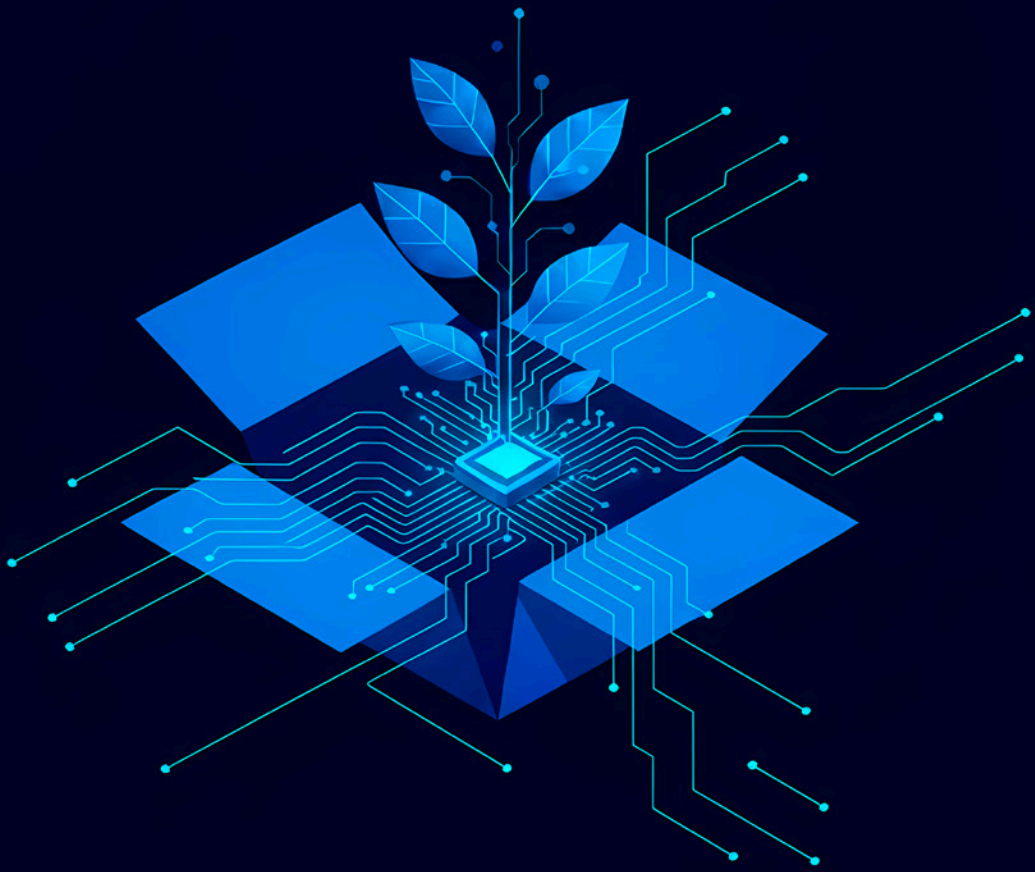
PACKAGING SUSTAINABILITY AND CIRCULARITY: A SYSTEMIC DESIGN PERSPECTIVE

FuturE-Pack

Designing Smart Packaging for Circular and Sustainable Made in Italy

edited by Erik Ciravegna



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Summary

3. PACKAGING SUSTAINABILITY AND CIRCULARITY: A SYSTEMIC DESIGN PERSPECTIVE

Silvia Barbero, Mariapaola Puglielli, Martina Spinelli, Veronica Pasini, Caterina Antonia Dattilo

Abstract: This chapter explores the transformative potential of design in supporting a sustainable transition through packaging, emphasising the necessity of a systemic perspective. Packaging is gaining relevance, not only due to increasing social and environmental awareness, but also because of its evolving role in the context of digitalisation. Tools such as digital twins, intelligent sensors, and traceability platforms enable real-time monitoring of material flows, lifecycle optimisation, and the implementation of circular strategies. The integration of these technologies calls for careful attention to environmental impacts. In this light, considering the growing complexity of socio-technical systems, packaging is no longer conceived solely as a functional artefact but as a dynamic node mediating interactions between products, users, supply chains, and environmental impacts. The chapter examines four interrelated dimensions of packaging design: the artefact itself, its relationship with the contained product, its interaction with multiple stakeholders across the supply chain, and its broader socio-environmental and regulatory context. By adopting a systemic design approach, packaging evolves from a tangible artefact into a strategic tool that aligns local operational practices with global sustainability goals, fostering circularity, resilience, and socio-environmental responsibility.

Keywords: Systemic Design, sustainable packaging, packaging supply chain, Circular Economy, regulatory framework.

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3.1. Design for sustainability and circularity

The growing awareness of the climate crisis, social inequality, and economic instability has redefined the role of design, calling it to contribute to transitions toward more sustainable futures. Sustainability is now conceived as a multidimensional balance—environmental, social, and economic (World Commission on Environment and Development, 1987)—which calls designers to move beyond form and function, engaging with responsibility, justice, and resilience (McAloone & Pigosso, 2017). This entails not only responsible choices of materials and processes but also the rethinking of consumption models, the extension of lifecycles, and the promotion of cultural and behavioural change. In this scenario, packaging is particularly relevant, as both a major source of waste and a potential ground for experimentation with new circular models.

Its relevance is also enhanced by the digital transition, which is reshaping packaging systems with data-driven tools, platforms, and smart technologies. These enable the monitoring of material flows, the extension of lifecycles, and recovery optimisation. Digital twins, blockchain traceability, and intelligent labelling provide infrastructures for circular practices, supporting reuse systems and closed loops. Here, design translates both technologies into tangible solutions while ensuring their accessibility and meaning for both companies and end users. Yet, digitalisation can also generate rebound effects such as energy consumption, obsolescence, and e-waste if not critically governed (Pagoropoulos et al., 2017).

This consideration demonstrates that the digital transition cannot be considered in isolation.

Evidence for this can be found in the twin transition (Rehman et al., 2023), which signifies the intertwined progression of digitalisation and sustainability. Digital tools have the potential to curtail material consumption, prolong product lifecycles, and facilitate low-carbon systems.

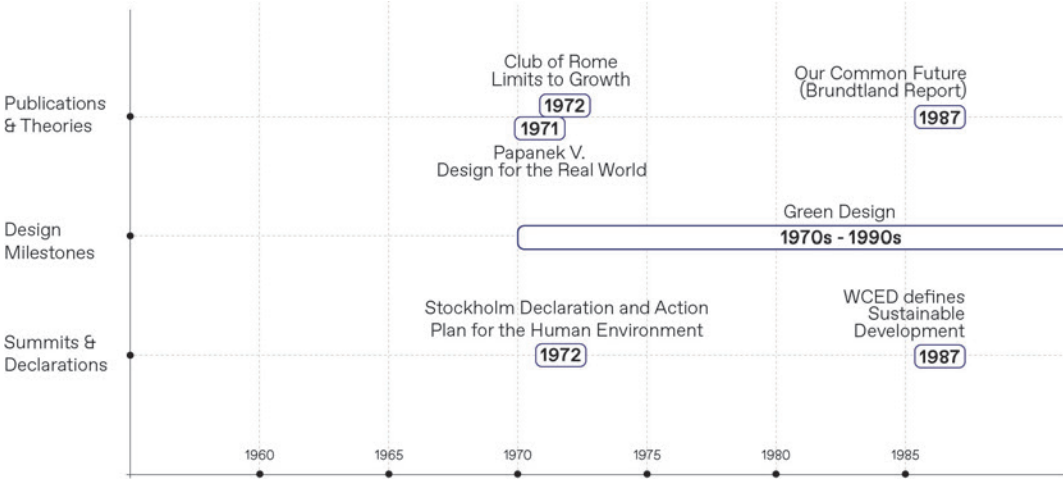
Designers are thus required to shape responsible circular experiences, enable reuse and sharing models (Manninen et al., 2018), and make digital systems intelligible and accountable (Xu et al., 2021).

From a sustainability point of view, the circular economy (European Commission [EC], 2015, 2020; Kirchherr et al., 2017; Kirchherr et al., 2023) offers a systemic alternative to the linear "produce–consume–dispose" model. Its strategies, summarised by the 9R framework (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle) (Muñoz et al., 2024), provide concrete pathways to preserve material value and minimise waste. Designers are called to embed principles such as modularity, reparability, and regenerative capacity into their practice, developing solutions that allow products and packaging to circulate within technical and biological systems without value loss (Bhamra & Lofthouse, 2007).

The evolution of sustainable design shows a progression from product-level efficiency to socio-technical strategies (fig. 1). In the 1970s and 1980s, early "green design" prioritised environmental efficiency, while Papanek's *Design for the Real World* (Papanek, 1971) stressed ethical and social responsibilities (Geissdoerfer et al., 2017). In the 1990s, Ecodesign became institutionalised through methodologies and regulations such as the European Union's Ecodesign Directive (European Parliament & Council of the European Union [EP & Council], 2005), embedding environmental considerations and responsibilities into industrial practice (McAloone & Pigosso, 2017).

The 2000s introduced systemic approaches such as Product–Service Systems (PSS) (Manzini & Vezzoli, 2002; Tukker & Tischner, 2004) and Systemic Design (Bistagnino, 2011; Barbero & Bicocca, 2017), while *Cradle to Cradle* (McDonough & Braungart, 2002) popularized regenerative cycles, positioning design as a means of continuous renewal rather than mitigation. By the 2010s, sustainability-oriented design had evolved into a socio-technical field, framing design as an agent of transition at multiple levels (Ceschin & Gaziulusoy, 2016), from product innovation to community-scale infrastructures and lifestyle change. Packaging, as the main interface between products and users, thus becomes a communicative and educational medium for sustainable practices.

As this historical summary demonstrates, the evolution of packaging design is often concomitant with broader trends in

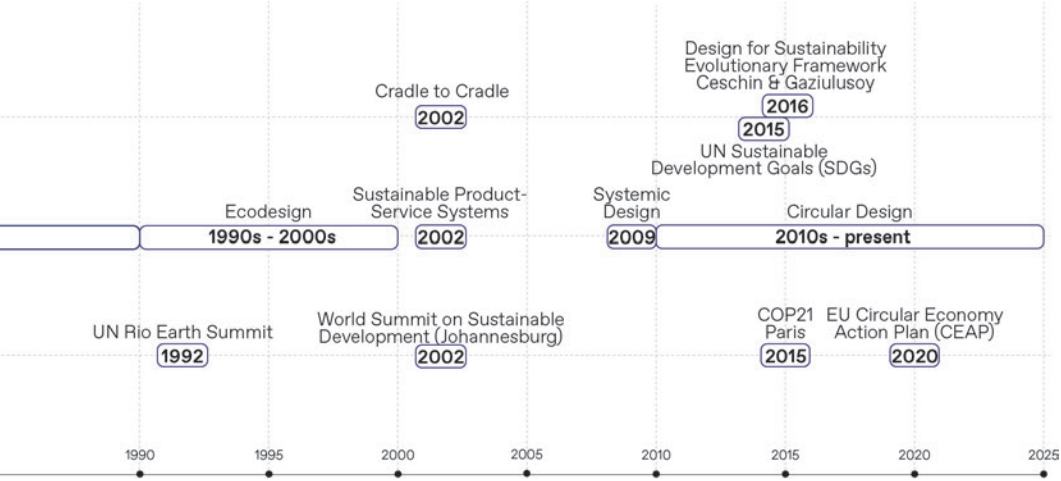


1. Timeline of the evolution of design approaches and influencing factors. Elaborated by the Authors.

design. From the 1990s into the 2000s, frameworks such as *Cradle to Cradle* reframed packaging through material metabolisms and certification systems, embedding goals of recyclability, reuse, and material. By the 2000s–2010s, bioplastics (e.g., PLA) and compostables entered mainstream markets, while corporations and municipalities pledged to curb single-use plastics and tested refill-and-return systems. Since the 2010s, there has been an expansion in focus toward circular economy strategies, with the development of reuse platforms, novel bio-based materials, and innovations in mono-material design, which are contributing to systemic circularity. Concurrently, regulations and corporate commitments have established packaging as a pivotal catalyst for sustainable transitions, both from a technical and cultural standpoint (Liu et al., 2023)

This trajectory converges in Transition Design (Irwin, 2015; Irwin, 2018), which positions design as a catalyst and driver of long-term transformation, focusing on everyday practices, cosmopolitan localism, and infrastructures for new cultural and ecological paradigms (Irwin et al., 2020). Within this framework, digital tools (such as smart materials, sensors, and intelligent labelling) open new possibilities for strengthening circular design strategies.

For packaging design, this implies moving from product efficiency to systemic responsibility (Succini et al., 2024). The challenge is to situate packaging within the broader ecosystem



of production, distribution, use, and recovery, where regulatory frameworks and policies, further explored in the next sections, play a key enabling role. Designers must therefore balance the opportunities of digitalisation with its risks, ensuring that innovation fosters circularity, transparency, and responsibility (Manninen et al., 2018).

3.2. How design is changing: A systemic approach to the packaging sector

This historical evolution reflects the increasing complexity of contemporary socio-technical systems that are reshaping how we conceive artefacts, even seemingly simple ones like packaging. The intricacy of supply chains and production networks, characterised by multiple levels of interaction among diverse stakeholders, global outsourcing, and intertwined logistical flows (Appolloni et al., 2021; Massari & Giannoccaro, 2021; Castelli & Brun, 2010), makes it reductive to consider packaging as an isolated design object. It functions simultaneously as a practical device and a systemic node, whose design choices influence products, users, infrastructures, and the broader socio-environmental system. Adopting a systemic approach to packaging design is therefore crucial for effectively transitioning to circular and sustainable models, since sustainable design

requires consideration of the interdependencies that shape the entire system.

Systemic Design extends beyond the level of individual products or services, encompassing the broader context in which they are produced, used, and disposed of, thereby considering the entire life cycle. It addresses large-scale, multi-organisational, and interconnected challenges within supply chains (Jones, 2014). By reimagining traditional linear supply chains as open, interconnected systems, Systemic Design promotes continuous flows, where outputs from one process serve as inputs for another, mirroring the circularity of natural ecosystems. Collaboration and synergy among diverse stakeholders help not only to reduce resource waste and emissions, but to pave the way for long-term, sustainable transformation (Bistagnino, 2011). The key point is that incremental improvements to single components are insufficient; sustainability requires integrated interventions across all nodes and relationships within the system. A systemic perspective situates packaging across three dimensions, each with distinct design implications (fig. 2).

The first dimension frames packaging as an artefact, primarily designed to serve as a container. This perspective emphasizes the packaging's relationship with its internal product. It highlights its performative requirements (Ciravegna, 2010), such as resistance to shocks, protection against physical, chemical, or microbiological threats, and storage stability ensured by dimensional optimisation, volume reduction, and secure closure (Badalucco, 2011). The challenge here is maintaining product integrity and usability while minimising resource use. Structural optimisation, modularity, and material efficiency reduce waste without compromising performance. Designers must account for environmental conditions at every supply chain step: from manufacturing, transport, and storage to retail and disposal. For instance, temperature-sensitive products require packaging that preserves stability during long-distance shipping and variable climates. Material choice, weight, and shape influence product preservation and logistics efficiency, reducing emissions and facilitating handling. Innovations such as smart features or aseptic technologies can actively monitor product integrity and alert stakeholders to deviations along the supply chain.

2. Relationship between packaging dimensions and the types of requirements involved. Elaborated by the Authors.

The second dimension addresses packaging and its multiple users along the supply chain, not just the end consumer. Therefore, it must meet operational requirements that facilitate handling, transport, opening, resealing, dispensing, and disposal. This includes manufacturers and assemblers integrating packaging into production flows, logistics operators managing storage and distribution, retailers displaying products, and waste managers overseeing recycling. The rise of multi-stakeholder logistics networks, particularly under the pressures of e-commerce and same-day delivery, requires packaging to adapt to new operational dynamics. The "Physical Internet" concept envisions modular, standardised containers that move seamlessly through multimodal networks, reinforcing the systemic role packaging plays in efficient and sustainable logistics (Barbero & Pereno, 2020). Communicative requirements (Ciravegna, 2010) are also critical: packaging must provide clear information about the product, instructions for use, and guidance on end-of-life options. Informative, prescriptive, persuasive, identificative, and evocative functions allow packaging to serve as an interface for both practical instruction and brand values (Badalucco, 2011).

In this dimension, the design of packaging must consider both the product's life and the consumer behaviour, as users are active participants in maintaining, using, and disposing of both products and packaging. Designers must anticipate who will interact with the packaging at each stage—assembling operators, transporters, end-users, and recyclers—and design to facilitate handling, disassembly, and separation of multi-material components. For example, in multi-material e-commerce packaging, modular inserts can simplify product insertion, protect items, and enable easier separation of materials for recycling or reuse, creating circular loops.

The third and broadest dimension positions packaging within the socio-technical system, encompassing normative and environmental requirements. Normative requirements include binding obligations such as EU Directive 97/129/EC on packaging and packaging waste (EC, 1997), which standardises material identification for recycling, and Italian Legislative Decree No. 116/2020 (Italy, 2020), introducing mandatory environmental labelling. Voluntary standards and extended producer

responsibility (EPR) schemes further emphasise the systemic dimension, holding producers accountable for impacts throughout the life cycle (EP & Council, 1994; Italy, 2020). Environmental requirements span all categories, requiring packaging to minimise its ecological footprint across production, use, and disposal. This means to work at design level and involves prioritising local and renewable resources, integrating recycled content, reducing components, designing for mono-materiality, and enabling compostability, recyclability, or reuse (Badalucco, 2011). Designers also need to consider the infrastructure for recycling and reuse, including take-back systems, refillable packaging, and closed-loop frameworks, ensuring that material flows connect all stakeholders effectively (Ellen MacArthur Foundation, 2023).

From a practical standpoint, Systemic Design encourages anticipating interactions and behaviours at each supply chain step. Therefore, packaging can actively mediate material, energy, and information flows. Mapping supply chain stages—including raw material sourcing, conversion, assembly, transport, retail, consumption, and disposal—helps designers identify opportunities for waste reduction, circularity, and reuse. For instance, a mono-material PET beverage bottle reduces transport weight, facilitates recycling, and, with proper labelling, guides consumers toward collection schemes. Similarly, modular e-commerce packaging can be optimised to protect products, reduce transport volume, and be returned or reused, creating multiple circular loops.

The systemic approach demonstrates that sustainability cannot be achieved through isolated improvements. Packaging must be reconceived as a dynamic node within an interconnected network, balancing functional and communicative roles with compliance, usability, and environmental responsibility. By integrating functional, communicative, normative, and environmental requirements, designers can reduce waste and ecological impact while reshaping socio-technical systems toward resilience, efficiency, and circularity. Even if the final output is a tangible artefact, the design process becomes a strategic tool to align products, users, and material flows, bridging local operational realities with global sustainability goals.

3.3. Evolution of regulatory framework in the packaging industry

This systemic vision finds concrete expression in regulatory and technical instruments. Guidelines and technical standards have been developed to translate sustainability goals into measurable design and production requirements aimed at the reduction of impacts associated with packaging systems. These recommendations are grounded in Life Cycle Thinking (LCT) and target interventions across the entire packaging value chain (from design to end-of-life) while addressing the specific challenges posed by e-commerce distribution models.

Current guidelines emphasize eco-design principles to improve efficiency, reduce material use, and enhance recyclability, through key strategies such as material optimization (light-weighting); modular, stackable, and compact designs to reduce empty space, especially in shipping; simplified packaging structures to facilitate mechanical sorting and recycling; avoidance of over-packaging and double-packaging, particularly common in e-commerce logistics. The eco-design strategies are strictly related to materials:

- recyclable, compostable, or reusable, in line with EU regulations (e.g., single-use);
- renewable and responsibly sourced, such as FSC-certified paper or bio-based plastics;
- containing post-consumer recycled (PCR) content, particularly in secondary and tertiary packaging.

The European Union (EU) has developed a progressively coherent policy framework addressing sustainability, packaging, and product design. The European Green Deal (EC, 2019) represents a significant evolution in this regard, as it adopts an integrated approach to these issues. Under the European Green Deal, the EU has committed to achieving climate neutrality by 2050. Packaging has emerged as a strategic policy focus due to its pivotal role in material consumption, waste generation, and consumer engagement.

The legislative framework established in the early stages laid the foundation for the regulatory landscape that is in place today.

The Packaging and Packaging Waste Directive 94/62/EC (EP & Council, 1994), subsequently amended by Directive 2018/852 (EP & Council, 2018), was instrumental in harmonizing national regulations pertaining to packaging management and establishing targets for recycling and recovery. Concurrently, a more extensive set of regulations pertaining to products came into being. The Ecodesign Directive 2009/125/EC (EP & Council, 2009) and its subsequent measures addressed energy-related products, while the REACH Regulation 1907/2006/EC (EP & Council, 2006) and the CLP Regulation 1272/2008/EC (EP & Council, 2008) provided safeguards on chemicals and product safety. These frameworks established the principle of extended producer responsibility, gradually linking product design to waste prevention and safe material use.

The policy trajectory has undergone a shift from incremental measures to systemic transformation. The Circular Economy Action Plan (EC, 2020) identified packaging as a priority sector for waste reduction, reuse promotion, and recyclability. The Ecodesign for Sustainable Products Regulation (ESPR) (EC, 2022a; EP & Council, 2024c) expanded the scope of ecodesign requirements beyond energy efficiency, encompassing durability, repairability, and recyclability. At the core of ESPR is the Digital Product Passport (DPP, 2023), a system that facilitates the exchange of lifecycle data. Smart packaging technologies, including QR codes, NFC tags, and RFID chips, are regarded as pivotal enablers of the DPP, facilitating the acquisition of real-time data on material composition, disposal pathways, and reuse potential.

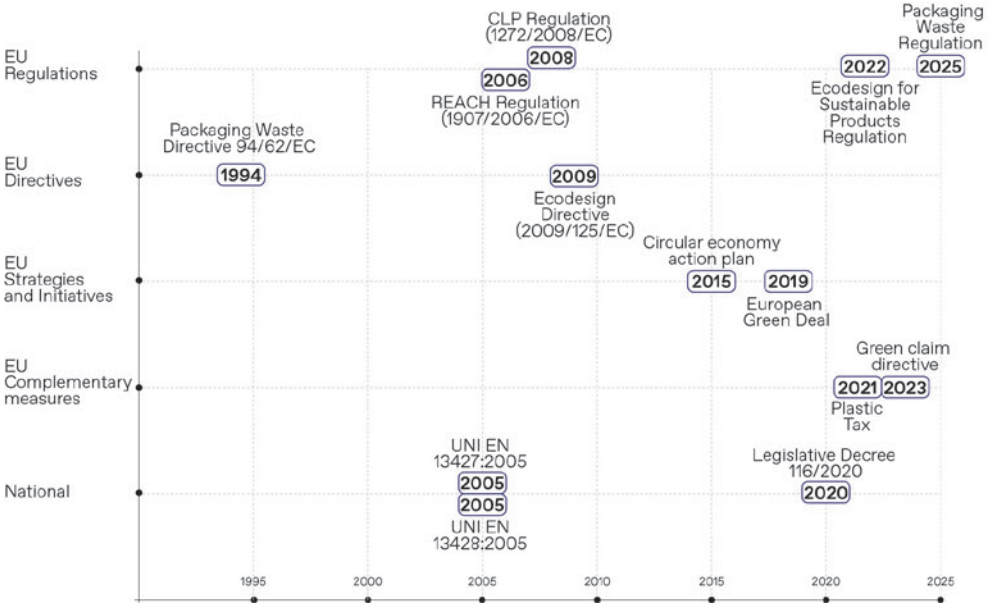
The Packaging and Packaging Waste Regulation (PPWR) (EC, 2022b; EP & Council, 2025) is a legislative initiative that aims to further advance these objectives. The new directive introduces binding EU-wide targets for recyclability, reuse, and waste reduction, transforming what were previously national-level obligations into harmonized requirements. Digital features embedded in packaging directly align with the principles of the PPWR by offering consumers guidance on proper disposal and traceable sustainability data. This operationalizes circular economy goals. These measures are reinforced by the Directive on Empowering Consumers for the Green Transition (EP & Council, 2024a) and the Right to Repair initiative (EP & Council,

2024b), both of which underscore the significance of accessible product information.

Complementary initiatives further illustrate the integrated nature of EU policy. The Single-Use Plastics Directive 2019/904 (EP & Council, 2019) and the Plastic Tax, after the entry into force in 2021 of the Own Resources Decision (Council of the European Union, 2020, 2021), are direct responses to the issue of plastic packaging waste. Recent legislation aims to phase out certain single-use formats by 2030 and expand deposit-return systems. In addition to the realm of packaging, a series of horizontal measures have been implemented, including a proposal for an EU Green Claims Directive (EC, 2023) and the EU Deforestation Regulation (EP & Council, 2023). These measures have expanded sustainability requirements to encompass supply chains and corporate communication, thereby enhancing accountability and fostering consumer trust.

National measures are in alignment with and serve to reinforce the objectives of the EU. Italian Legislative Decree No. 152 of 3 April 2006 (Italy, 2006) and Italian Legislative Decree No. 49 of 14 March 2014 (Italy, 2014) transpose EU directives into national law. Standards such as UNI EN 13427:2005 (Ente Italiano di Normazione [UNI], 2005a)—which transposes the European standard EN 13427:2004 (European Committee for Standardization [CEN], 2004a)—and UNI EN 13428:2005 (UNI, 2005b)—which transposes the European standard EN 13428:2004 (CEN, 2004b)—provide technical requirements for packaging design and establish provisions for waste prevention through source reduction.

When considered collectively, these policies evince a discernible progression (fig. 3): from the management of waste at the conclusion of the product lifecycle to the integration of sustainability at the design stage, and ultimately, to the incorporation of digital tools that facilitate the connection of products, consumers, and regulators. Consequently, packaging transitions from being a source of environmental pressure to a catalyst for systemic change. The Digital Product Passport, a smart technology, facilitates a nexus between product design, consumer behaviour, and environmental policy, thereby serving as a pivotal instrument in the EU's transition to a circular and climate-neutral economy.



3. Timeline of regulations, standards, and directives relevant to packaging. Elaborated by the Authors.

The rapid evolution of e-commerce calls for the adoption of sustainable practices, beginning with the selection of packaging that is easily recyclable, eco-friendly, renewable, and reusable. This entails optimizing packaging usage through thoughtful design to enhance efficiency, in accordance with relevant European directives. An important aspect of this transition is educating customers about circular policies aimed at reusing packaging to minimize waste. It is evident that collaboration among various stakeholders—such as manufacturers, suppliers, and customers—is essential to create the most sustainable e-commerce landscape possible. To promote a sustainable future and maximize the life cycle of packaging, it is crucial to adopt reusable packaging systems, particularly in business-to-business (B2B) environments and within e-commerce. Solutions like reusable mailers with integrated return labels, refillable containers for cosmetics and household items, and innovative closed-loop systems or packaging-as-a-service platforms not only help reduce waste but also contribute to a greener economy.

To effectively influence consumer behaviour and encourage responsible end-of-life management, companies should adhere to several guidelines:

1. Implement clear environmental labelling that includes recyclability symbols, material identification, and precise disposal instructions. This transparency enables consumers to make informed choices.
2. Utilize QR codes or digital labels to provide detailed information on sustainability performance, enhancing trust and engagement.
3. Maintain honesty in marketing to build credibility. In the realm of e-commerce, packaging serves as the primary physical connection between brands and consumers. Therefore, effectively conveying sustainability efforts through packaging is crucial for strengthening brand loyalty and fostering positive change.

3.4. Packaging as an orchestrating tool: Embracing complexity in the design process

This scenario redefines the role of design, recognising its potential as a strategic tool for navigating the increasingly complex paradigms of transition. Contemporary awareness of the interwoven nature of societal challenges has highlighted that each must be understood as a wicked problem (Rittel & Webber, 1973). In this light, designers can no longer approach sustainability by addressing isolated dimensions, be they environmental, social, political, or economic. These domains are deeply interconnected, and design interventions must be situated within an integrated framework in which every decision generates ripple effects across multiple scales. Within this complexity, Systemic Design provides both an interpretative and operative lens, enabling designers to move beyond reductive notions of efficiency or optimisation and instead embrace interdependencies as opportunities for innovation and transformation.

This shift changes how designers engage with practice. Traditionally, design focused on tangible artefacts such as products and services. While the material dimension remains significant, systemic transitions require a repositioning of priorities. Designers are increasingly called upon to operate within an expanded field, shifting from the tangible to the intangible, from the material to the relational. Central, therefore, is not merely the object itself but the network of relations it generates and sustains along the entire supply chain. In this sense, packaging emerges as a relational device: mediating between producers and consumers, logistics operators and retailers, waste managers and recycling infrastructures. Its material attributes, composition, structure, and labelling are not only functional in protecting the product but also instrumental in enabling flows of matter, energy, and information throughout socio-technical systems. Conceived in this way, packaging is no longer the endpoint of production but becomes a connective node and a catalyst for stakeholder collaboration.

Such a perspective transforms packaging into a medium of systemic value creation. Designing a package is no longer limited to its form or material selection. However, it extends to designing the relationships it facilitates: its integration into indus-

trial processes, its performance within distribution networks, its communicative role for users, and its capacity to re-enter the cycle at end-of-life. The design process thus becomes strategic, aligning micro-level decisions with macro-level objectives and bridging local operational realities with global sustainability agendas. Framed as an infrastructural element rather than a mere container, packaging shapes socio-technical systems that are more resilient, circular, and responsive to ecological and societal demands.

Within this landscape, the regulatory framework assumes a decisive role. Regulations translate sustainability objectives into measurable requirements, compelling designers to embed life-cycle thinking, traceability, and circularity into their practice. Recent European and national initiatives exemplify this reorientation. As illustrated by the Ecodesign for Sustainable Products Regulation, the focus is shifting from waste management and end-of-life considerations towards design-stage interventions. At the same time, instruments such as the Digital Product Passport extend responsibility across the entire supply chain, underscoring that sustainability must be pursued at every stage of a product's life cycle rather than confined to its use phase. Far from constituting restrictive impositions, such frameworks should be understood as opportunities for innovation, stimulating the integration of digital technologies, systemic strategies, and collaborative approaches into packaging design. In this perspective, compliance becomes a driver of experimentation, generating solutions that reconcile ecological responsibility with competitiveness and usability.

Finally, Systemic Design situates packaging at the intersection of material and immaterial dimensions, positioning artefacts as vehicles for relational and ecological transformation. The designer's task becomes that of orchestrating interactions among diverse actors, infrastructures, and contexts, ensuring that packaging fulfils its immediate protective and communicative functions and its role in enabling broader societal transitions. This change of perspective calls for recognising complexity as an essential ingredient of the design process, enabling designers to leverage local interventions without losing sight of broader global objectives.

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