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FROM TRADITIONAL PACKAGING TO PACKAGING 5.0: REDEFINING THE ROLE OF PACKAGING IN INDUSTRY 4.0 AND INDUSTRY 5.0

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ABSTRACT: The paper aims to examine whether current understandings of packaging correspond to the challenges posed by Industry 4.0 and Industry 5.0, and to propose a broader systemic perspective. A narrative literature review was conducted, including selecting academic, regulatory, and industry sources, followed by qualitative and comparative analysis. The study reveals that traditional, object-oriented definitions of packaging are insufficient. Packaging increasingly functions as a technological and socio-environmental system integrating digitalisation, circularity, and stakeholder needs. Key gaps in terminology and standardisation were identified. The study is conceptual and based on secondary sources; further empirical validation is needed. The findings indicate potential directions for redefining packaging strategies in the context of innovative, sustainable, and human-centric industries. Packaging contributes to environmental responsibility and consumer trust. The paper redefines packaging as a multi-dimensional system essential for Industry 4.0 and 5.0 transitions.

KEYWORDS: packaging, packaging 4.0, packaging 5.0, Industry 4.0, Industry 5.0

Introduction

The structure of world trade, which largely determines the functioning of the global economy, is primarily product-centric. The latest data show (World Trade Organisation, 2024) that in 2024, sales of goods accounted for 72.8% (World Trade Organisation, 2024), while services accounted for 27.2%. Even in highly developed countries, where services dominate GDP (e.g., Belgium's services account for ~72% (World Bank Open Data, 2024a), and in the USA, ~77% (World Bank Open Data, 2024b)), international trade and global value chains remain based mainly on physical products. Services often play a supporting role (e.g., logistics, finance, IT), but the chain's core is a tangible product that must undergo transport, storage, and packaging processes (EBSCO, 2024).

Most physical products require packaging, whether retail, bulk, or transport. The global packaging market exceeded \$1 trillion in 2023 (STATISTA, 2025) and is growing faster than many other industries. This means that modern product trade cannot exist without packaging: it is not only a physical carrier of goods, but also a gateway to logistics, distribution, and sales.

There is a lack of fully accessible data showing the structure of the packaging market by application. However, based on fragmentary reports and publicly available estimates, the approximate sizes of key sub-sectors can be indicated as follows:

- Food and beverages: 44.6% (~ 468.3 billion USD)(Market Research Future, 2025),
- Cosmetics & Personal Care Packaging: 40.9% (~\$429.2 billion)(Allied Market Research, 2023),
- Pharmaceutical Packaging: 14.7% (~\$154.8 billion)(Mordor Intelligence, 2025),
- Industrial packaging: 6.1% (~\$64.0 billion)(IMARC Group, 2025),
- Electronics Packaging: 2.2% (~\$22.5 billion)(Towards Packaging, 2025),
- E-commerce Packaging: 9.2% (~\$96.4 billion)(Precedence Research, 2025).

It should be emphasised that these estimates are subject to methodological error. The data on the size of the categories refer to different years (2022-2025), and the sum of the shares exceeds 100% (approx. 117%), which indicates an overlap of segments in market reports; therefore, the shares should be interpreted with caution. Despite these limitations, the summary allows one to grasp the scale and importance of individual sub-sectors of the packaging market, confirming its key role in global trade.

Methodology

This article aims to verify whether the current understanding of packaging corresponds to the challenges of Industry 4.0 and 5.0 and to indicate directions for developing the definition and concept of packaging in the context of digitalisation, sustainability, and the needs of various stakeholders.

Due to the interdisciplinary approach to packaging in the literature, the analysis was based on a narrative review (Snyder, 2019) of English-language literature, focusing on the most recent literature (from the last 5-10 years). The starting point for the search was the term “packaging” in databases that provide open access to works, followed by subject searches for selected concepts (using ScienceDirect, Scopus, MDPI database; section: new types of packaging).

When searching for classic packaging definitions, the most general and universal concepts were sought (those referring to a specific industry, e.g., food packaging, were rejected) and the most recent or widely cited ones. As packaging is an issue that is subject to legal regulations, definitions developed by institutions/organisations relevant to the industry were also taken into account.

I4.0 and I5.0

Industry 4.0 (I4.0) and Industry 5.0 (I5.0) represent distinct yet interconnected stages in the evolution of manufacturing and industrial processes.

I4.0 is a techno-centric framework that relies on automation, digital connectivity, and standardised data exchange (Rosário & Raimundo, 2025). Its foundations rest on the widespread use of the Internet of Things (IoT), cyber-physical systems (CPS), and conventional artificial intelligence for process optimisation and efficiency, with little emphasis on human intervention (Enang et al., 2023).

I5.0 builds upon this base by introducing human-centric and ethical enhancements. Key innovations include:

- Human-centred artificial intelligence—emphasising explainability, education, and collaborative decision-making (Rosário & Raimundo, 2025).
- Collaborative and cognitive robotics that support co-working and mass customisation (Zeb et al., 2022).
- The integration of blockchain and edge computing for decentralised, transparent, and resilient operations (Zeb et al., 2022).

Requirements for packaging in the context of I4.0 and I5.0

Considering the general characteristics of I4.0 and I5.0, packaging requirements and examples of applications have been developed so that packaging can be an integral part of the architecture of both systems – see Table 1.

Table 1. Requirements for packaging in the context of Industry 4.0 and Industry 5.0 – conceptual approach

I4.0		I5.0	
Requirement	Examples of applications	Requirement	Examples of application
Digitisation and traceability	• Integration with IoT, RFID, NFC, 2D/QR code systems for real-time tracking. • Enabling data collection and exchange throughout the supply chain (e.g., temperature, location, transport time).	Human-centric design	• Packaging designed to make life easier for users (e.g., easy opening for seniors, ergonomic shapes). • Considering user experience, such as intuitiveness and accessibility for people with disabilities. • Personalisation is not only for marketing purposes but also for the individual needs of consumers.
Automation and robotics compatibility	• Packaging must be designed to be easily handled by automated packaging lines and robots that pick and place them. • Standardisation of dimensions, shapes, and materials to work with smart warehouses and AGV/AMR systems.	Integration of humans and technology	• Use of collaborative robots (cobots) and AI in packaging processes – packaging must be adapted for use by humans and intelligent machines. • Smart labels and interfaces that facilitate human collaboration with digital systems (e.g., digital product passports accessible via smartphones).
Data integration throughout the supply chain	• Packaging must be a “data carrier” supporting ERP, MES, and SCM systems. • Enabling automatic data exchange between the manufacturer, logistics, retailer, and end user.	Ethics and social responsibility	• DPP (Digital Product Passport), blockchain, and AI are used ethically, with respect for privacy and transparency. • Transparency regarding the sources of materials (traceability from raw material to consumer). • Information about environmental and social impact on packaging (eco-labeling, social score). • Compliance with responsible design principles – avoiding greenwashing and absolute waste reduction.
Logistics optimisation	• Packaging design with Logistics 4.0 in mind (easy to track, modular, compatible with smart warehouses). • Increased transport efficiency (better cargo space use, reduced empty runs).	Symbiosis with nature	• Packaging that minimizes negative impact and has a positive effect – e.g., biodegradable materials that enrich the soil, or packaging that has a second life as valuable objects.

I4.0		I5.0	
Requirement	Examples of applications	Requirement	Examples of application
Product safety and protection	• Anti-counterfeit solutions (holograms, dynamic codes, blockchain). • Built-in tamper-evident indicators. • Monitoring of critical conditions (e.g., for pharmaceuticals and food).	Resilience	• Packaging supports supply chain resilience through flexible materials and standardisation. • Product protection against counterfeiting and cyber threats (e.g., blockchain for authenticity verification). • Built-in tamper-evident and tracking features in crises.
Sustainability and circular economy	• Materials that are easy to recycle, biodegradable, compostable, or reusable. • Minimisation of packaging weight and volume, optimisation of carbon footprint. • Transparency of environmental footprint through digital labels and blockchain.	Sustainability and regenerative approach	• Packaging should support climate neutrality and environmental regeneration. • Development of bio-based, compostable, reusable materials. • Cradle-to-cradle design – fully considering the life cycle from production to recovery.
Personalisation and production flexibility	• Ability to mass personalise packaging (e.g., digital printing, variable data) while maintaining efficiency. • Short production runs tailored to e-commerce, direct-to-consumer, and dynamic markets.	Personalisation and co-creation	• Packaging is a medium for co-creating value between the manufacturer and stakeholders. • The consumer is treated as a co-creator (the possibility of co-designing the appearance and functionality of packaging, e.g., through digital platforms). • Integration of AR/VR experiences in packaging, but in the service of building relationships, not just sales.

Source: author's work based on (Bányai, 2022; Jefroy et al., 2022; Oyekunle et al., 2024; Piccarozzi et al., 2024).

In I4.0, packaging becomes a tool for efficiency – digital, automated, logistically optimised. In I5.0, however, it is a tool for relationships and regeneration – designed for people, the environment, and a responsible economy. In I5.0, it is not only automation that matters – human-centricity, i.e., the cooperation of people with technology (e.g., cobots), and a three-dimensional balance of efficiency, sustainability, and resilience of supply chains are also important.

There has been a noticeable evolution in packaging requirements – from the digitalisation and automation characteristic of the I4.0 paradigm to human-centric design, ethics, and symbiosis with nature within I5.0 – indicating that packaging is no longer solely a technical and logistical element, but is becoming a vehicle for social, environmental, and relational values.

This raises the question of whether the definitions of packaging that exist in the literature and are promoted by normative and industry organisations reflect this broader perspective. The following section reviews theoretical and practical approaches to assess the extent to which the current scientific and regulatory discourse is keeping pace with the transformation of the understanding of the role of packaging in the economy.

The classic scientific and market understanding of packaging

The analysis began with a review of the most general and fundamental concept, i.e., packaging itself, which should be the point of reference for all further considerations. Next, narrower concepts were considered, relating to new categories and innovative forms of packaging, such as active, smart, connected, and digital packaging, which should develop and refine the basic functions of packaging. This approach allows for capturing both traditional and contemporary perspectives and identifying areas where there is a divergence between the classic understanding of packaging and its latest, technologically and socially expanded interpretations.

Literature studies show that there is no single, consistent definition of “packaging” applicable to all industries. This may be because packaging is an interdisciplinary (analysed in terms of logistics, marketing, law, commodity science, etc.) and multifunctional issue. There are also different packaging levels (primary, secondary, tertiary). Each level has different functions and often different regulations within the industry. A definition that fits logistics (packaging is both a pallet for transporting goods, a container, and fillers in the packaging) does not reflect the role of packaging in marketing (e.g., brand design). Different industries give different priorities to packaging, which is challenging to capture in a single framework. For example, in pharmaceuticals, packaging is part of the medical system, where the emphasis is on patient safety and dosage information. In FMCG, it is a silent salesperson, a tool for building a brand. In the plant protection industry, it is important to ensure tightness and stability, legible warning labels, and chemical durability of the packaging (the packaging must be resistant to the substance itself). In the electronics industry, packaging must protect delicate devices from mechanical and electrostatic damage and ensure product authentication (protection against counterfeiting).

The difficulty in developing a uniform definition may also stem from the fact that there are different levels of analysis (micro, meso, and macro). In order to take them into account, it would be necessary to prepare a definition that reconciles economic, environmental, and social interests. For an entrepreneur, packaging is often a cost (legal changes, R&D, legal protection, materials, logistics, losses due to damage, and disposal costs). For the consumer, packaging can be a value (safety, convenience, aesthetics, ecology). From a macroeconomic perspective (national economies), however, packaging is waste (the problem of recycling, implementation of a circular economy).

An overview of the latest definitions of packaging (Ambrose & Harris, 2017; Hellström et al., 2016; Manglik, 2024), commonly cited in the literature (Kotler et al., 2008; Saghir, 2004; Soroka, 1999) and normative, legal and industry standards, (American Society for Testing and Materials, 2023; International Organisation for Standardisation, 2016; Directive, 2004; European Environment Agency, 1994) indicates that packaging is usually considered as a noun (object) or verb (action). Analysis of these definitions concludes that packaging, in the classical sense, is a physical form of protection and presentation of a product, whose basic tasks arise from the needs of transport, storage, and sale. Packaging is, therefore, a static, physical object containing printed information that cannot be updated or synchronised in real time. Nor is it adapted to the digital age, as it does not fit into the logic of data flow, automation, and integration characteristic of I4.0. In the common understanding, packaging is rarely understood as an infrastructure element. However, digitising the value chain requires that packaging not only protect and promote the product, but also be a data carrier, an element of tracking and real-time management.

It is worth noting, however, that not all of the above definitions refer to packaging as a physical artefact (although this is the most common approach), i.e., an object that can be weighed, measured, and disposed of. Packaging can also be understood as an activity, a set of actions that prepare a product for sale and use: design, material selection, packaging, labelling, logistics, recycling (ISO 21067-1:2016). This approach focuses on operations and flows, rather than just the physical carrier. The emphasis is therefore on activities and functionality, rather than on the object itself. The third approach, on the other hand, views packaging as a system of interconnected vessels (Saghir, 2004; Soroka, 1999), i.e., an integrated logistics and communication system in which the following elements are intertwined: material and form (artifact), design and service processes (process), actors: producers, logisticians, sellers, consumers, recyclers. Packaging becomes part of a network that protects the product, conveys information, supports sales, and enables recovery and the circular economy.

This shift in definitions from “packaging as an object” to “packaging as a system” significantly broadens the understanding of packaging from a simple object to a tool for managing products, logistics, communication, and ecology. This makes it possible to examine not only what packaging is, but also what it does and what effects it has throughout the value chain. It is this latter approach that allows packaging to be integrated into:

- Industry 4.0, where it becomes a node in a cyber-physical network connecting, among others, the manufacturer, distributor, retailer, and consumer;
- Industry 5.0, where packaging becomes part of a socio-technical system designed to create value for people and protect the planet.

New types of packaging

With economic development, researchers are identifying new types of packaging that use new technologies to varying degrees – see Table 2.

Table 2. New types of packaging

Type of packaging	Brief description	Definition	Example	Is it an object or an approach to design?	Is it applicable in I4.0 or I5.0?
Smart packaging	packaging enhanced with additional features such as sensors and indicators that enable monitoring of freshness, temperature, humidity, or tracking of products in the supply chain	(Lokuge, 2025; Bhatlawande et al., 2023)	active packaging, intelligent packaging, connected packaging	object	I4.0 I5.0 (if it integrates environmental and social aspects)
Active packaging	packaging containing active substances that interact with the product (e.g., oxygen absorbers, moisture control systems) to extend its shelf life (reducing waste) and improve safety	(Bhatlawande et al., 2023)	antimicrobial packaging, packaging using oxygen scavengers/ethylene absorbers/moisture control systems	object	I4.0
Intelligent packaging	packaging that provides information about the history and quality of the product, often through time-temperature indicators, gas sensors, or smart labels	(Robertson, 2016)	packaging using time-temperature indicators/ gas sensors/ smart labels/ nanocomposite sensors	object	I4.0 I5.0
Circular packaging	packaging designed in line with the circular economy, which can be reused, easily recycled, or made from renewable materials	(Efficient Consumer Response Community et al., 2024)	Compostable packaging, reusable packaging, edible packaging, recyclable packaging	approach to design	I5.0
Sustainable packaging	a philosophy of packaging design and production that considers the entire life cycle, minimises environmental impact, and promotes renewable materials, compostability, and reusability	(Hwang, 2024; Sustainable Packaging Coalition, 2023)	biodegradable packaging	approach to design	I5.0
Digital packaging	virtual packaging and/or packaging equipped with digital elements (e.g., QR codes, AR, NFC) that enable interaction with the consumer, personalisation of content, and data collection	(Huyen, 2021; Wojciechowska & Wiszumirska, 2021)	packaging using Augmented Reality, QR codes, NFC tags	object	I4.0
E-commerce packaging	packaging designed specifically for online commerce, optimised for shipping, returns, and reusability	(Brüel Grönberg & Hulthén, 2022)	Reusable/refillable e-commerce package	object	I4.0 I5.0
Connected packaging	packaging connected to digital systems, which, thanks to mobile technologies (QR, RFID, AR), provide access to real-time information, transparency, and product tracking	(Manaswini et al., 2025)	Packages with QR codes, NFC, and using Augmented Reality	object	I4.0 I5.0 (transparency, social values)
Package digital twin	virtual representation of packaging or the packaging process, including data on design, material properties, life cycle, and interaction with the product, supporting simulations and optimisation	(Smart Packaging Hub, 2025)	None The software can integrate, e.g., the Internet of Things, artificial intelligence, and data analytics to improve the output.	virtual object	I4.0
Packaging 4.0	a systemic approach to packaging in the spirit of Industry 4.0, integrating IoT, sensors, the cloud, and intelligent platforms throughout the entire packaging life cycle – from production to consumption	(Sadeghi et al., 2022)	None It is an intelligent, digitally integrated packaging system that collects and processes data throughout the entire product life cycle.	approach to design	I4.0 I5.0 (in the part related to sustainability and human-technology interaction)

Analysing this landscape of definitions from a scientific perspective, it can be seen that they implement the pillars of I4.0 and even I5.0. However, the picture of the definitions is scattered and heterogeneous. For example, some researchers treat “smart packaging” as an umbrella term for active and intelligent packaging, while others separate them into separate categories. The term “digital packaging” sometimes appears in the literature as “interactive packaging”, and “circular” and “sustainable” are often used interchangeably, despite their differences. There is, therefore, an overlap of concepts and a lack of definitional clarity. At the same time, the existing packaging categories (smart, active, sustainable, connected, etc.) are fragmentary and do not reflect the overall role that packaging is beginning to play in the architecture of I4.0 and I5.0. Each focuses on a different aspect (technology, sustainability, logistics, consumer interaction). There is no conceptual umbrella that would comprehensively address all the needs of I4.0/I5.0.

Literature studies also highlight the problem of divergent perspectives – for example, logistics literature emphasises sensors, IoT, and blockchain, while marketing literature is closer to customer experience and brand engagement.

The definitions of individual types of packaging vary significantly in terms of precision and scope. Some are technical and functional (e.g., active packaging, intelligent packaging), while others are umbrella terms or conceptual frameworks (e.g., sustainable packaging, packaging 4.0). Many of them are not sufficiently clear to be applied strictly, which results in a terminological landscape rather than a coherent system of concepts. Definitions are helpful for research (they describe the evolution of technology), but they are more challenging to apply in comparative analysis.

When analysing these definitions from an economic perspective (market entities), the categories can often be unclear and vague. For example, a manufacturer may describe its solution as smart packaging, while from another entity’s point of view, it is connected or digital packaging. The lack of clear boundaries means that definitions can be used for marketing rather than operational purposes. For regulators, the difficulties are even greater. If there are no clear criteria to distinguish between types of packaging, it is challenging to develop legal norms, industry standards, or certification systems. In the economy, therefore, these definitions form a mosaic of trends rather than a coherent dictionary. They can inspire innovation and marketing strategies, but do not provide a sufficient basis for standardisation.

From the perspective of I4.0 needs, i.e., digitalisation and automation, concepts firmly rooted in technology (smart, connected, digital, digital twins) are noticeable. However, due to their blurred boundaries, they do not yet form a complete and unambiguous map of the phenomenon. From the perspective of I5.0, the picture is more fragmented. Definitions such as sustainable or circular packaging refer to environmental issues. However, there is a lack of consistent language that would combine human-centeredness, social responsibility, and the integration of technology with values. So, although the picture of packaging types and their definitions is rich, it is not complete or consistent enough to fill the conceptual space associated with Industry 4.0 and 5.0 on its own. A layer of meta-definition or systematisation is needed to link the different types of packaging into a coherent model that corresponds to both industrial paradigms.

Summary

The analyses carried out indicate that the role of packaging in the global economy is evolving from a classic physical product carrier to an element of digital and socio-environmental infrastructure. In the I4.0 paradigm, packaging is an optimisation tool integrated with the IoT, robotics, and logistics systems, supporting efficiency and safety. Within I5.0, its significance is expanding to include a human-centric and ethical dimension: packaging is becoming a carrier of social, environmental, and relational values, co-creating the consumer experience and supporting the regenerative economy.

At the same time, an analysis of definitions reveals a lack of consistent language and clear conceptual boundaries – terms such as smart, intelligent, connected packaging overlap and create a ‘terminological landscape’ rather than a systematic typology. This hinders comparative research as well as standardisation and regulation processes.

In the face of the transformation of the economy – from linear to circular and from physical to multi-channel – it is necessary to promote the understanding of packaging not as a static object, but

as a complex system integrating various technologies and responding to the needs of many stakeholders.

The analysis concludes that there is a need to develop a meta-definition or integrated model that combines digital technologies, environmental requirements, and social factors into a coherent concept of ‘packaging of the future’. Such a model could form the basis for further empirical research, as well as for economic practice and regulatory policy.

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OD OPAKOWAŃ TRADYCYJNYCH DO OPAKOWAŃ 5.0: REDEFINICJA ROLI OPAKOWAŃ W PRZEMYŚLE 4.0 I PRZEMYŚLE 5.0

STRESZCZENIE: Celem artykułu jest zbadanie, czy obecne rozumienie opakowania odpowiada wyzwaniom stawianym przez Przemysł 4.0 i Przemysł 5.0, a także zaproponowanie szerszej, systemowej perspektywy. Przeprowadzono narracyjny przegląd literatury, obejmujący wybór źródeł akademickich, regulacyjnych i branżowych, a następnie analizę jakościową i porównawczą. Analizy pokazują, że tradycyjne, zorientowane na obiekt definicje opakowania są niewystarczające. Opakowanie coraz częściej funkcjonuje jako system technologiczny i społeczno-środowiskowy, integrujący cyfryzację, cyrkularność i potrzeby interesariuszy. Zidentyfikowano kluczowe luki w zakresie terminologii i standaryzacji. Artykuł ma charakter koncepcyjny i opiera się na źródłach wtórnych; konieczna jest dalsza walidacja empiryczna. Wyniki wskazują potencjalne kierunki redefiniowania strategii opakowaniowych w kontekście przemysłów innowacyjnych, zrównoważonych i zorientowanych na człowieka. Opakowania odgrywają istotną rolę w budowaniu odpowiedzialności środowiskowej i zaufania konsumentów. Artykuł redefiniuje opakowanie jako wielowymiarowy system, niezbędny w transformacji ku Przemysłowi 4.0 i 5.0.

SŁOWA KLUCZOWE: opakowanie, opakowanie 4.0, opakowanie 5.0, przemysł 4.0, przemysł 5.0