycle management (Martinelli *et al.*, 2021; Mabkhot *et al.*, 2021). Through real-time monitoring and data-driven decision-making, these technologies can significantly improve resource efficiency and environmental performance. For example, IoT systems facilitate product traceability and predictive maintenance, AI can optimise energy consumption and production planning, while additive manufacturing may reduce material waste through more precise production processes (Ortega-Gras *et al.*, 2025).

The convergence
of digital and green
transitions in the
furniture sector.
Source: Koch *et al.*
(2022).



Several studies have also highlighted the growing relationship between Industry 4.0 and CE implementation. Rosa *et al.* (2019) identified strong complementarities between digital technologies and circular strategies, particularly in areas such as product lifecycle extension, reverse logistics, and resource recovery. Similarly, Laskurain-Iturbe *et al.* (2021) demonstrated that Industry 4.0 technologies positively influence CE implementation by improving transparency, efficiency, and information exchange across industrial ecosystems. More recent research has reinforced the importance of integrated approaches to the twin transition, especially within manufacturing sectors characterised by high material consumption and increasing sustainability pressures (Siedschlag *et al.*, 2024; Tabares *et al.*, 2025).

Despite these opportunities, the furniture and wood sector still faces important challenges in adopting KETs to support circularity. Many companies in the sector are SMEs with limited financial resources, low digital maturity, and insufficient technical capabilities. Previous studies have identified barriers such as high implementation costs, lack of specialised skills, organisational resistance to change, technological complexity, and uncertainty regarding economic returns (Moeuf *et al.*, 2017; Orzes *et al.*, 2018; Ortega-Gras *et al.*, 2025). Nevertheless, recent studies suggest that the sector presents significant innovation potential linked to sustainability-oriented strategies, product customisation, ecodesign approaches, and the development of circular business models enabled by digital transformation (Tabares *et al.*, 2025).

Understanding how KETs can support CE strategies in the furniture sector is therefore essential to accelerate the twin transition and improve industrial sustainability and competitiveness. Exploring the interaction between digitalisation and circularity can help identify practical pathways for companies to develop more resilient, efficient, and environmentally responsible production systems.

7.1 Introduction to Key Enabling Technologies in the Furniture Sector

The term *key enabling technologies* (KETs) refers to a set of advanced digital and physical technologies with broad cross-sectoral applicability and significant potential to drive innovation, improve competitiveness, and address societal challenges (European Commission, 2023a; European Parliament, 2021). In the context of the furniture and wood sector, KETs are particularly relevant because of the sector's structural characteristics: it is fragmented, with many small and medium-sized enterprises (SMEs) operating along complex value chains; it is material-intensive, relying on wood, metals, textiles, foams, and plastics; and it faces increasing pressure to reduce its environmental footprint while meeting evolving consumer and regulatory demands (Ortega-Gras *et al.*, 2021a; Tabares *et al.*, 2025).

The adoption of KETs in the furniture sector is not a single event but a process of progressive integration. It begins with digitisation, that is, converting analogue information into digital formats, such as product drawings or inventory records. It evolves into digitalisation, meaning the use of digital technologies to improve business processes, for instance through computer-aided design (CAD) or digital manufacturing. And it culminates in digital maturity, understood as the full embedding of digital capabilities across the organisation, enabling data-driven decision-making, real-time operational control, and agile response to market and environmental changes (Verhoef *et al.*, 2021; Vial, 2019).

This progression is closely aligned with the principles of Industry 4.0, which envisions manufacturing systems characterised by interconnectivity, information transparency, technical assistance, and decentralised decision-making (Kagermann *et al.*, 2013; Hermann *et al.*, 2016). In the furniture sector, Industry 4.0 translates into smart factories where machines, sensors, and systems communicate in real time; where AI algorithms optimise production flows and anticipate maintenance needs; and where digital twins provide virtual replicas of products and processes for testing and continuous improvement (Javaid *et al.*, 2022; Ortega-Gras *et al.*, 2021a).

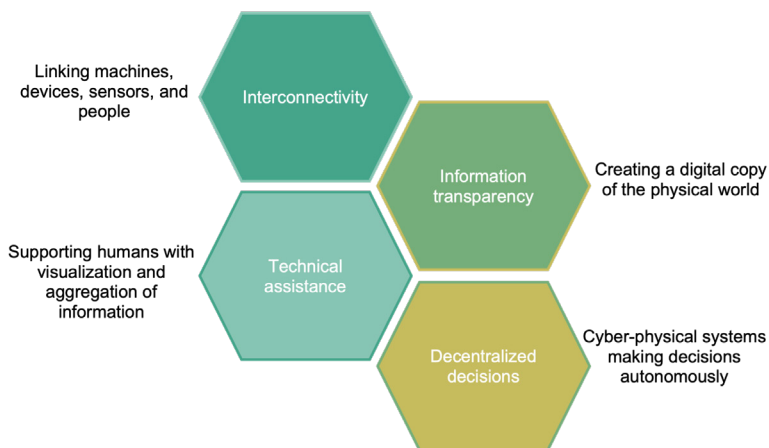


Figure 2.
Key principles of Industry 4.0 applied to the furniture sector.
Source: CirCLER Consortium (2025a).

Crucially, the adoption of KETs is not only about operational efficiency. It is also about enabling new circular business models, such as product-as-a-service (PaaS) or furniture-as-a-service (FaaS), in which manufacturers retain ownership of products and offer usage rights to customers. These models create incentives for durability, reparability, and end-of-life recovery, because the manufacturer benefits from keeping products in use for as long as possible (Tukker, 2015; Bocken *et al.*, 2016). Digital technologies, particularly IoT sensors, cloud platforms, and data analytics, are what make these models operationally viable: they allow remote monitoring, predictive maintenance, and lifecycle tracking that would otherwise be impossible to sustain at scale (Kristoffersen *et al.*, 2020; Moreno *et al.*, 2016).

7.2 Core Enabling Technologies and Their Circular Applications

The furniture sector now has a growing set of digital and advanced manufacturing technologies that are making the shift toward CE models genuinely possible. These are not abstract trends: in practice, they allow companies to manufacture more intelligently, get more out of their materials, extend product lifespans, and recover them once they reach the end of their useful life. Figure 3 offers an overview of the seven core enabling technologies covered in this section, along with the role each one plays in driving circularity across the furniture

industry. These technologies should not be understood as isolated solutions, but rather as interconnected elements within a broader digital ecosystem that enables more sustainable, resilient, and circular industrial models.

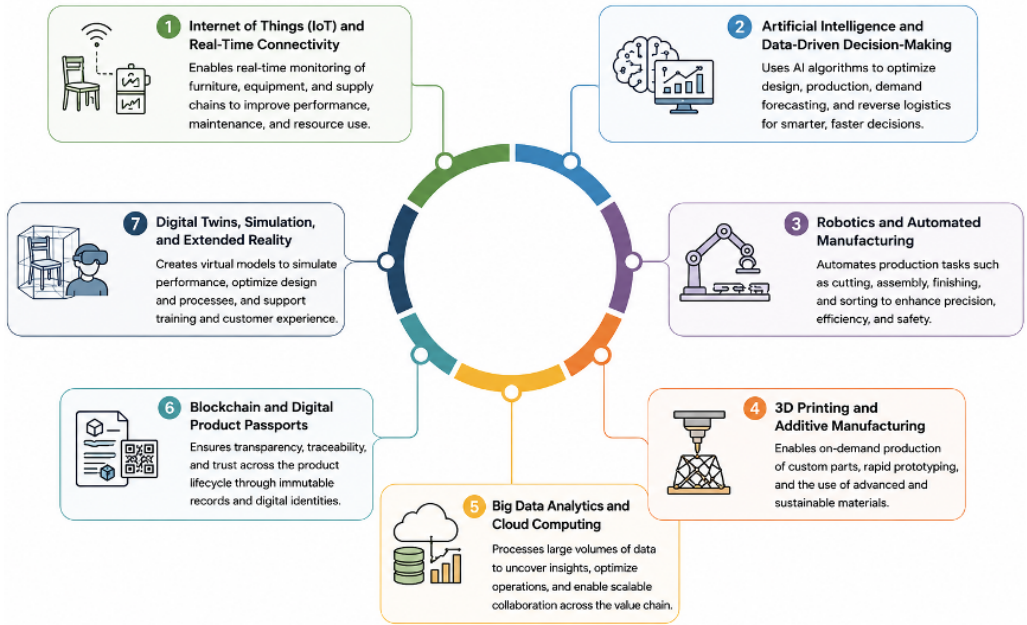


Figure 3.
Overview of the
seven core enabling
technologies supporting
CE strategies in the
furniture sector.
Source: author's own
elaboration using
ChatGPT (OpenAI).

7.2.1 Internet of Things and Real-Time Connectivity

The IoT connects physical objects (machines, products, sensors, and tools) to digital networks, enabling them to collect, exchange, and process data in real time (Atzori *et al.*, 2010; Madakam *et al.*, 2015). In the furniture sector, IoT provides the connectivity infrastructure required for smart manufacturing, responsive supply chains, and extended product lifecycles aligned with CE principles (Rosa *et al.*, 2019).

Within production environments, IoT-integrated machinery collects operational data continuously, allowing manufacturers to detect inefficiencies, adjust production parameters, and prevent unexpected downtime through predictive maintenance strategies (Lee *et al.*, 2015). Smart inventory systems supported by IoT sensors improve demand forecasting accuracy and reduce overproduction and excess stock, contributing to resource efficiency and waste reduction (Ben-Daya *et al.*, 2019). Connected production lines can automatically

adapt workflows based on real-time demand conditions, ensuring that resources are only consumed when necessary, which is an important contribution to waste reduction.

Beyond manufacturing, IoT enables the development of connected furniture products equipped with embedded sensors that monitor usage patterns, environmental conditions, and structural integrity. This data supports predictive maintenance and lifecycle extension strategies by enabling early interventions before product failure occurs (Porter & Heppelmann, 2014). RFID tags and digital tracking systems further support end-of-life management by recording material composition, handling instructions, and recovery pathways, improving sorting, refurbishment, and recycling operations (Kristoffersen *et al.*, 2020).

IoT also underpins circular business models such as furniture-as-a-service. When product usage and condition are tracked remotely, manufacturers can manage leased or shared furniture more effectively, scheduling maintenance and refurbishment at optimal times and recovering products for reuse when usage contracts end (Tukker, 2015). Integration with blockchain systems can further enhance supply chain transparency, verifying responsible and ethical production practices across the value chain (Sabeti *et al.*, 2019).

7.2.2 Artificial Intelligence and Data-Driven Decision-Making

AI encompasses a set of computational methods that enable machines to learn from data, identify patterns, and make decisions with varying degrees of autonomy (Russell & Norvig, 2021). In the furniture sector, AI is transforming design, production, supply chain management, and customer engagement.

In product design, AI-powered generative design tools allow engineers and designers to explore a wide range of structural and aesthetic possibilities while optimising for material efficiency, strength, and circularity criteria (Bouschery *et al.*, 2023). These tools can propose configurations that minimise material use, improve disassembly potential, and support end-of-life recyclability, embedding circular principles from the earliest stages of product development. A notable example is the *A.I.* chair developed by designer Philippe Starck in collaboration with Kartell and Autodesk, widely recognised as the first mass-produced chair designed with the assistance of artificial in-

telligence, which achieved significant reductions in material use while maintaining durability and aesthetic quality (Suzuki, 2021).

In manufacturing, AI-powered quality control systems use computer vision and machine learning to detect defects in real time, reducing waste and preventing defective products from progressing through production lines (Javaid *et al.*, 2022). Predictive maintenance algorithms analyse sensor-generated data to anticipate equipment failures, thereby reducing downtime and extending machinery lifespan (Lee *et al.*, 2015). AI also optimises production scheduling, inventory management, and demand forecasting, helping manufacturers align production with actual market needs and avoid overproduction.

AI additionally plays a critical role in CE operations, particularly in material sorting and reverse logistics. AI-powered systems can identify material types with high precision, improving the quality and value of recycled outputs (Rosa *et al.*, 2019). In reverse logistics systems, AI tools assess the condition of returned products and calculate the most cost-effective recovery or recycling strategies, supporting decision-making regarding efficient remanufacturing and refurbishment operations.

7.2.3 Robotics and Automated Manufacturing

Robotics encompasses a range of automated systems, from industrial robot arms to collaborative robots (cobots) and autonomous mobile robots (AMRs), capable of performing physical tasks with high levels of precision, speed, and repeatability (Bahrin *et al.*, 2016). In the furniture sector, robotics is increasingly transforming manufacturing operations and end-of-life recovery activities.

In production, robotic systems handle repetitive and physically demanding operations such as cutting, assembly, sanding, finishing, and packaging. These systems reduce human error, improve consistency, and minimise material waste caused by defects (Javaid *et al.*, 2022). Cobots, designed to work safely alongside human operators without protective barriers, are particularly valuable in the furniture sector where small-batch and customised production is common. They enhance flexibility, support ergonomic working conditions, and can be rapidly reprogrammed for different product configurations (Villani *et al.*, 2018).

In end-of-life management, robotics supports disassembly and material recovery processes by identifying and separating components made from different materials, thereby improving recycling efficiency and material purity (Rocca *et al.*, 2020). Autonomous mobile robots manage internal logistics within production facilities, transporting components between workstations and optimising material flows, thereby reducing inefficiencies and idle time.

The integration of AI with robotics further enhances flexibility and adaptability. AI-enabled robots can learn from operational experience, adapt to varying product configurations, and collaborate more effectively with human workers, making them key drivers of flexible, sustainable, and circular manufacturing systems (Nahavandi, 2019).

7.2.4 Additive Manufacturing

Additive manufacturing (AM), also known as 3D printing, is a production technology that builds objects layer by layer from digital models, offering significant advantages for sustainability, customisation, and CE alignment (Gebler *et al.*, 2014; Ford & Despeisse, 2016). Unlike traditional subtractive manufacturing processes, which remove material from a solid block and often generate substantial waste, AM uses only the material needed to fabricate the object, thereby significantly reducing material losses and improving resource efficiency (Huang *et al.*, 2013).

In the furniture sector, AM supports rapid prototyping, allowing designers to test and refine product concepts quickly without the costs and waste associated with traditional prototyping techniques (Ngo *et al.*, 2018). It also enables the production of complex geometries, including internal cavities, organic forms, and intricate joints, that would be difficult or impossible to achieve with conventional techniques, opening new possibilities for lightweight, material-efficient design (Attaran, 2017). Furthermore, AM supports on-demand and localised manufacturing strategies, reducing the need for large inventories and minimising overproduction and transportation-related impacts (Ford & Despeisse, 2016).

For CE applications, AM facilitates the production of spare parts on demand, enabling products to be repaired and extended in use without the need to maintain costly physical inventories (Rosa *et al.*,

2019). This capability is especially relevant in the furniture sector, where products often remain in use for decades and replacement components may otherwise be unavailable. AM additionally enables the incorporation of recycled and bio-based materials into production systems, contributing to closed-loop material cycles and reduced dependency on virgin resources (Gebler *et al.*, 2014).

Practical applications of AM in the furniture sector are increasingly visible. Pianca, an Italian furniture manufacturer, has integrated 3D printing technologies into its internal research and development processes to improve prototyping speed, reduce lead times, and minimise material waste through the use of biodegradable PLA filaments (Raise3D, n.d.). Elli Design, an innovative Italian startup, has further explored large-scale robotic 3D printing to manufacture modular furniture products from recycled and recyclable materials, demonstrating the potential of AM technologies to support flexible and circular production systems (Caracol, 2024).

7.2.5 Big Data Analytics and Cloud Computing

Big data analytics refers to the use of advanced computational methods to process and analyse large and complex datasets in order to generate actionable insights and support decision-making processes (Chen *et al.*, 2012). In the furniture sector, big data analytics enables evidence-based decision-making across the value chain, including material sourcing, production planning, logistics optimisation, customer behaviour analysis, and sustainability performance assessment.

When data generated through IoT devices, smart sensors, enterprise resource planning (ERP) systems, and digital platforms are aggregated and analysed collectively, manufacturers gain enhanced visibility into material flows, energy consumption, production efficiency, and product usage patterns (Wamba *et al.*, 2017). These insights support the identification of inefficiencies, optimisation of resource use, reduction of waste, and implementation of more sustainable and circular business strategies. Real-time data on material types, quantities, and locations enables more accurate inventory management, reduces waste throughout the supply chain, and supports just-in-time manufacturing approaches, reducing unnecessary

stock accumulation and overproduction. Cloud computing provides the scalable digital infrastructure that enables the operational deployment of big data analytics systems (Mell & Grance, 2011). By delivering computing resources, storage capabilities, software services, and analytics tools over the internet, cloud platforms allow companies, particularly SMEs, to access advanced digital capabilities without the need for costly on-premise IT infrastructure (Hashem *et al.*, 2015). Cloud-based environments additionally facilitate collaboration among geographically distributed stakeholders through shared design platforms, real-time information exchange, and coordinated decision-making processes across supply chains.

Together, big data analytics and cloud computing provide the cognitive and infrastructural backbone for circular economy strategies. They enable manufacturers to track products and materials throughout their lifecycles, anticipate maintenance needs, optimise reverse logistics, and generate the sustainability performance metrics needed for regulatory compliance and stakeholder communication.

7.2.6 Blockchain and Digital Product Passports

Blockchain is a decentralised and tamper-resistant digital ledger technology that enables secure, transparent, and traceable recording of transactions and information exchanges across distributed networks (Casino *et al.*, 2019). Within the furniture sector, blockchain is increasingly explored as a mechanism for improving supply chain traceability, verifying sustainability claims, and supporting circular economy practices (Saber *et al.*, 2019).

When blockchain systems are integrated with QR codes, RFID tags, or IoT devices, furniture products can be assigned a unique digital identity that records information about its material origins, production processes, usage history, repair and maintenance interventions, and end-of-life pathways (Kouhizadeh *et al.*, 2021). Such traceability infrastructures support more informed decision-making among manufacturers, retailers, repair providers, recyclers, and consumers throughout the entire product lifecycle.

Digital Product Passports (DPPs) represent one of the most promising applications of these technologies in the context of circular economy implementation. As introduced in Chapter 2, Section 2.5.2,

the DPP is a key instrument of the Ecodesign for Sustainable Products Regulation (ESPR), providing accessible digital information on product composition, environmental footprint, repairability, disassembly instructions, and recycling guidelines. Within the furniture sector specifically, DPPs facilitate maintenance operations, improve end-of-life recovery processes, and enhance supply chain transparency and accountability.

A practical example of DPP implementation is provided by Royal Ahrend, a Dutch office furniture company. Building on that model, Ahrend integrates QR-code-based asset tracking into its circular Furniture-as-a-Service offering. Each Ahrend furniture item is connected to a centralised asset database recording usage history, condition, and location, enabling more effective refurbishment, reuse, and recovery planning while minimising material losses (Ellen MacArthur Foundation, 2021).

Figure 4.
Conceptual
representation of the
FaaS model.
Source: author's own
illustration.



7.2.7 Digital Twins, Simulation, and Extended Reality

Digital twins are virtual representations of physical products, systems, or processes that operate in real time, reflecting the state and behaviour of their real-world counterparts through real-time data exchange (Tao *et al.*, 2019). In the furniture sector, digital twins provide manufacturers with unprecedented visibility into every stage of the product lifecycle, from design and production to use and end-of-life.

During the design phase, digital twins enable virtual prototyping and simulation-based testing, allowing designers to evaluate structural integrity, material efficiency, and product performance before physical production begins (Negri *et al.*, 2017). In the production phase, digital twins enable real-time monitoring of production systems, predictive maintenance, process optimisation, and virtual commissioning of production lines. During use, digital twins monitor product use and maintenance; at end of life, they support disassembly, material recovery, and decisions on refurbishment, remanufacturing, or recycling.

Simulation technologies extend these capabilities further. They allow circular processes to be tested and optimised in virtual environments, removing the need for costly and resource-intensive physical trials (Rocca *et al.*, 2020). Material flow simulations can model the movement of resources across production, use, and end-of-life stages, identifying bottlenecks, reducing overstocking, and optimising recycling streams. Virtual factory simulations allow manufacturers to test energy-efficient configurations, compare the environmental impacts of different materials and processes, and model circular workflows before implementing them in real operations.

Extended Reality (XR), which encompasses Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), provides immersive and interactive tools supporting product design, workforce training, maintenance, customer engagement, and circular service development (Ortega-Gras *et al.*, 2023). AR allows customers to visualise furniture in their own spaces before purchasing, reducing returns and associated waste. VR supports immersive training experiences for maintenance and repair technicians. MR enables collaborative design processes where physical and digital elements coexist, supporting the development of modular, repairable, and recyclable furniture.

A practical example is provided by Crate & Barrel's AR application, which allows customers to visualise furniture products in domestic spaces through mobile interfaces and QR-code-based interaction systems, improving purchasing confidence and reducing unnecessary product returns (Heady, n.d.).

7.3 Digital Tools for Circular Economy Operations

Beyond the foundational KETs described previously, a growing ecosystem of specialised digital tools and platforms is transforming how furniture companies implement CE strategies in their day-to-day operations (Kristoffersen *et al.*, 2020; Rosa *et al.*, 2019). These tools operationalise circularity across product development, resource management, logistics, maintenance, and recovery activities, enabling companies to transition from linear production models toward more regenerative and data-driven systems. Broadly, these technologies can be categorised into tools supporting product lifecycle and design management, and tools focused on operational efficiency and resource optimisation.

7.3.1 Design for Circularity Tools and Cloud-Based Design Platforms

Design for Circularity (DfC) tools empower manufacturers to integrate CE principles directly into product development processes from the earliest stages (Bocken *et al.*, 2016; Moreno *et al.*, 2016). These tools include digital material selection databases that allow designers to compare environmental indicators such as recycled content, embodied carbon, toxicity levels, and recyclability potential across alternative materials (Ashby, 2009). Modular design frameworks additionally support the creation of furniture products with standardised and interchangeable components that simplify maintenance, upgrading, repair, and eventual disassembly (den Hollander *et al.*, 2017).

Many DfC systems also incorporate circularity scoring methodologies capable of evaluating products according to criteria such as disassembly time, material purity, repairability, durability, and end-of-life recovery potential (Mesa *et al.*, 2018). These scoring systems allow

companies to benchmark circular performance and identify opportunities for product improvement before manufacturing begins.

Cloud-based collaborative design platforms further enhance these capabilities by providing real-time, shared design environments accessible across departments, suppliers, and geographically distributed teams (Hashem *et al.*, 2015). Features such as design version control, digital traceability, and collaborative workflows help ensure that circular strategies, including modularity, ease of disassembly, reduced toxic content, and lightweight design, remain embedded throughout product development processes.

The integration of lifecycle assessment (LCA) tools within cloud-based design environments enables designers and engineers to evaluate environmental impacts in real time during product development (Sassanelli *et al.*, 2020). This supports informed decision-making regarding material selection, manufacturing processes, transportation impacts, and energy consumption, thereby reducing the environmental footprint of products from the earliest stages of development.

7.3.2 Material Traceability Platforms and Enterprise Resource Planning

Material traceability platforms utilise digital technologies, such as blockchain, IoT sensors, and RFID tags, to monitor products and materials throughout their lifecycles (Saber *et al.*, 2019; Kouhizadeh *et al.*, 2021). These systems provide detailed visibility into sourcing, processing, and distribution, ensuring that materials remain recoverable and reusable at the end of a product's life. Real-time tracking capabilities additionally facilitate reverse logistics operations by monitoring returned furniture products and components, thereby improving refurbishment, remanufacturing, recycling, and reintegration into production systems (Kristoffersen *et al.*, 2020).

ERP systems equipped with integrated sustainability and circularity modules provide centralised platforms for integrating environmental objectives into daily business operations (Elragal & Haddara, 2012). These systems connect data across procurement, production, inventory, and logistics, enabling informed decision-making for circularity.

Integrated dashboards and reporting tools support the monitoring of sustainability indicators such as carbon emissions, water con-

sumption, waste generation, and recycled material content, facilitating regulatory compliance and corporate sustainability reporting.

ERP systems additionally improve coordination among suppliers, logistics providers, refurbishment centers, and recycling operators, supporting the implementation of take-back schemes, closed-loop supply chains, and remanufacturing operations (Rosa *et al.*, 2019).

7.3.3 AI-Powered Inventory Management and Digital Marketplaces

AI-powered inventory management systems optimise procurement and production planning by analysing historical sales patterns, seasonal trends, and market signals to forecast demand with greater precision (Wamba *et al.*, 2017). This allows manufacturers to align production with actual needs, avoiding overproduction and the associated waste of resources.

Real-time monitoring of stock levels and sales performance enables continuous inventory optimisation, while AI algorithms can identify slow-moving or obsolete products suitable for resale, refurbishment, redesign, donation, or material recovery (Javaid *et al.*, 2022). Such capabilities contribute to extending product lifespans and reducing waste generation across furniture value chains.

Digital marketplaces represent another important category of circular digital tools (Antikainen *et al.*, 2018). Peer-to-peer second-hand sales platforms extend product lifecycles through the direct exchange of used furniture between individuals. Business-to-business redistribution platforms connect companies holding surplus furniture inventory with companies or institutions requiring affordable reused products, improving resource utilisation and reducing waste.

FaaS platforms further support CE models by offering leasing and rental systems that incentivise manufacturers to design products that are modular, durable, repairable, and recoverable (Tukker, 2015). These digital service platforms enable product tracking, maintenance scheduling, refurbishment management, and reverse logistics coordination, making circular business models operationally viable at scale.

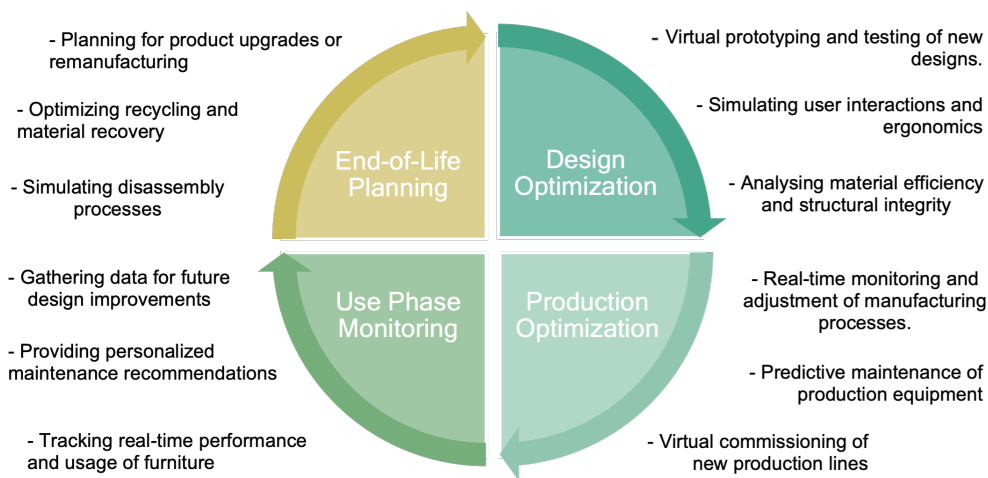
Platforms such as IKEA Preowned and Reyooz (Reyooz, n.d.) illustrate the growing trend toward digitally enabled circular commerce within the furniture sector, supporting second-hand exchange, product recovery, and service-based consumption models.

7.4 Enabling Technologies across the Product Lifecycle

The contribution of KETs to CE goals in the furniture sector can be more effectively understood when their applications are examined across the different phases of the product lifecycle: design, production, distribution, use, and end-of-life (Rosa *et al.*, 2019; Kristoffersen *et al.*, 2020). Rather than acting as isolated technological solutions, KETs form interconnected digital ecosystems that support resource efficiency, product longevity, waste reduction, and material recovery throughout the entire lifecycle of furniture products.

In the design phase, some of the most impactful technologies include AI-powered generative design systems, digital material libraries, simulation and virtual prototyping tools, and additive manufacturing for rapid prototyping (Bocken *et al.*, 2016; Attaran, 2017). These technologies allow designers to integrate circular principles, such as durability, repairability, modularity, disassemblability, and recyclability, from the earliest stages of product development, thereby reducing the environmental impacts associated with downstream lifecycle phases (den Hollander *et al.*, 2017). Digital simulation environments and virtual prototyping tools further reduce the need for physical testing iterations, minimising material waste and accelerating sustainable product development processes (Negri *et al.*, 2017).

Figure 5.
Application of key enabling technologies across the furniture product lifecycle.
Source: CirCLER Consortium (2025b).



During the production phase, IoT-enabled smart manufacturing systems, advanced robotics, CNC machining technologies, and AI-powered quality control systems optimise resource consumption, minimise waste generation, and improve production consistency and efficiency (Javaid *et al.*, 2022; Lee *et al.*, 2015). Real-time monitoring of production lines enables immediate corrective actions when inefficiencies or defects are detected, while predictive maintenance systems extend equipment lifespan and reduce unplanned downtime (Porter & Heppelmann, 2014). Robotics and automation additionally contribute to precision manufacturing and reduced material losses, particularly in customised and small-batch furniture production environments (Villani *et al.*, 2018).

In the distribution phase, AI-driven logistics optimisation systems, smart packaging solutions, blockchain-enabled supply chain traceability, and automated warehouse technologies contribute to reducing the environmental footprint associated with transportation, packaging, and inventory management (Saber *et al.*, 2019; Wamba *et al.*, 2017). Advanced logistics algorithms optimise routing, load management, and warehouse operations, improving service reliability while reducing fuel consumption and greenhouse gas emissions. Companies such as IKEA have implemented digital logistics optimisation systems to improve supply chain efficiency and reduce carbon emissions associated with global distribution operations (IKEA, 2022).

In the use phase, connected IoT-enabled furniture products, AR and VR customer engagement tools, digital service platforms, and smart energy management systems contribute to extending product lifespans and facilitating service-based business models (Kristoffersen *et al.*, 2020). Connected furniture systems support predictive maintenance and usage monitoring, enabling proactive interventions that delay product failure and replacement. AR and VR technologies additionally enhance customer experience by enabling virtual product visualisation and supporting maintenance and repair training activities (Peddie, 2017). Digital platforms supporting rental, sharing, repair, and second-hand redistribution services also reduce demand for new production by extending the circulation of existing furniture products (Tukker, 2015).

Finally, in the end-of-life phase, technologies such as DPPs, digital twins for disassembly simulation, robotic disassembly systems, AI-powered material sorting technologies, and digital recovery platforms maximise resource recovery and support the transition from linear disposal models toward circular recovery systems (European Commission, 2024; Rocca *et al.*, 2020). These technologies improve the identification, separation, and reintegration of materials and components into new production cycles while reducing landfill disposal and resource losses. AI-assisted sorting systems and robotic disassembly technologies are particularly relevant for improving the quality and efficiency of material recovery operations in increasingly complex furniture products (Rosa *et al.*, 2019).

Table 1.
Key enabling technologies and their primary contributions across the furniture product lifecycle.

Technology	Design	Production	Distribution	Use	End-of-Life
IoT	Product monitoring.	Smart production lines.	Supply chain tracking.	Usage monitoring, predictive maintenance.	Material recovery.
AI	Generative design, material selection.	Quality control, predictive maintenance.	Demand forecasting, logistics.	Customer engagement, behaviour analysis.	Sorting, recycling optimisation.
Robotics	Prototyping support.	Assembly, finishing.	Warehouse automation.	—	Disassembly, sorting.
3D Printing	Rapid prototyping.	Complex components, custom parts.	—	Spare parts on demand.	Remanufacturing.
Big Data & Cloud	LCA integration, material databases.	Process optimisation.	Route optimisation.	Usage analytics.	Lifecycle tracking.
Blockchain & DPPs	Material documentation.	Process certification.	Origin verification.	Product information.	Disassembly instructions, recycling guidelines.
Digital Twin	Virtual prototyping.	Process simulation.	—	Condition monitoring.	Disassembly simulation.
Extended Reality	Collaborative design, VR prototyping.	Training, quality inspection.	Virtual showrooms.	AR customer engagement.	Repair guidance, technician training.

7.5 Challenges and Opportunities in Technology Adoption

The adoption of KETs within the furniture sector creates important opportunities for CE implementation, operational efficiency, and competitive differentiation. However, it also introduces technological, organisational, financial, and cultural challenges that companies must address carefully to ensure successful digital transformation processes (Moeuf *et al.*, 2017; Orzes *et al.*, 2018). Understanding both the barriers and opportunities associated with KET adoption is essential for designing realistic and effective twin transition strategies.

7.5.1 Key Challenges

High initial investment remains one of the most significant barriers to technology adoption within the furniture industry. The implementation of advanced digital infrastructures requires considerable investments in hardware, software, integration services, cybersecurity, and workforce training (Moeuf *et al.*, 2017). This challenge is particularly relevant for SMEs, which represent the majority of furniture manufacturers and often face limited financial resources and uncertainty regarding long-term returns on investment (Orzes *et al.*, 2018).

Skills gaps and workforce readiness constitute another major challenge. The successful deployment of advanced digital technologies depends on the availability of technically skilled personnel capable of operating and maintaining complex digital systems (European Commission, 2023b). Many furniture companies experience shortages of expertise in areas such as data analytics, AI systems, robotics programming, digital manufacturing, and systems integration. Addressing these gaps requires investment in reskilling and upskilling initiatives, as well as stronger collaboration between industry and educational institutions to develop new digital competencies aligned with Industry 4.0 requirements (Ortega-Gras *et al.*, 2021b).

Integration with legacy systems additionally represents a significant obstacle for many furniture manufacturers. Existing machinery, enterprise software, and organisational processes are often incompatible with modern digital technologies, requiring substantial redesign of workflows, software infrastructures, and operational practices

(Kagermann *et al.*, 2013). Data interoperability and management issues emerge when different systems and stakeholders cannot effectively exchange information, limiting the potential value generated by digital investments and reducing operational transparency across supply chains (Rosa *et al.*, 2019).

Organisational culture and resistance to change can further hinder technological adoption processes. Employees and managers accustomed to traditional production systems may perceive digital transformation as disruptive, risky, or unnecessary, particularly when expected benefits are not clearly communicated (Vial, 2019). Successful implementation therefore requires strong leadership commitment, participatory approaches, effective communication strategies, and continuous organisational learning processes to support cultural adaptation and workforce engagement.

7.5.2 Key Opportunities

Despite these challenges, the opportunities associated with KETs adoption are substantial and continue to grow. One of the most immediate benefits is increased resource efficiency. IoT systems and AI-powered analytics enable companies to monitor and optimise material and energy consumption in real time, reducing operational costs, environmental impacts, and regulatory risks (Javaid *et al.*, 2022).

KETs also enable the development of new circular business models. Technologies such as IoT, cloud platforms, AI, and DPPs make PaaS and FaaS models operationally viable by supporting product tracking, predictive maintenance, reverse logistics, and lifecycle management (Tukker, 2015; Kristoffersen *et al.*, 2020). These models shift business strategies from one-time product sales toward long-term service relationships, aligning economic incentives with product durability, repairability, reuse, and recycling.

Improved product quality and mass customisation represent additional opportunities. AM, CNC machining, and AI-assisted design tools enable the creation of customised, durable furniture products tailored to user needs while minimising material waste and production errors (Attaran, 2017). Higher product personalisation can additionally strengthen emotional attachment between users and products, reducing premature disposal and supporting longer product lifespans.

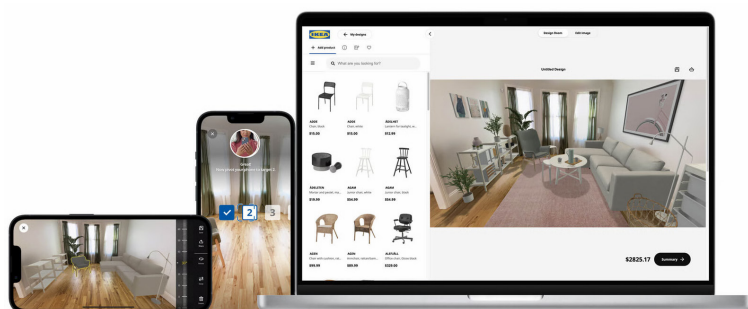
Enhanced transparency and traceability constitute another important opportunity. Blockchain technologies, IoT systems, and DPPs create robust information infrastructures that improve supply chain visibility, support regulatory compliance, and facilitate circular activities such as repair, refurbishment, remanufacturing, and recycling (Saber *et al.*, 2019). Increasing consumer awareness regarding sustainability and environmental responsibility also creates market advantages for companies capable of demonstrating transparent and circular business practices.

Early adopters of circular digital technologies may additionally strengthen their competitive positioning within increasingly sustainability-oriented markets. As environmental regulations become more demanding and stakeholder expectations evolve, companies with embedded digital circular capabilities will likely be better positioned to differentiate themselves, attract environmentally conscious consumers and investors, and respond proactively to future policy requirements.

7.6 Case Studies of Successful Technology Implementation

7.6.1 IKEA: AI-Driven Design and Circular Consumer Experience

Figure 6.
IKEA Kreativ: AI-powered
room design and virtual
furniture placement.
Source: IKEA (2022,
July 5).



IKEA, the world's largest furniture retailer, provides a compelling example of how KETs can be deployed at scale to support both digital innovation and circular economy goals. Through its IKEA Kreativ platform, developed in collaboration with Geomagical Labs, the company has integrated AI and spatial computing to allow customers to create

realistic digital replicas of their homes, remove existing furniture virtually, and test product alternatives with high precision. This approach reduces the number of product returns, limiting the associated waste and carbon emissions of reverse logistics. Beyond design, IKEA integrates AI and machine learning across its supply chain to optimise inventory, anticipate demand, and manage reverse logistics, supporting initiatives such as product recycling, refurbishment, and buy-back programs (IKEA, 2022). The company has also deployed advanced logistics software to optimise its global supply chain, reducing carbon emissions and improving service reliability.

7.6.2 Royal Ahrend: Furniture-as-a-Service and Digital Lifecycle Management

Royal Ahrend, a Dutch office furniture company, has developed one of the most comprehensive examples of CE implementation in the furniture sector, combining smart technology, modular design, and service-based delivery. Every Ahrend product is marked with a QR code linked to a centralised asset database that records condition, usage history, and location, supporting planning for refurbishment, reuse, and recovery. Through its FaaS model, Ahrend offers desks, chairs, and tables on a subscription basis: customers use the furniture for as long as needed, then return it when their needs change. Returned items are inspected and either reused, upgraded with new components, or reassembled into new configurations. This model gives Ahrend full control over material flows and enables significant reductions in waste and emissions (Ellen MacArthur Foundation, 2021). Collaborative partnerships, including the recovery of KLM Airlines upholstery materials and the creation of modular desktops from cellulosic waste with DSM and ECOR, further reinforce the company's circular credentials.

7.6.3 Herman Miller: IoT-Enabled Smart Workplace Furniture

Herman Miller illustrates how IoT can transform furniture into an active component of workplace intelligence. The company's Live OS platform uses embedded sensors and cloud-based software to allow users to personalise their sit-to-stand desks, track wellness goals, and adapt furniture to their preferences. For organisations, the platform collects

anonymised data on furniture interactions and occupancy, enabling more informed decisions about space planning, layout redesign, and real estate investments. The impact extends to circularity: furniture equipped with Live OS generates data that supports better maintenance planning, timely refurbishments, and resource-efficient lifecycle management, reducing the need for unnecessary replacements and extending the productive life of products (Himmelstein, n.d.).

7.7 Conclusion

KETs are not simply productivity tools: they are catalysts for the structural transformation of the furniture sector toward more sustainable, circular, and competitive models. When digital intelligence is embedded across every phase of the product lifecycle, from design and manufacturing to use and end-of-life, it becomes possible to reduce waste, extend product lifespans, recover materials more efficiently, and develop new service-based business models that align commercial success with environmental responsibility.

The integration of IoT, AI, robotics, AM, big data analytics, blockchain, digital twins, and XR is no longer a future scenario. As demonstrated by companies such as IKEA, Royal Ahrend, Herman Miller, Pianca, and Elli Design, these technologies are already reshaping the furniture industry and generating tangible environmental, operational, and commercial benefits. Their experiences show that technology adoption delivers the greatest value when it is guided by clear CE objectives and supported by appropriate organisational capabilities.

For SMEs, which represent the majority of the furniture sector, the path to technology adoption may require incremental steps, collaborative approaches, and targeted support from public programs and industry associations. Although challenges related to investment, skills, and system integration remain significant, they can be overcome when digital transformation is understood as a long-term strategic investment rather than a short-term operational cost.

Ultimately, the twin digital and green transition is not parallel processes but mutually reinforcing transformations. Digital technologies provide the data, connectivity, and coordination necessary to scale

CE practices, while circularity gives technological innovation strategic direction and societal value. Together, they are shaping a furniture sector that is not only more efficient and innovative, but also more resilient, transparent, and prepared for the environmental and economic challenges ahead.

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8. Vocational Education and Training for the Furniture Sector

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ABSTRACT

This chapter examines vocational education and training (VET) systems as a key policy lever supporting the circular transition of the furniture sector. Building on the CirCLER project, it positions VET providers as strategic actors linking education, industrial transformation, and labour market demand. The analysis highlights the need for hybrid skill profiles combining technical competences in eco-design, sustainable materials, lifecycle assessment, and digital manufacturing with systems thinking, adaptability, and collaborative problem-solving. It calls for flexible curricula, modular pathways, work-based learning, micro-credentials, competence-based frameworks, and new profiles such as the Circular Economy Transition Manager. Drawing on CirCLER pilots and stakeholder engagement, the chapter stresses the need to anticipate skills needs and strengthen cooperation between VET providers, enterprises, and public authorities through integrated regional skills ecosystems.

8.1 Circular Transition and Emerging Skills Needs in the Furniture Sector

The transition towards a circular economy represents a profound transformation of industrial systems rather than a simple environmental adjustment (European Commission, 2020, 2024). In the furniture sector, circularity increasingly influences production processes, business models, supply chains, and organisational strategies. European sustainability policies, increasing pressure on energy and material resources, and evolving market demands are pushing companies to develop more sustainable and resilient production models.

In furniture manufacturing, circularity involves the growing adoption of practices such as eco-design, repairability, recycling, remanufacturing, lifecycle optimisation, and the use of secondary raw materials. As a consequence, companies are required to rethink not only products, but also internal workflows, sourcing strategies, and relationships with suppliers and stakeholders across the value chain (Los & Timmer, 2015; Pace, 2025).

These changes are closely linked to the broader Industry 5.0 perspective, which promotes a more sustainable, resilient, and human-centred model of industrial development (Furn5.0 Project, 2025). Technological innovation is therefore increasingly combined with environmental and social goals, reshaping production systems, work organisation, and industrial competitiveness.

The furniture sector is particularly affected by these dynamics because of its strong connection with local production systems and the widespread presence of small and medium-sized enterprises. In many European regions, furniture manufacturing is deeply rooted in territorial industrial ecosystems shaped by specialised craftsmanship and networks of interconnected firms. For this reason, the circular transition should be understood not only at company level, but also as a wider transformation involving labour markets, governance structures, and training systems (Culpepper, 2003).

At the same time, the circular transition is strongly connected with broader green and digital transformations taking place across European manufacturing industries. Furniture companies are progressively introducing more sustainable practices, including waste reduction,

responsible sourcing, lifecycle assessment, and energy efficiency measures. Production environments are also becoming more technologically integrated, with increasing attention to automation, digital coordination, and process optimisation (Hsu *et al.*, 2023).

These developments are generating important organisational changes. Production systems are becoming more interconnected and flexible, while workers are increasingly expected to adapt to multidisciplinary and continuously evolving environments. As a result, organisational innovation is becoming just as important as technological investment, especially in highly competitive industrial sectors (Asheim, 2002).

Within this context, the transition towards circular and digitally integrated production systems is creating growing demand for hybrid competences that combine technical, environmental, and transversal skills. Knowledge related to eco-design, sustainable materials, recycling practices, and lifecycle thinking is becoming increasingly important across different professional roles.

In parallel, transversal competences such as adaptability, communication, problem-solving, teamwork, and systems thinking are gaining strategic importance. Workers are increasingly required to operate within complex industrial environments characterised by continuous technological and organisational change (Lewis, 2023; Durazzi & Tonelli, 2024).

CirCLER stakeholder consultations and competence mapping highlighted the relevance of these evolving skill profiles across the EU.

The project also contributed to the definition of the Circular Economy Transition Manager (CETM) profile, designed as a professional figure able to connect sustainability objectives, industrial processes, and organisational coordination. The emergence of these hybrid competences has important implications for vocational education and training systems, which are increasingly required to adopt interdisciplinary and competence-oriented approaches.

At the same time, the furniture sector is experiencing labour shortages and recruitment difficulties, particularly in technical and manufacturing occupations. Companies report challenges in finding workers who combine specialised competences with the adaptability required by green and digital transitions (Furn5.0 Project, 2025).

8.2 Reconfiguring VET Systems for the Circular Economy

The growing complexity of industrial transitions is progressively reshaping the role of vocational education and training systems within manufacturing economies. In sectors such as furniture production, characterised by the interaction between sustainability objectives, technological transformation, and organisational change, VET systems are increasingly expected to support workforce adaptation and industrial innovation.

Traditional educational models based on relatively stable occupational profiles are becoming progressively less effective in contexts characterised by continuous technological and environmental transformation. Consequently, VET systems are increasingly required to strengthen their flexibility, responsiveness, and capacity for anticipation.

Within this perspective, the role of VET providers extends beyond the transmission of technical knowledge (Parrilli & Heras, 2016). Training institutions progressively operate as intermediary actors connecting enterprises, public authorities, research organisations, and local stakeholders. Their activities increasingly involve partnership development, curriculum co-design, and support for innovation processes within territorial production systems.

Figure 2.
Europe's VET revolution:
from green skills to
economic resilience.
Source: Cedefop (2025).



The transformation of industrial systems also generates the need for more competence-based and interdisciplinary educational approaches. Competence-based training focuses on learning out-

comes and operational capabilities rather than exclusively on formal knowledge acquisition (Nunes & Lopes, 2015). Within circular economy frameworks, this approach becomes especially relevant because emerging professional profiles increasingly combine technical, environmental, digital, and organisational dimensions.

As a consequence, learning pathways need to become more flexible and modular. Rather than being organised around rigid occupational categories, training provision increasingly requires the integration of transversal competences, practical learning experiences, sustainability-related knowledge, and technological adaptation capacities.

Work-based learning therefore acquires growing strategic importance in supporting industrial transitions. Internships, apprenticeships, practical laboratories, and collaborative projects contribute to strengthening the relationship between education systems and real production environments (Alhusen *et al.*, 2020). In the furniture sector, where manufacturing traditions remain closely connected to applied craftsmanship and production practice, experiential learning continues to represent a crucial dimension of competence development.

Cooperation between VET providers and enterprises also becomes increasingly necessary in order to improve the responsiveness of training systems. Collaborative approaches involving enterprises directly in the definition of training priorities may contribute to reducing labour market mismatches and strengthening workforce adaptability (Asheim, 1996, 2002; Asheim & Gertler, 2006; Asheim & Isaksen, 2002).

The CirCLER project highlighted the importance of these collaborative dynamics through pilot activities and stakeholder engagement processes aimed at connecting training provision with emerging sustainability and innovation needs within the furniture sector.

The growing relevance of lifelong learning further reinforces the need to rethink traditional educational structures. In manufacturing sectors characterised by technological acceleration and ecological transition, workers are progressively required to update their competences throughout their professional trajectories.

Within this context, upskilling and reskilling become central policy priorities. Flexible learning models, blended learning approaches, and modular educational solutions become increasingly important in

facilitating access to continuous training opportunities, particularly for SMEs facing organisational and financial constraints.

Micro-credentials are progressively emerging as relevant policy tools within European education and training systems. Their growing diffusion reflects the need for more flexible and transferable learning opportunities capable of supporting lifelong learning and rapid competence adaptation (Pirkkalainen *et al.*, 2023; Tamoliune *et al.*, 2023). Within the circular transition, micro-credentials may support the development of targeted educational pathways connected to sustainability, digitalisation, and emerging professional profiles. Their modular structure may also contribute to improving permeability between vocational education, higher education, and continuing professional training.

From a governance perspective, the increasing importance of modular and competence-based approaches reflects broader European efforts aimed at strengthening transparency, portability, and comparability of competences across different educational and labour market systems. Frameworks such as EQF and ESCO play an important role in supporting these processes.

Ultimately, the reconfiguration of VET systems within the circular economy transition requires moving beyond static conceptions of vocational education towards more adaptive, collaborative, and ecosystem-oriented approaches capable of integrating sustainability objectives, industrial innovation, and continuous workforce development.

8.3 Training Approaches and Pilot Experiences

The CirCLER project was developed to support the circular transition of the furniture sector through the promotion of innovative training approaches and competence development strategies. The project brought together VET providers, universities, research centres, industrial stakeholders, and intermediary organisations from different European countries. The project aimed to identify emerging skills needs linked to circular economy and Industry 5.0 dynamics while developing

practical educational tools capable of supporting workforce adaptation within the furniture sector.

One of the central activities of the project concerned the mapping of circular competences required by enterprises operating within the furniture industry. Stakeholder consultations and comparative analyses highlighted the growing importance of integrated skill profiles combining sustainability, technological, and organisational dimensions.

The mapping activities also revealed the importance of transversal competences such as adaptability, communication, systems thinking, and collaborative problem-solving. These findings confirmed the need for more interdisciplinary and competence-based training approaches.

A significant outcome of the project was the development of the Circular Economy Transition Manager (CETM) profile, introduced in Section 8.1. For the full CETM profile definition and competence framework, see Chapter 3.

The CirCLER project also experimented with multiple training methodologies aimed at strengthening the relationship between theoretical learning and practical industrial application. Pilot activities included workshops, collaborative laboratories, stakeholder consultations, and practical training sessions involving enterprises and learners.

Particular attention was devoted to participatory approaches capable of involving companies directly in the definition of competence needs and educational priorities. This contributed to improving the relevance and applicability of training activities while strengthening cooperation between VET systems and industrial stakeholders.

The project also contributed to the alignment of competence frameworks with European transparency tools such as ESCO and EQF. This alignment supports comparability, portability, and recognition of competences across different educational and labour market contexts.

The transnational dimension of the project highlighted the importance of cooperation and knowledge exchange between European stakeholders operating within the furniture sector. At the same time, the project demonstrated the importance of adapting training solutions to territorial and industrial specificities. Effective competence development strategies therefore require balancing European coordination with local flexibility and stakeholder involvement.

8.4 Conclusions: Towards Skills Ecosystems for the Circular Furniture Sector

The complexity of industrial transitions increasingly requires ecosystem-based approaches capable of integrating education systems, enterprises, public institutions, and intermediary actors within coordinated territorial frameworks (Durazzi & Tonelli, 2024).

Within the furniture sector, skills development is strongly influenced by local production systems, manufacturing traditions, and industrial specialisations. Consequently, effective training policies depend on the quality of cooperation between stakeholders operating at territorial level (Nunes & Lopes, 2015).

The circular transition also requires stronger coordination between European, national, regional, and local governance systems. Policies related to education, labour markets, industrial innovation, and sustainability increasingly overlap within manufacturing transitions. For this reason, institutional coordination becomes essential in supporting coherent and long-term competence development strategies.

Within these ecosystem-based approaches, VET providers increasingly operate as intermediary actors connecting enterprises, learners, public institutions, and innovation systems. Their role extends beyond educational delivery towards functions linked to coordination, skills anticipation, and partnership development.

Regional partnerships therefore play a crucial role in supporting industrial transitions because they facilitate cooperation between training systems and local production ecosystems. In territorially embedded sectors such as furniture manufacturing, the effectiveness of skills policies depends heavily on the capacity to mobilise local stakeholders around shared development strategies.

The findings emerging from the CirCLER project highlight the need for more integrated and anticipatory VET policies capable of responding to industrial transformation processes. From a European perspective, greater emphasis should be placed on flexibility, lifelong learning, competence transparency, and cooperation between education and industrial stakeholders.

At regional level, policies should strengthen ecosystem-based approaches and support collaboration between enterprises, VET providers, and public authorities. In this perspective, skills ecosystems may represent an effective governance model capable of connecting sustainability, industrial innovation, and social inclusion within long-term development strategies.

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9. Training Methodologies for Circular Economy Education

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ABSTRACT

The transition towards a circular economy requires new skills and innovative training approaches to rethink production systems, materials management, and business models. Within the CirCLER project, a flexible, interactive, and practice-oriented training methodology was developed for the furniture sector. It is based on modular *learning pills* combining clear learning outcomes, theoretical content, multimedia resources, and practical assignments. Each pill integrates videos, podcasts, readings, quizzes, and self-reflection questions to support different learning styles and self-paced learning, complemented by formative and summative assessments. Experiential and work-based learning is central to the approach, using case studies, industry good practices, digital tools, collaborative activities, and project-based assignments. Overall, the methodology provides a flexible and scalable framework combining modular digital learning, interactive pedagogy, and industry-oriented practice to develop competencies for the circular transition.

9.1 Introduction

The transition towards a circular economy requires not only technological innovation and regulatory adaptation, but also a profound transformation in the way professionals, organisations, and citizens acquire and apply knowledge. The increasing complexity of sustainability (Bianchi *et al.*, 2022) challenges demands educational approaches capable of fostering systemic thinking, interdisciplinary collaboration, critical analysis, and practical problem-solving skills. Within this context, the CirCLER project proposes an innovative educational framework designed to strengthen competences related to circular economy principles in the furniture and manufacturing sectors.

The CirCLER training methodology was conceived as a flexible, learner-centred, and practice-oriented model capable of responding to the needs of diverse target groups, including students, workers, trainers, managers, and professionals involved in industrial transition processes. The methodology integrates digital learning environments, microlearning strategies, multimedia educational resources, interactive activities, and work-based learning experiences to create a comprehensive educational ecosystem.

This chapter presents the pedagogical foundations, structural organisation, digital tools, and assessment strategies that define the CirCLER educational methodology. It also discusses the relevance of multimodal learning, personalised pathways, and experiential approaches in promoting the acquisition of circular economy competences.

9.2 Pedagogical Foundations of the CirCLER Methodology

The CirCLER educational model is based on a competency-based learning approach aligned with the evolving demands of sustainable industrial transformation. Circular economy education requires learners not only to understand theoretical concepts such as resource efficiency, product life-cycle management, eco-design, waste reduction, and industrial symbiosis, but also to develop the capacity to apply these principles in real-world contexts.

For this reason, the methodology combines theoretical content with practical applications, reflective learning activities, and collaborative exercises. The pedagogical approach incorporates principles of active learning, self-regulated learning, constructivism, and experiential education. Learners are encouraged to participate actively in their own educational process through self-assessment, case analysis, simulations, and project-based activities.

The methodology also recognises the diversity of learner profiles. Participants may differ significantly in terms of professional experience, digital competences, sectoral knowledge, and educational background. Consequently, the CirCLER framework promotes adaptable learning paths and multimodal content delivery, allowing participants to engage with materials according to their individual needs and preferences.

A key principle of the methodology is the integration of industry-oriented learning experiences. Circular economy competences are closely connected to operational realities within companies and organisations. Therefore, the educational model prioritises authentic scenarios, real case studies, and work-based Projects (Leal Filho *et al.*, 2022) capable of bridging the gap between theoretical knowledge and professional practice.

9.3 Structure of the Learning Pills

The core element of the CirCLER methodology is the *learning pill*, a modular educational unit designed to provide focused, flexible, and accessible learning experiences. Each pill follows a standardised structure intended to ensure pedagogical coherence, consistency across modules, and high educational quality.

Every learning pill includes a title, a concise description, keywords, learning outcomes, and a micro-credential statement linked to the competences developed during the activity. The educational contents are organised into a structured report that includes an introduction, thematic development, key takeaways, references, and glossary terms.

The methodology establishes the use of multiple educational formats to enhance learner engagement and accessibility. Written

content is complemented by audiovisual resources such as short instructional videos, podcasts, interviews with professionals, and interactive exercises. This multimodal approach supports different learning styles while facilitating flexible and self-paced learning.

The inclusion of self-reflection questions encourages metacognitive processes and promotes deeper understanding of the concepts addressed in each module. In parallel, additional online resources provide opportunities for extended learning and independent exploration.

A significant component of the *learning pill* structure is the integration of practical and contextualised experiences. Each pill incorporates at least one good practice example related to circular economy implementation within companies or organisations. Whenever possible, case studies are also included to illustrate operational challenges, innovation processes, and sector-specific solutions.

The methodology additionally promotes work-based projects connected to the realities of the learners' professional environments. These activities facilitate the direct application of acquired competences and reinforce the transferability of knowledge to real industrial contexts.

9.4 Digital Learning Environments and Multimedia Resources

The CirCLER project adopts digital education as a central component of its methodology. The virtual learning environment is designed around a Moodle-based structure capable of integrating diverse educational resources, assessment tools, and communication channels.

The digital campus is organised into thematic sections and *learning pills*, allowing learners to navigate progressively through the educational content. Introductory videos, self-diagnostic quizzes, multimedia lessons, podcasts, formative assessments, and final evaluation activities are integrated into each module.

One of the main advantages of the digital model is its capacity to support self-paced learning. Participants can access materials according to their schedules and learning rhythms, an essential feature for adult learners and professionals engaged in continuous education.

The Moodle Book resource plays a particularly relevant role within the methodology. This tool allows the organisation of complex content into chapters and subchapters, facilitating structured navigation and reducing cognitive overload. The integration of multimedia elements such as videos, images, interactive activities, and external resources enhances learner engagement and supports multimodal knowledge acquisition.

Podcasts are also incorporated as flexible educational resources capable of supporting autonomous learning processes. Audio-based content enables learners to access educational materials in diverse contexts and promotes active listening, reflection, and conceptual reinforcement.

The methodology further encourages the use of interactive and immersive technologies. Gamification strategies, virtual simulations, augmented reality resources are considered valuable instruments for increasing participation and experiential learning.

Virtual classrooms and immersive environments can simulate industrial scenarios related to circular economy practices, enabling learners to explore complex processes in safe and collaborative settings. These technologies support experiential learning while fostering creativity, problem-solving capacities, and teamwork.

9.5 Assessment and Learning Analytics

Assessment within the CirCLER methodology is conceived as a continuous and formative process aimed at supporting learning progression and competence acquisition. The evaluation system combines self-assessment, formative assessment, and summative assessment strategies.

Self-diagnostic quizzes are integrated at the beginning of each *learning pill* to help learners identify their initial level of knowledge and establish personalised learning objectives. Formative quizzes are used throughout the modules to reinforce understanding, provide immediate feedback, and promote autonomous regulation of learning.

The methodology recommends the use of varied question formats, including multiple-choice questions, true-or-false activities,

matching exercises, and short-answer tasks. Immediate automated feedback allows learners to identify misconceptions and revisit relevant content areas.

Summative assessment activities are designed to evaluate the achievement of learning outcomes and the acquisition of circular economy competences. The methodology highlights the importance of aligning assessment tasks with educational objectives and real-world applications.

An important feature of the digital learning environment is the implementation of activity completion systems and learning analytics. These tools allow both learners and instructors to monitor progress, identify difficulties, and ensure structured progression through the course.

The methodology also supports mastery-based learning approaches (Calvo & De la Torre, 2021) by linking access to advanced activities with the successful completion of prerequisite tasks. This sequential structure helps ensure that learners develop foundational competences before progressing towards more complex topics.

9.6 Interactivity, Collaboration, and Work-Based Learning

One of the defining characteristics of the CirCLER methodology is the strong emphasis placed on interactivity and collaborative learning. Circular economy challenges are inherently interdisciplinary and require the integration of multiple perspectives, including environmental, technological, economic, and social dimensions.

For this reason, the methodology promotes collaborative educational experiences capable of fostering dialogue, peer learning, and collective problem-solving. Discussion forums, group projects, peer interaction activities, and collaborative virtual environments contribute to the creation of active learning communities (Caeiro *et al.*, 2021).

Special attention is devoted to work-based learning methodologies. Learners are encouraged to apply acquired knowledge within their own organisational or professional contexts through practical projects and industry-oriented assignments.

The project also incorporates hackathons, pilot experiences, and innovation challenges designed to stimulate creativity, entrepreneurship, and applied problem-solving. These activities facilitate direct interaction between education and industry while promoting the practical implementation of circular economy strategies.

Industry simulations and role-playing activities further strengthen the experiential dimension of the methodology. Through realistic scenarios, learners can analyse operational decisions, evaluate sustainability trade-offs, and develop strategic thinking skills (European Training Foundation, 2023) relevant to circular business models.

The methodology additionally recognises the value of mentorship, professional interviews, and interaction with industry experts. These elements contribute to contextualising learning experiences and strengthening the relevance of educational contents.

9.7 Flexibility and Personalisation of Learning Pathways

Flexibility constitutes a fundamental principle of the CirCLER educational framework. The methodology acknowledges that learners possess different educational needs, professional objectives, and levels of prior knowledge.

To address this diversity, the educational model incorporates adaptable learning pathways and personalised progression opportunities. Skills self-assessment tools can support the identification of competence gaps and facilitate the selection of relevant modules according to individual profiles.

The use of modular *learning pills* allows learners to access specific thematic areas without necessarily following rigid sequential structures. This flexibility is particularly relevant in professional education contexts, where participants may seek targeted upskilling or reskilling opportunities. The methodology also supports accessibility and inclusion by promoting mobile-friendly educational resources, multimodal content delivery, and adaptable digital environments. These elements contribute to reducing barriers to participation and facilitating broader access to circular economy education.

Furthermore, the integration of additional online resources, external repositories, and complementary readings enables learners to deepen their understanding according to personal interests and professional needs.

9.8 Innovation and Future Perspectives

The CirCLER methodology reflects the increasing importance of innovation in contemporary education and sustainable industrial transformation. The integration of immersive technologies, interactive platforms, and digital collaboration environments demonstrates the project's commitment to educational innovation.

Emerging technologies such as augmented reality, virtual reality, blockchain, and AI-driven systems may play an increasingly relevant role in circular economy education. These technologies can support the simulation of industrial processes, material traceability analysis, predictive sustainability modelling, and interactive product life-cycle visualisation.

At the same time, the methodology highlights the importance of maintaining pedagogical coherence and learner-centred approaches when incorporating technological innovation. Technology is not an end in itself, but a tool for enhancing accessibility, engagement, personalisation, and competence development (UNESCO, 2021).

9.9 Conclusion

The CirCLER training methodology represents a comprehensive and innovative approach to circular economy education. By combining competency-based learning, digital technologies, multimodal resources, practical experiences, and flexible educational pathways, the methodology responds effectively to the complex demands of sustainable industrial transformation.

Its modular structure, emphasis on interactivity, integration of real-world applications, and commitment to learner-centred education create a robust framework (European Commission, 2023) for devel-

oping circular economy competences across diverse professional and educational contexts.

Beyond knowledge transmission, the methodology seeks to promote critical thinking, collaboration, creativity, and problem-solving capacities essential for supporting the transition towards more sustainable production and consumption systems. In this sense, the CirCLER project contributes not only to vocational education and training, but also to the broader transformation of industrial culture and sustainability-oriented innovation.

The educational strategies developed within the project demonstrate how digital learning environments, experiential methodologies, and collaborative approaches can strengthen the preparedness of professionals and organisations facing the challenges of the circular economy transition. As sustainability becomes an increasingly central dimension of industrial competitiveness and social responsibility, educational initiatives such as CirCLER will play a decisive role in shaping the skills (Cedefop, 2022) and mindsets required for the future.

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10. Distance Learning for the Improvement of Professional Competences

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ABSTRACT

Distance learning is a key mechanism for improving professional competences, promoting lifelong learning, and reducing inequalities in access to education and training across Europe. Digital platforms, virtual learning environments, and open educational resources expand opportunities for people facing barriers to face-to-face learning, including rural populations, employees, people with family responsibilities, unemployed persons, and persons with disabilities. This report analyses online learning as a tool for employability, technological adaptation, and continuous professional development, examining its pedagogical, organisational, and economic advantages alongside challenges related to the digital divide, learner motivation, quality assurance, and technological accessibility. It also reviews European policies and initiatives led by the European Commission, Cedefop, and UNESCO, highlighting the role of online education in building a more inclusive, flexible, and accessible educational system.

10.1 Introduction

Technological development over recent decades has profoundly transformed educational processes and the acquisition of professional competences. The expansion of internet connectivity, the digitisation of educational resources and the emergence of virtual learning environments have enabled distance education to evolve from a complementary methodology into a central component of modern education and vocational training systems (Area Moreira & Adell, 2021).

Within the European context, online learning has acquired strategic relevance due to the necessity of improving economic competitiveness, strengthening social inclusion and responding to labour market transformations associated with automation and digitalisation (European Commission, 2020). The increasing demand for digital and transversal competences has encouraged European institutions and national governments to promote lifelong learning policies and continuous professional development initiatives (UNESCO Institute for Lifelong Learning, 2022).

The COVID-19 pandemic represented a decisive turning point in the consolidation of distance learning models (OECD, 2021). Restrictions on mobility forced educational institutions, companies and public administrations to transfer significant proportions of their training activities to virtual environments. This accelerated digital adoption processes and simultaneously revealed both the strengths and limitations of online education.

At present, distance learning is widely recognised as a fundamental instrument for broadening educational opportunities and reducing inequalities in access to knowledge. Its flexibility enables individuals to combine training with employment and family responsibilities, while the reduction in costs associated with transport and physical attendance facilitates participation among economically disadvantaged groups.

This report examines the importance of distance learning for the improvement of professional competences, paying particular attention to its role in overcoming barriers that traditionally limit access to education and vocational training.

10.2 Conceptualisation of Distance Learning

Distance learning may be defined as a teaching and learning process in which teachers and learners are not necessarily located within the same physical environment and where educational interaction is mediated through communication technologies.

Historically, distance education relied mainly on printed materials and postal correspondence systems. However, the incorporation of digital technologies has generated more dynamic educational models, including e-learning, blended learning and mobile learning.

E-learning is based on the use of digital platforms that allow learners to access educational content, complete activities, participate in tutorials and interact within collaborative environments. Blended learning combines face-to-face sessions with online activities, while mobile learning employs smartphones and portable devices to facilitate permanent access to educational resources.

Online education presents several distinctive characteristics:

- Temporal and geographical flexibility.
- Personalised learning processes.
- Continuous access to educational resources.
- Greater autonomy in learning.
- Collaborative digital interaction.
- Scalability and cost reduction.

These characteristics make distance learning particularly appropriate for professional updating, lifelong learning and vocational reskilling (Cedefop, 2020).

10.3 Professional Competences and Lifelong Learning

Professional competences encompass the knowledge, abilities and attitudes required for effective professional performance. In contemporary labour markets, these competences evolve rapidly as a consequence of technological innovation, globalisation and organisational transformation.

The European Union has repeatedly highlighted the importance of lifelong learning as a mechanism for ensuring employability, economic sustainability and social cohesion. The Council Recommendation on Key Competences for Lifelong Learning emphasises the necessity of developing digital, linguistic, social and entrepreneurial competences (European Union, 2018).

Within this framework, distance learning performs a crucial function by facilitating continuous access to vocational training and professional development programmes. Employees are able to acquire new competences without abandoning their employment, thereby improving adaptability to changing productive environments.

Digital transformation has significantly increased the demand for technological competences associated with data analysis, cybersecurity, artificial intelligence, programming and digital management (Cedefop, 2022). Online educational platforms provide rapid and accessible opportunities for specialised training in these areas.

In addition to technical competences, online learning environments also contribute to the development of transversal abilities such as autonomy, time management, digital communication and collaborative work (González Calatayud *et al.*, 2018).

10.4 Main Barriers to Accessing Training and Education

Access to education and vocational training is not distributed equally across society. Multiple barriers continue to limit participation in professional development processes.

Geographical Barriers

Individuals living in rural or geographically isolated areas frequently encounter limited educational provision. The necessity of travelling to training centres often generates considerable economic and temporal costs. Distance learning substantially reduces these limitations by enabling remote access to educational content and learning activities through digital technologies.

Economic Barriers

Traditional face-to-face education frequently involves expenses related to transport, accommodation, educational materials and, in some cases, loss of income due to absence from employment.

Online learning significantly reduces these costs by allowing participants to access educational resources from their homes or workplaces.

Scheduling Incompatibility

Many employees experience difficulties attending face-to-face training activities because of professional obligations or family responsibilities. The flexibility of online learning enables individuals to organise their educational activities according to personal circumstances. Asynchronous learning resources facilitate compatibility between training, employment and domestic life.

Disability-Related Barriers

People with disabilities may encounter physical and organisational obstacles in traditional educational settings.

Accessible digital platforms, screen readers, automated subtitles and adaptive technologies contribute to improving educational inclusion and accessibility.

The Digital Divide

Although online learning reduces many traditional barriers, it may also generate new inequalities related to internet connectivity, technological infrastructure and digital literacy. The digital divide particularly affects older adults, low-income households and territories with insufficient technological infrastructure (Eurostat, 2023).

10.5 Online Learning as a Tool for Social Inclusion

One of the principal social contributions of distance learning lies in its capacity to democratise access to knowledge (UNESCO, 2021).

Virtual educational platforms significantly expand educational coverage and facilitate access for groups traditionally excluded from

conventional educational systems. This inclusive potential is particularly relevant within European policies aimed at reducing social and territorial inequalities.

Methodological flexibility also supports personalised learning pathways adapted to individual needs and learning rhythms (Area Moreira, 2010). Students may revisit materials, repeat activities and access complementary educational resources whenever necessary.

Furthermore, online education facilitates participation in international programmes and promotes cooperation between institutions located in different countries, thereby encouraging knowledge exchange and strengthening the European educational area.

The expansion of open educational resources has additionally contributed to the democratisation of education by enabling universities and international organisations to provide low-cost or free courses accessible from virtually any location (Pérez Sánchez *et al.*, 2017).

10.6 Advantages of Distance Learning for Professional Development

Flexibility

Flexibility represents one of the most significant advantages of online education (Bates, 2019). Learners are able to organise study schedules according to their professional and personal responsibilities.

Continuous Updating of Competences

Rapid technological transformation requires continuous professional updating. Online learning facilitates immediate access to specialised educational content and updated training programmes.

Personalised Learning

Digital platforms adapt activities and resources to learners' competences, preferences and needs (Redecker, 2017).

Cost Reduction

The elimination of travel and the reuse of digital resources substantially reduce educational costs for both institutions and participants.

Global Access

Online education enables access to international institutions, programmes and specialised training opportunities.

Development of Digital Competences

Participation in virtual learning environments contributes directly to the development of digital skills that are increasingly essential within contemporary labour markets (Instituto Nacional de Tecnologías Educativas y de Formación del Profesorado [INTEF], 2022).

10.7 Challenges and Limitations of Online Learning

Despite its numerous advantages, distance learning also presents several important challenges.

Motivation and Student Retention

The autonomy required in virtual learning environments may generate difficulties related to motivation, continuity and course completion.

Pedagogical Quality

Not all online programmes meet pedagogical standards. Effective on-line education needs interactive content, tutoring and active learner participation (Zawacki-Richter & Anderson, 2014).

Digital Inequalities

Limited access to internet connectivity or insufficient digital competences may restrict participation among certain social groups.

Information Overload

The excessive quantity of digital content and educational resources may complicate learning organisation and concentration.

Assessment and Accreditation

Online assessment systems present challenges associated with academic integrity, competence verification and identity authentication.

The increasing use of educational technologies requires strict guarantees regarding data protection, cybersecurity and ethical management of personal information.

10.8 European Policies Promoting Digital Education

The European Union has developed multiple initiatives aimed at promoting educational digitalisation and lifelong learning.

The Digital Education Action Plan 2021-2027 establishes strategic priorities for improving digital competences and strengthening digital education ecosystems (European Commission, 2020a).

Similarly, the European Skills Agenda promotes initiatives intended to improve employability through continuous competence development and vocational reskilling (European Commission, 2020b).

Cedefop has repeatedly emphasised the necessity of strengthening lifelong vocational education in response to labour market transformations across Europe (Cedefop, 2020).

Furthermore, the Erasmus+ programme includes specific support measures for virtual learning, educational innovation and digital cooperation projects.

These initiatives demonstrate institutional recognition of online learning as a strategic instrument for economic competitiveness, employability and social cohesion.

10.9 Technological Innovation and the Future of Online Education

The future development of distance learning will be strongly influenced by emerging technologies.

Artificial intelligence is expected to facilitate personalised learning pathways and adaptive educational systems capable of responding to individual student progress (Sangrà, 2022).

Virtual reality and augmented reality technologies may provide immersive learning experiences particularly beneficial within technical and vocational education (Sangrà, Guitert, & Behar, 2023). Research has also demonstrated the usefulness of immersive technologies in language learning and social integration contexts, particularly among migrant populations using virtual learning environments (Sánchez *et al.*, 2023).

Learning analytics systems will enable educational institutions to identify learning difficulties and improve pedagogical effectiveness.

In addition, micro-credentials and digital certifications are likely to acquire increasing relevance within competence accreditation systems and labour market recruitment processes.

The consolidation of these innovations will require the implementation of ethical principles related to accessibility, equality of opportunity, transparency and data protection.

10.10 Conclusions

Distance learning has become a fundamental instrument for improving professional competences and promoting lifelong learning. Its capacity to overcome geographical, economic and temporal barriers makes it a particularly valuable mechanism for expanding educational opportunities and reducing inequalities.

The flexibility and accessibility of virtual learning environments facilitate compatibility between education, employment and personal responsibilities, thereby supporting continuous competence development within a rapidly evolving digital economy.

Nevertheless, the consolidation of high-quality online learning systems requires addressing persistent challenges associated with digital inequality, learner motivation, pedagogical quality and technological accessibility.

European institutions increasingly recognise the strategic importance of digital education and continue to promote initiatives aimed at strengthening professional and technological competences.

Consequently, online education should not be regarded merely as an alternative teaching methodology, but rather as an essential

instrument for constructing more inclusive, flexible and socially responsive educational systems adapted to the demands of the twenty-first century.

10.11 Application within the CirCLER Project

The principles discussed throughout this chapter were directly applied in the design of the Circular Economy Transition Manager (CETM) online course developed within the CirCLER project. The furniture sector presented exactly the kind of access barriers described in Section 10.4: a workforce dispersed across more than a dozen European countries, working in small and medium-sized enterprises with limited training budgets, and largely unable to take extended periods away from production activities to attend face-to-face training. A fully asynchronous, self-paced distance learning model was therefore adopted as the most appropriate response to these conditions, structured into modular *learning pills* rather than a conventional course sequence (see Chapter 9 for the pedagogical structure of these units).

This choice reflects several of the advantages discussed in Section 10.6. Temporal and geographical flexibility (Section 10.2) allowed learners from over a dozen countries to access the same curriculum in seven languages without travel costs or scheduling conflicts. Cost reduction made the course free of charge, removing one of the main economic barriers identified in Section 10.4 for SMEs with limited training budgets. Personalised learning pathways allowed each learner, whether a company owner, a designer, or a sustainability manager, to progress through the material according to their professional background and prior knowledge, consistent with the principle of methodological flexibility discussed in Section 10.5.

At the same time, the challenges discussed in Section 10.7 were directly observed during the CETM pilot phase, delivered between December 2025 and March 2026. Learner motivation and course completion in an asynchronous environment proved, as anticipated, to be a central challenge: sustaining engagement across a self-paced course required more than content delivery alone. This was ad-

dressed through the Circular Furniture Mentors' Club, a peer-learning community of trainers who coordinated tutoring and learner support throughout the course (described in detail in Chapter 11), which functioned as a practical response to the motivation and retention risks inherent to fully online, self-paced formats.

The CirCLER experience therefore illustrates, in a real sectoral context, both the inclusive potential of distance learning discussed in Section 10.5 and the practical limitations that any large-scale online training initiative must actively manage. The main results of the pilot implementation, including learner numbers, participant profiles and satisfaction ratings, are presented in Chapter 11.

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11. Mentoring and Training Tools for the Circular Transition: Experience from the CETM Pilot within the CirCLER Project

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ABSTRACT

Despite the availability of circular economy training, trainers often lack practical support to adapt content to real teaching contexts. This chapter introduces the Circular Furniture Mentors' Club, a peer-to-peer environment supporting trainers delivering the Circular Economy Transition Manager in the furniture industry (CETM) online course. It draws on observations from the pilot implementation in English and six other European languages, including course delivery, trainer interactions, and feedback processes. The chapter examines how shared resource repositories, multilingual forums, coordination calls, and peer support help trainers access materials, remain connected, and refine training practices without adding administrative burden. Findings highlight the value of mentoring during early-stage implementation, while identifying challenges in activating learner participation in asynchronous environments and the need for additional trainer engagement. The model provides a scalable and replicable approach for supporting facilitators in self-paced training.

11.1 Introduction

The furniture industry is undergoing a radical shift, moving away from linear *take-make-waste* models toward circularity. Transitioning from theoretical knowledge to industrial practice requires a skilled workforce capable of managing this change.

However, a major bottleneck exists: the lack of a defined professional profile capable of orchestrating this transition, combined with a significant skills gap in green, digital, and transversal competencies (CirCLER Project, 2025c). The Erasmus+ project, *Circular Economy Transition Manager*, co-funded under Grant Agreement 101140033, was launched to bridge this gap by designing a joint European curriculum for the Circular Economy Transition Manager (CETM) at EQF levels 4, 5, and 6.

The resulting course, comprising 10 modules and 50 concise *learning pills*, features key CE fundamentals, circular design, business models, production and strategy. It is freely available online (<https://circlercourse.eu>).

Delivering high-quality training across 8+ European countries presents significant pedagogical challenges, as adult learners often struggle with feelings of isolation due to the asynchronous, text-based nature of digital learning (Farmer, 2010).

To ensure consistent delivery of the CETM course across diverse national contexts, CirCLER established the Circular Furniture Mentors' Club, a collaborative peer-to-peer community supporting all CETM trainers.

This chapter investigates how this lightweight mentoring structure and low-barrier digital tools support trainers in delivering asynchronous, self-paced circular economy training. By drawing on primary data from the pilot implementation of the CETM course, this chapter provides a replicable model for building trainer networks.

11.2 Methodology

The chapter draws primary data from the pilot implementation of the CETM course (Dec 2025 – Mar 2026). It combines qualitative and

quantitative evidence to analyse implementation processes and outcomes through four main data sources:

- Qualitative records from the Circular Furniture Mentors' Club interactions, including transcripts of four monthly coordination meetings (Dec 2025 – Mar 2026) and the shared repository.
- Mentor Survey: Structured pedagogical and usability evaluations completed by 20 active trainers representing VET centers, universities, clusters, and research institutions across 8 European countries. Throughout the pilot, these trainers (referred to as tutors within the learning platform) participated in the Circular Furniture Mentors' Club (CirCLER Project, 2026c).
- Learner Survey: Post-course satisfaction questionnaires completed by 236 learners across 10+ countries (CirCLER Project, 2026c).
- Platform Analytics: Quantitative data tracking enrolment, learning path preferences, and forum activity of the 856 registered learners.

Quantitative survey items utilised a 1-to-5 Likert scale (where 1 represents the lowest rating and 5 the highest).

11.3 Circular Economy Transition Manager in the Furniture Industry Course (CETM) Pilot Scope

The pilot course constitutes the practical validation stage of the CirCLER training programme on Circular Economy Transition Manager. During the pilot phase December 2025 – March 2026 the pilot reached 856 registered learners across 14 countries, including students (88%) and industry professionals (12%). The largest participation numbers were in Spain, Italy, Romania, and Ukraine, reflecting the diverse national contexts in which the CETM curriculum operated.

The CETM course is modular: 10 thematic units totalling 50 *learning pills*, each including multimedia lectures, readings, and quizzes.

Learners progress at their own pace on the CirCLER learning platform. An initial Skills Self-Assessment directs learners to the most relevant modules. All materials are multilingual in 7 languages and co-designed by project partners (NGOs, universities, industry networks) in 8 countries.

The strategic implications of these pilot results, including their relevance for the long-term scalability and transferability of the CETM model beyond the original consortium, are analysed in Chapter 12.

11.4 Concept of the Circular Furniture Mentors' Club

The project consortium developed a simple concept of the Mentors' Club before the launch of the pilot phase.

The main aim of the Mentors' Club is to build and maintain a virtual trainer community that collaborates on the Circular Economy Transition Manager (CETM) course delivery, ensuring its lasting impact on circular economy practices in the furniture sector.

Membership in the Club was voluntary and open to all CETM trainers who were either delivering or preparing to deliver the course. It included two groups: (1) founding tutors nominated by CirCLER partners and automatically enrolled in the pilot phase, and (2) external trainers who joined later through invitation, partner nomination, or direct request.

In total, the Club brought together 21 trainers from 8 countries. They participated in four structured online coordination meetings between December 2025 and March 2026 and maintained ongoing exchange through online forums and shared digital repositories.

Participation was designed to remain flexible and low-burden. Members could follow updates, share materials when relevant, and post short reflections on teaching experience. No mandatory reporting or formal deliverables were required.

This approach was intended to support engagement without adding administrative complexity.

The Club was launched with an introductory event during one of the project meetings. Updates were distributed via CirCLER newsletters and communication channels, allowing future expansion

through partnerships across Europe if the community remains active over time.

Key innovative elements for support included:

1. Peer community structure. A virtual community for trainers, coordinated by one of the project partner organisations, responsible for maintaining the mentor registry, supporting onboarding, and consolidating insights into periodic newsletters.
2. Membership model. Participation was open and voluntary, allowing trainers to join without formal barriers and engage according to their availability.
3. Digital tools. Each national learner group was supported through language-specific discussion forums integrated into the online learning platform and moderated by project trainers. In parallel, trainers used a dedicated English-language forum for cross-country coordination, troubleshooting, and exchange of teaching practices. Complementary teaching materials were stored in a common Google Drive repository accessible to trainers (CirCLER Project, 2026a).
4. Coordination. The Club held four structured calls aligned with the pilot cycle: launch (Dec 2025), mid-pilot (Jan, Feb 2026), and wrap-up (Mar 2026). Each call addressed issues emerging from trainers' feedback (e.g. technical bugs, learner engagement, monitoring pilot progress) while also coordinating dissemination activities across partner countries.

Thus, the pilot combined a circular economy course with an online community for trainers involved in its co-creation and implementation. While implementing the course, trainers simultaneously tested and refined it in practice, sharing feedback and adapting delivery within their own educational contexts.

11.5 Results: Circular Furniture Mentors' Club as Replicable Model

We identified several core components of trainer coordination and peer mentoring, which serve as a framework for replication in similar training contexts (Table 1). The table summarises how coordination

structure, knowledge sharing, networking, and learner engagement mechanisms operated in practice, along with their observed effects and conditions for replication.

Component	Description	Role in training implementation	Tools used	Evidence from CETM Pilot	Conditions for replications
Coordination structure	Structured, minimal moderation; coordinated by a dedicated partner.	Ensures alignment across VET/ HE delivery and provides structured synchronisation points across countries.	Monthly coordination calls; periodic internal update emails.	Four calls held; aligned 21 trainers across 15 partner organisations.	Requires a clearly assigned coordinator and predefined meeting rhythm linked to implementation milestones.
Knowledge repository	Open, unmoderated Drive folder for supplementary materials.	Reduces preparation load; enables adaptation and reuse of teaching resources across contexts.	Shared Google Drive <i>Resource Corner</i> with folders Feedback notes, Newsletters, Resources.	Resources, feedback files, and newsletters shared among partners.	Requires simple folder structure; permission access in trainer emails.
Trainer networking	Informal cross-country communication network based on shared contact information and institutional profiles (Mentor Registry).	Mitigates trainer isolation; enables direct peer exchange and collaboration across countries.	Shared contact registry (Excel-based <i>Mentor Registry</i>).	Enabled direct exchange of case studies between trainers from different countries.	Requires consent-based data sharing and onboarding of all participating trainers.
Learner engagement	Proactive facilitation in language-specific online discussion spaces.	Strengthens learner engagement and shifts participation from passive to interactive.	Language-specific discussion forums (DE, EN, ES, IT, RO, SI, UA) at the learning platform.	Increased participation observed when trainers actively initiated discussion prompts.	Requires training of trainers in using active initiation strategies.

The table shows that the effectiveness of the model does not depend on advanced technological infrastructure. Instead, implementation relied on a limited number of coordination routines embedded into the trainers' everyday workflow.

Table 1.
Summary of Mentors' Club components, functionalities, and conditions for replication.

11.5.1 Course Coordination

The Mentors' Club played a stabilising role during the early phases of implementation and provided immediate support in handling course-related questions. Trainers utilised the Club meetings to coordinate the cleaning of duplicate learner accounts, and resolve

immediate technical bugs, such as platform direct messaging errors and duplicated course videos.

It also served as a practical immediate decision-making space. When learners requested to modify their registered learning paths mid-course, trainers used the coordination calls to collectively agree on switching approach, allowing learners to switch levels seamlessly. The overall platform functionality was rated highly by learners (4.1/5), which aligns with satisfaction results for content quality (4.1/5). The programme was generally perceived as informative, relevant, and easy to follow (CirCLER Project, 2026c).

11.5.2 Knowledge Repository

The Mentors' Club established a shared repository for teaching materials. Over the four-month pilot period, trainers uploaded approximately 15 resources, including teaching materials, feedback notes, and contextual examples. Its role was not content production, but continuity of practice allowing trainers to build on each other's work without additional administrative complexity.

11.5.3 Active Facilitation and Learner Engagement

One of the main challenges identified during the pilot was limited learner participation in asynchronous discussion forums. Learners rated forum usefulness relatively low (3.51/5), and qualitative feedback suggested many simply missed them or didn't even know it was there (CirCLER Project, 2026c).

During the pilot, the Mentors' Club facilitated a shift toward active initiation. As noted in the Trainers' Handbook (CirCLER Project, 2025c), the tutor role moved from content delivery to proactive facilitation. Engagement improved when trainers:

1. Posted short prompts tied to the training materials.
2. Applied simple, targeted *nudge* strategies to re-engage inactive learners.

Countries with higher enrolment, particularly Spain and Italy, showed stronger forum activity when trainers coordinated discussion prompts through the Mentors' Club. Consistent with Farmer (2010), learners in distance-learning environments require social motivation; this low-effort tactic can be recommended for similar pilots.

11.5.4 Informal Knowledge Exchange and Trainer Networking

Beyond structured coordination, the Mentors' Club enabled continuous informal exchange among trainers. Participants shared not only teaching materials but also practical approaches for improving learner motivation, managing low engagement, and adapting content to local conditions. This informal exchange represents one of the durable results of the CirCLER project, providing a basis for continued collaboration beyond the pilot phase.

Overall, the Mentors' Club functioned primarily as an implementation support mechanism, enabling consistent course delivery across multiple countries through simple coordination and low-barrier digital tools.

11.6 Conclusions

This chapter examined how mentoring and collaborative learning mechanisms support asynchronous, self-paced circular economy training in a multi-country context. Based on the CETM pilot within the CirCLER project, it developed and validated a replicable Mentors' Club model for trainer coordination.

The findings show that effective asynchronous training depends not only on digital infrastructure, but also on a structured trainer network supported by simple tools and clear routines of interaction. The Mentors' Club used no specialised platforms, only widely available tools such as shared drives and video conferencing, yet it provided an enabling infrastructure for exchange. At its core is a lightweight peer coordination structure that allows trainers to align delivery, share experience and respond collectively to implementation challenges. At the same time, the pilot confirms that asynchronous learning environments require active facilitation. Without structured trainer intervention, learner participation remains limited. Human coordination therefore remains essential even in highly digital learning environments.

The findings further suggest three conditions for replication of the model across countries and educational contexts with minimal adaptation:

1. Stable trainer network and coordination: one organisation should host the network and set a regular meeting schedule.
2. Low-barrier tools: use tools that trainers already know (shared drives, spreadsheets, basic forums) integrated into their daily workflow.
3. Regular interaction: coordination (e.g. monthly calls) aligned with course milestones to maintain continuity and shared understanding among trainers.

Overall, theMentors' Club illustrates a scalable approach to implementing training programmes across multiple countries: through a combination of minimal coordination mechanisms, a shared resource repository, and an active peer network, the model provides the necessary peer support to sustain quality, consistency, and adaptability in asynchronous delivery.

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12. Lessons Learned from the CirCLER Project

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ABSTRACT

This last chapter synthesises key lessons from the CirCLER project, examining the outcomes of developing and piloting the Circular Economy Transition Manager (CETM) profile and its training ecosystem within the European furniture sector. It reflects on a multidisciplinary consortium of universities, research centres, industrial associations, VET providers, and technological organisations, whose complementary expertise supported innovative educational resources and training methodologies. The CETM role emerged as a key outcome, designed to help companies integrate circular economy principles into organisational processes, product development, manufacturing systems, and strategic decision-making. Building on project implementation data and the European regulatory context, the chapter examines circularity as a strategic resource, alongside challenges related to digital tools and systemic organisational change. It concludes by identifying opportunities, lessons learned, and future research directions for the circular transition of the furniture sector.

12.1 CirCLER Project: Conclusions and Reflections

The CirCLER project demonstrated that the transition towards circularity in the furniture sector cannot be reduced to the simple adoption of sustainable materials or recycling practices. Instead, circular transition requires a profound transformation involving organisational cultures, production models, value chains, and professional competences.

One of the most important lessons emerging from the project concerns the need for systemic approaches to sustainability. As highlighted by Kirchherr *et al.* (2017), the transition from linear to circular models implies a comprehensive reconfiguration of industrial ecosystems and decision-making processes.

Within this perspective, the project highlighted the importance of aligning sustainability education with emerging European approaches related to vocational education and training (VET), micro-credentials, and competence-based learning. In the first steps of the project, based on their own expertise, the consortium assessed several gaps related to circular economy practices, organisational readiness, and professional skills in the furniture sector (CirCLER Consortium, 2026).

These findings informed the development of the CETM curriculum by identifying which expertise gaps the online course needed to fill. The structure of the online course was designed on the basis of this curriculum, to which each partner contributed by drawing on its own experience.

12.1.1 Benefits of the European Consortium

A distinctive feature of the CirCLER project was the composition of its European consortium, which reflected the interdisciplinary nature of circular transition itself. Addressing the circular transition of a manufacturing sector as complex and fragmented as furniture cannot be done from a single disciplinary vantage point. The challenge involves regulatory interpretation, material science, product design, business model innovation, organisational change, pedagogical methodology and digital infrastructure, all at once, and all in interaction with one another. A consortium that brought together only universities, or only

industry associations, or only training providers, would have produced a more internally consistent but ultimately narrower outcome. The value of CirCLER's multi-actor structure lay precisely in the productive friction between these different ways of knowing: the tension between what is theoretically desirable and what is operationally feasible, between what companies say they need and what learners can actually absorb, between what a curriculum prescribes and what a platform can deliver.

The collaborative structure allowed the project to integrate academic research, industrial needs, technological innovation, and pedagogical methodologies within a common framework. Universities contributed scientific expertise related to circular design, business models, sustainability assessment, and manufacturing innovation. Industrial associations and clusters provided direct connections with companies and sectoral needs, while VET providers supported the translation of technical knowledge into accessible and flexible educational resources.

The integration of expertise from informatics and digital platform development sectors additionally made it possible to design an online educational ecosystem capable of combining multilingual training resources, self-assessment tools, learning modules, and interactive educational materials.

The international dimension of the consortium also represented an added value in terms of methodological exchange and dissemination capacity. During the pilot phase, carried out between December 2025 and March 2026, consortium partners promoted the CETM course through universities, companies, online networks, professional associations, and European dissemination channels, including the European Circular Economy Stakeholder Platform, EFIC, and sectoral portals related to furniture and vocational education (CirCLER Consortium, 2026).

This dissemination strategy contributed to the wide participation achieved during the pilot implementation. The online platform reached 856 registered learners distributed across seven language versions of the course: English, German, Italian, Romanian, Slovenian, Spanish, and Ukrainian. Participants originated from at least fourteen different countries, including contexts beyond the consortium itself,

demonstrating the scalability and transferability potential of the educational framework. Further pilot data, including participant profiles, the countries with the highest participation and satisfaction results, are reported in Chapter 11.

Another important contribution of the consortium was the creation of the *Circular Furniture Mentors' Club*, a peer-to-peer collaborative structure supporting tutors during the pilot implementation. Coordinated by FORZA, the initiative involved 21 tutors from partner organisations across Europe and facilitated technical coordination, pedagogical exchange, learner support, and dissemination activities (CirCLER Consortium, 2026).

Rather than representing a formal supervisory structure, the Mentors' Club functioned as a lightweight collaborative environment where tutors could share practical experiences, discuss operational problems, and coordinate learner engagement activities. This experience confirmed the importance of collaborative ecosystems within interdisciplinary sustainability education.

12.1.2 Circularity as a Key Resource for the Furniture Sector

The CirCLER project also contributed to reframing circularity as a strategic resource for the furniture industry rather than merely an environmental obligation. In recent years, circular economy principles have increasingly been recognised as drivers of innovation, resilience, and competitiveness within industrial systems (Stahel, 2016).

In the furniture sector, circularity can generate value through multiple strategies, including eco-design, product longevity, repairability, remanufacturing, material recovery, and product-service systems. Such approaches contribute not only to reducing environmental impact but also to strengthening supply chain resilience and creating new business opportunities.

One of the key reflections emerging from the project is that circularity should be understood as a systemic redesign process affecting the entire life cycle of products and services. This perspective aligns with contemporary circular economy research emphasising life cycle thinking and value retention strategies (Bocken *et al.*, 2016).

The pilot implementation provided direct evidence of this shift in perception. Participants from the furniture sector who engaged with

the CETM course did not approach circularity primarily as a compliance requirement. The feedback consistently showed that learners connected circular economy competences to concrete opportunities: the ability to differentiate products in a saturated market, to strengthen relationships with clients through service and take-back models, to reduce material costs through better end-of-life planning, and to attract talent increasingly motivated by sustainability-oriented work. This is a significant finding, because it suggests that the primary barrier to circular transition in the sector is not a lack of motivation among professionals, but a lack of the structured knowledge and practical frameworks needed to translate that motivation into operational decisions. Closing this gap, which is precisely what the CETM curriculum was designed to do, may therefore be more effective than further regulatory pressure alone.

The pilot implementation additionally highlighted how learners increasingly perceive circular economy competences as directly connected to employability and industrial innovation. Feedback collected during the pilot phase showed that participants particularly appreciated the practical orientation of the modules when concrete examples, industrial applications, and case studies were included (CirCLER Consortium, 2026).

At the same time, learners and mentors repeatedly identified the need for stronger integration between theoretical frameworks and practical implementation tools. Several respondents requested additional real-world case studies, practical scenarios, and more detailed guidance regarding the operational implementation of circular economy strategies within companies.

Another important aspect is the growing link between circularity and digitalisation. Participants highlighted the relevance of digital tools, artificial intelligence, traceability systems, and data-driven approaches for circular transitions. However, digital competences showed the lowest perceived improvement in the pilot evaluation, suggesting that future CETM developments should strengthen the integration of sustainability education and digital innovation (CirCLER Consortium, 2026).

12.1.3 Resources Developed During the Project

One of the main outcomes of the CirCLER project was the development of a multilingual online educational platform dedicated to the training of CETMs. The platform was conceived as a flexible learning environment accessible to students, professionals, VET providers, companies, and trainers across Europe. The course includes modules addressing circular economy fundamentals, sustainable materials, circular business models, circular design strategies, manufacturing processes, enabling technologies, and transition management practices. Educational resources include reports, podcasts, video lectures, interactive activities, self-assessment tools, and supplementary materials designed to support both theoretical understanding and practical application.

The pilot implementation represented an important validation stage for assessing the coherence, usability, and effectiveness of the training ecosystem developed within the project (CirCLER Consortium, 2026). Learners could select among three learning pathways (Junior, Intermediate, and Advanced CETM) according to their educational background and professional experience. The evaluation of the educational content produced particularly positive results. Learners appreciated the clarity, structure, comprehensiveness, and professional relevance of the training materials. Tutors similarly evaluated the pedagogical coherence of the modules positively, especially regarding alignment with learning objectives and educational quality.

Among the complementary educational tools developed during the project, the CETM Skills Self-Assessment Tool represented an important mechanism for guiding learners through the educational pathway. The tool allowed participants to evaluate their previous knowledge and receive personalised recommendations regarding modules and learning pills.

The project also generated theoretical outputs directly connected to the development of the CETM framework. Examples include the CETM curriculum, based on the Competence Framework developed in previous stages of the research through the empirical contribution of all consortium partners, and the adaptation of circular economy models specifically oriented towards the furniture sector.

12.2 Focus on the CETM Figure

12.2.1 Definition of the Role

The CETM figure represents one of the most significant outcomes of the CirCLER project. Rather than representing a single-discipline specialist, the role is conceived as a systemic mediator capable of connecting environmental objectives, organisational strategies, technological innovation, and industrial processes within the furniture sector. For the complete definition of the CETM profile and its full competence framework, see Chapter 3.

12.2.2 Interdisciplinarity of the Figure

Importantly, the CETM reflects the emergence of hybrid professional profiles increasingly required within sustainable industrial transitions. Companies need professionals capable of operating across disciplinary and organisational boundaries (Kirchherr *et al.*, 2017).

Circular transition affects multiple dimensions simultaneously, including design, production, logistics, procurement, communication, governance, and digital innovation. For this reason, the CETM cannot operate within isolated organisational structures. Instead, the role requires the ability to connect diverse actors and competences across the organisation and the broader value chain. Designers, engineers, suppliers, marketing teams, sustainability experts, policymakers, and managers all contribute to the circular transformation process.

The project demonstrated that interdisciplinary collaboration can generate significant innovation opportunities. By integrating environmental, technological, organisational, and managerial perspectives, companies can develop more resilient and adaptive business models capable of responding to emerging sustainability challenges (Geissdoerfer *et al.*, 2017).

12.3 Challenges and Opportunities

The furniture sector is entering a period of profound transformation driven by environmental regulations, resource scarcity, technological innovation, and changing consumer expectations (European Com-

mission, 2020). Circular economy principles are expected to play a central role in shaping future industrial strategies and competitive dynamics.

Nevertheless, several challenges remain open. Many companies still face difficulties in implementing circular business models due to economic constraints, limited technical knowledge, fragmented organisational cultures, and insufficient readiness for systemic transformation.

In addition, the lack of standardised metrics and circularity indicators complicates the assessment of environmental performance and transition progress (Saidani *et al.*, 2019).

The barriers to circular transition are not uniformly distributed across the sector. Larger companies with dedicated sustainability functions are generally better positioned to absorb new competences and to invest in the redesign of their products and processes, while smaller enterprises face tighter resource constraints and a more acute shortage of in-house expertise. Future research and policy interventions should be sensitive to this heterogeneity, designing support mechanisms that are accessible to the small and medium-sized enterprises that make up most of the furniture sector.

The CirCLER pilot implementation additionally revealed that one of the principal future challenges concerns the balance between technological innovation and organisational preparedness. While companies increasingly recognise the strategic relevance of sustainability and circular economy approaches, the transition process still requires significant investments in competences, educational systems, and organisational transformation.

At the same time, important opportunities are emerging. Product-service systems, digital traceability tools, sustainable materials, industrial symbiosis, and advanced manufacturing technologies may contribute to creating more resilient furniture ecosystems.

The project also demonstrated the importance of flexible educational ecosystems capable of supporting lifelong learning and continuous professional updating. The high participation rates observed during the pilot phase, especially among younger learners and university students, suggest growing interest in sustainability-oriented professional profiles connected to circular transition processes.

The scalability of the educational platform further represents an important opportunity for future exploitation activities. Tutors involved in the pilot strongly supported the wider adoption of the course within higher education institutions, VET centres, and professional training organisations, confirming the perceived relevance and applicability of the CETM framework (CirCLER Consortium, 2026).

12.3.1 Future Research

Three directions stand out as particularly important for future research, based on what the CirCLER experience revealed.

The first concerns the organisational and cultural conditions for circular transition. The pilot results confirmed that competence development alone is not sufficient: professionals who complete the CETM course return to organisational environments that may or may not support the application of what they have learned. Future research should investigate how companies can build the internal conditions (governance structures, incentive systems, cross-functional collaboration practices) that allow circular competences to translate into sustained operational change. This is partly a question of management practice and partly a question of organisational design, and it requires methodologies that go beyond individual skill assessment to examine collective learning and institutional change.

The second direction concerns the integration of digital tools and data systems into circular practice. Participants in the pilot frequently identified digital competences as an area where the current CETM framework needs further development. The growing relevance of digital product passports, AI-supported supply chain optimisation, material traceability platforms and lifecycle data systems means that future iterations of the CETM curriculum will need to address the intersection of sustainability knowledge and digital literacy more explicitly. At the same time, research should investigate how these tools can be made accessible to small and medium-sized enterprises, which often lack the technical infrastructure and the dedicated personnel needed to implement them effectively.

The third direction concerns the long-term evolution of hybrid professional profiles such as the CETM itself. The furniture sector is not static: regulatory requirements will tighten, material technologies will

evolve, and market expectations will continue to shift. A professional profile defined today will need to be revised, expanded and recalibrated over time. Future research should develop methods for monitoring the evolution of the CETM role in practice: tracking how companies actually use professionals with this profile, what new competence gaps emerge as the transition matures, and how the training ecosystem built within CirCLER can be sustained and updated beyond the duration of the project itself.

These lessons offer strategic implications for professional training, education policy, and industrial practice, contributing to the discussion on achieving the furniture sector's circular transition.

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The furniture sector holds a strategic place in the European economy, yet also one of the heaviest environmental footprints of any manufacturing industry: millions of tonnes of waste each year, still mostly incinerated or landfilled. Knowing a sector has high circular potential, however, is not the same as realising it: what is missing are the people able to translate strategy and regulation into everyday industrial decisions.

Developed from the results of the Erasmus+ project CirCLER, this volume brings together contributions from higher education institutions, research centres, sectoral associations and training providers across Europe, reading the circular transition of the furniture sector as a single systemic process spanning regulation, business models, design, technology and training.

The Circular Economy Transition Manager (CETM), a new hybrid professional profile bridging sustainability objectives and operational decisions across the wood-furniture value chain, is at the heart of this transition. Twelve chapters guide the reader from European policy to the concrete tools for designing, training and managing change. An interdisciplinary contribution for researchers, professionals and trainers.