DIGITAL ADVANCED DESIGN

TRANSITIONAL INDUSTRIAL APPROACHES FOR SUSTAINABLE INNOVATION

edited by
Flaviano Celaschi
Laura Succini
Michele Zannoni

Bologna
University Press

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
DIPARTIMENTO
DI ARCHITETTURA

Tutti i contributi pubblicati all'interno della Collana sono sottoposti a un processo di *double-blind peer review*.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA | DIPARTIMENTO DI ARCHITETTURA

Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani Piano Nazionale di Ripresa e Resilienza

This study was funded by the European Union - NextGenerationEU, in the framework of the "MICS - MADE IN ITALY CIRCOLARE E SOSTENIBILE" (PNRR - Missione 4 Componente 2 - Investimento 1.3 - Codice progetto PE00000004 - CUP J33C22002950001). The views and opinions expressed are solely those of the authors and do not necessarily reflect those of the European Union, nor can the European Union be held responsible for them.

Fondazione Bologna University Press
Via Saragozza 10, 40123 Bologna
tel. (+39) 051 232 882
ISSN 2385-0515
ISBN: 979-12-5477-602-5
ISBN online: 979-12-5477-603-2
DOI: 10.30682/9791254776032

www.buponline.com
info@buponline.com

In copertina: immagine realizzata dagli Autori
Progetto grafico: Gianluca Bollina-DoppioClickArt (Bologna)
Impaginazione: Oltrepagina (Verona)
Prima edizione: giugno 2025

Digital Advanced Design

Transitional Industrial Approaches for Sustainable Innovation

edited by Flaviano Celaschi, Laura Succini, Michele Zannoni

Bologna
University Press

Summary

DIGITAL DESIGN FOR CIRCULAR MATERIALS

INTRODUCTION

Flaviano Celaschi, Laura Succini*, Michele Zannoni**

**Department of Architecture, Alma Mater Studiorum - University of Bologna, Italy*

This research presents the launch of ten innovation fronts developed in parallel that will be followed in the ongoing projects by a phase of experimental testing and development of demonstrators, prototypes and living labs to validate methods and approaches for circular and sustainable design. The research is developed within *Spoke 1* of the extended partnership MICS (*Made in Italy Circolare e Sostenibile*), part of PNRR Mission 4 funded through the NextGenerationEU program with the aim of developing an innovation for the development of a new production system. With a focus on Digital Advanced Design, Spoke 1 explores how design and digital innovation can support the sustainable and circular transformation of three key *Made in Italy* sectors—furniture, fashion and automation—by strengthening the skills of industrial designers through knowledge, digital tools and interoperable processes.

The research, dedicated to *Digital Advanced Design: technologies, processes and tools*, involves several departments of the University of Bologna and other Italian universities, national institutions, leading companies in the relevant sectors, and additional research groups and entrepreneurial entities activated through Cascade Calls.

Through four thematic clusters—*Digital Design for Manufacturing, Digital Design for Advanced Interaction, Digital Design for Knowledge Sharing, and Digital Design for Circular Materials* — the goal is to develop a portfolio of accessible digital tools that enable industrial designers to orchestrate complex choices oriented to sustainability and circularity from both tangible and intangible points of view, in continuous innovation along the production chains of *Made in Italy*. In addition, from ongoing research is emerging the figure of the *Transitional Industrial Designer*, a designer capable of connecting knowledge systems and production systems, through anticipatory actions, continuous and punctual data control systems and interdisciplinary contamination processes.

The publication closes with a preview of future developments related to Spoke's digital portfolio, a tool developed as an infrastructure to support the sustainable transformation of the Italian manufacturing system.

FUTURE-PACK. TOWARD A TAXONOMY OF SMART SOLUTIONS FOR ADVANCED PACKAGING DESIGN

Erik Ciravegna, Silvia Barbero**, Davide Pletto*, Mariapaola Puglielli**, Martina Spinelli***

1. Introduction

Packaging is a complex artifact (Ciravegna, 2010; 2017) that, beyond its nature as an object of use, is a powerful means of communication capable of conveying not only product qualities and brand values but also relevant information concerning the entire sector in which it is inserted, thus constituting a mediating element, a key point of contact between actors in the supply chain and between them and the end-users. Moreover, thanks to digital technology, packaging has transformed over time into a truly “smart device” that can track the supply chain, check the integrity and safety of goods, and potentially record the entire history of each product and its impacts.

The convergence of megatrends such as sustainability and digitalization (Lichtenthaler, 2021), particularly the rise of e-commerce, has sparked a profound transformation in the packaging industry. The growing emphasis on the circular economy (European Commission, 2020; Kirchherr et al., 2017), coupled with stricter regulations on packaging waste—such as the so-called “Packaging and Packaging Waste Regulation” (PPWR) (European Commission, 2022)—and heightened consumer awareness of sustainability issues (Bar Am et al., 2023), is compelling companies to re-evaluate their products and processes to minimize environmental impact and enhance overall value (Marrone & Raimo, 2021). Simultaneously, technological advancements, including the proliferation of digital devices and social media platforms, alongside the rapid shift towards online shopping accelerated by the COVID-19 pandemic (LaBerge et al., 2020), present both significant challenges and transformative opportunities for sustainable manufacturing and business practices (Moghrabi et al., 2023).

Within the context of the MICS extended partnership’s re-

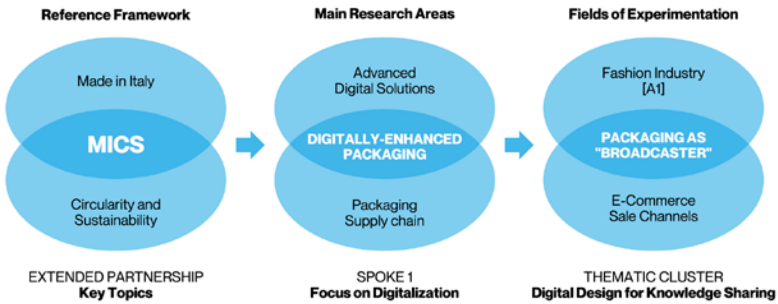
**Department of Architecture, Alma Mater Studiorum - University of Bologna, Italy*

***Department of Architecture and Design, Politecnico di Torino, Italy*

search activities, the study *FuturE-Pack: Digital Advanced Design for the Enhancement of Packaging as a 'Broadcaster' in the Made in Italy Supply Chain* (Project 1.1) investigates the utilization of digital solutions to augment packaging functionality as a communication tool within Made in Italy sectors. This research, conducted by a collaborative team from the University of Bologna, the University of Florence, and the Polytechnic University of Turin, examines how digital technology can transform packaging into an intelligent device capable of tracking and monitoring product integrity and safety throughout the supply chain. A digitally enhanced container also has the potential to record comprehensive product histories and associated environmental impacts, all while effectively communicating brand identity and values.

The project "FuturE-Pack" aims to develop a portfolio of digitally advanced solutions to enhance the role of packaging as both a mediator and a communication medium ("broadcaster") within the supply chain. These solutions will facilitate the recording, archiving, and disseminating of product-related information (e.g., sustainability metrics, brand identity) by simplifying and translating complex data into formats accessible to various stakeholders. The primary objectives are twofold. First, to equip stakeholders in the Made in Italy supply chain with digital tools that streamline information exchange, thereby promoting the safe, cost-effective, and efficient handling of goods, and contributing to the development of sustainable (*green*) logistics practices. Second, to enhance the end-user experience by providing transparent, accessible, and inclusive product information, including details about their impacts, according to the three pillars of sustainability (Purvis et al., 2019): *planet* (environmental), *people* (social), and *profit* (economic). This will also enable clearer communication of territorial and brand identity, along with associated tangible and intangible values, particularly for luxury brands.

The initial phase of this research focused on mapping and analyzing the current state of the art by collecting relevant case studies of existing and potential digital solutions for packaging, along with their functionalities. Additionally, a comprehensive review of the scientific literature about life cycle assessment and product impact analysis was conducted. Future research will analyze the supply chain and stakeholder ecosystem related



1. Conceptual framework and structuring of the project.
All images are reproduced in color in the online edition of the book.

to packaged goods, especially within the e-commerce and fashion industry (A1 sector), which are the primary areas of analysis and experimentation for this project (fig. 1).

This essay focuses on the initial phase of research, presenting the work conducted on the collection, cataloging, and analysis of case studies. This analysis resulted in the development of a taxonomy of smart solutions that can be integrated into advanced packaging design to address the significant contemporary challenges of sustainability and circularity.

2. Smart packaging: Utilized technologies and applications

Originally intended as a simple containment element, packaging has evolved into an integral part of product design, serving not only to contain but also to protect and preserve (Lydekaityte & Tambo, 2020). However, this traditional view of packaging is undergoing a paradigm shift due to the increasing complexity of products and rising consumer expectations. Moreover, packaging is now recognized as a vital facilitator of the transition to a circular economy, encompassing functionalities such as life cycle assessment, product life extension, and a more sustainable supply chain. This transformation is further driven by the rapid development of digital technologies, such as the Internet of Things, biopolymers, and nanomaterials (Schaefer & Cheung, 2018; Palazzo et al., 2023). In light of these developments, the term *packaging* alone is no longer adequate to describe the current state of the art. The focus is now shifting from the basic concept of packaging to the more advanced concept of *smart packaging*.

2. Main packaging functions for each type of smart packaging. Adapted from Lydekaityte & Tambo, 2020.

Smart packaging refers to any packaging that incorporates advanced technologies to enhance its primary functions or introduce new functionalities going beyond those of conventional packaging. Brockgreitens and Abbas (2016) define smart packaging as incorporating advanced technologies for the purpose of achieving these goals. As Nandanwade Priyanka & Nathe Parag (2013) explain, the functionality of smart packaging goes beyond merely improving essential functions. It can also respond to stimuli emanating from the packaged product or its surrounding environment, thereby ensuring efficient preservation, protection, facilitating convenience, and enabling communication between various stakeholders in the supply chain, including consumers. The technologies used in smart packaging can be chemical, electrical, electronic, mechanical, or digital network-connected in nature, or a combination of these. Packaging can be categorized into three main types (fig. 2) based on their primary function, the type of technology used, and their interaction with both the content and the users: *active packaging*, *intelligent packaging*, and *interactive packaging* (Lydekaityte & Tambo, 2020; De Kruijf et al., 2002; Ozcan, 2020).

Active Packaging: This type of packaging interacts directly with the product to improve its quality and shelf life. It creates and maintains an optimal internal environment through mechanisms such as absorption (removal of unwanted substances) or release (supply of beneficial compounds).

Intelligent Packaging: Incorporating systems capable of sensing, tracking, and communicating information, intelligent packaging aims to facilitate decision-making, extend shelf life, and improve product safety and quality. Unlike active packaging, it monitors and provides information without directly altering the product. It contains hardware components such as indicators (for time-temperature, freshness, and integrity), sensors (including biosensors, gas sensors, and thermochromic inks), RFID systems, and innovative tags (e.g., QR codes, NFC, WebAR codes, and digital watermarks) that provide additional information when scanned.

Interactive Packaging: This type of packaging actively engages the consumer through design or technology, enhancing their experience and interaction with the product or its functionality. It leverages advances in printed electronics, augmented reality,

3. Preliminary taxonomy of the main technologies used in smart packaging.

IoT, and NFC—along with standardized communication protocols—to create a more dynamic user experience. As Nilsson et al. (2012) noted, interactive packaging can enable digital services that are accessible via the internet, which significally expands design possibilities and application potential, especially through the integration of IoT technologies.

Preliminary research on smart packaging led to an initial taxonomy of technologies used in this field, encompassing *sensors*, *indicators*, *data carriers*, *emitters*, *preservative releasers*, and *other active and interactive systems* (fig. 3). This preliminary taxonomy was developed to facilitate the efficient collection, categorization, and subsequent analysis of case studies. In line with the project's objectives, elements related to active packaging were excluded, limiting the focus to case studies involving intelligent and interactive packaging (i.e., those utilizing digital technologies).

This taxonomy enabled the systematic collection and analysis of some relevant case studies, particularly those focusing on digital solutions for product labeling, tracking, and tracing. A preliminary analysis of these case studies is presented below.

Tab. 1. Preliminary collection and analysis of case studies.

#	Project Name	Type	Description	Country	Reference Link
1	The Lime Loop	Temperature Sensor, Motion Sensor, Geolocation, Packaging	Reusable packaging allows for real-time tracking of dispatched parcels and can be returned for further use after delivery	United States	https://thelimeloopshop.com/
2	Living Packets	Motion Sensor, Temperature and Humidity Sensor, Geolocation, Integrity Indicator	This sturdy, reusable box made from expanded polypropylene features a code-activated closure, ensuring secure delivery. Real-time tracking is available, and the box can be reused for future shipments	France	https://livingpackets.com
3	Flagship Tracker	Motion Sensor, Temperature and Humidity Sensor, Geolocation, Integrity Indicator	A device placed inside parcels for shipping large items. It monitors various parameters during transit, including location, temperature, humidity, impacts, and product orientation	Australia, India, Germany, USA	https://globalcoldchain.com/en/product/flagship-tracker/

4	R Collective and Avery Dennison	QR Code	Avery Dennison, collaborating with The R Collective and Levi's, introduced eco-friendly labels with QR codes for their "Denim Reimagined" collection. These labels offer consumers access to garment information and sustainability messages	Worldwide	https://apparelsolutions.averydennison.com/
5	Sheep inc	NFC	An NFC-enabled label attached to wool textiles allows customers to virtually experience the origin of the wool in New Zealand	New Zealand	https://eu.sheepinc.com/
6	Trimco Group	Motion Sensor, Temperature and Humidity Sensor, Geolocation, Integrity Indicator	Trimco Group specializes in RFID technology for branding and supply chain traceability. Their RFID tags and labels enable tracking of individual products from production to point-of-sale and beyond, enhancing data reliability and inventory management	France	https://www.trimco-group.com/
7	Atma.io.	Motion Sensor, Temperature and Humidity Sensor, Geolocation, Integrity Indicator	This platform assigns unique digital IDs to products, enabling end-to-end transparency by tracking and managing every event throughout a product's lifecycle, from source to consumer and beyond, promoting circularity	France	https://www.atma.io/

3. A taxonomy of smart solutions for advanced packaging design

The investigation of the different smart packaging types and the initial analysis of case studies provided crucial insights for developing a comprehensive overview of existing digital solutions as an essential conceptual framework for the project. The preliminary exploration led to the creation of a standardized data collection and classification system, which facilitated the development of a more detailed taxonomy of technologies currently employed in packaging. This framework, in turn, served as the basis for the creation of an expanded catalog of case studies.

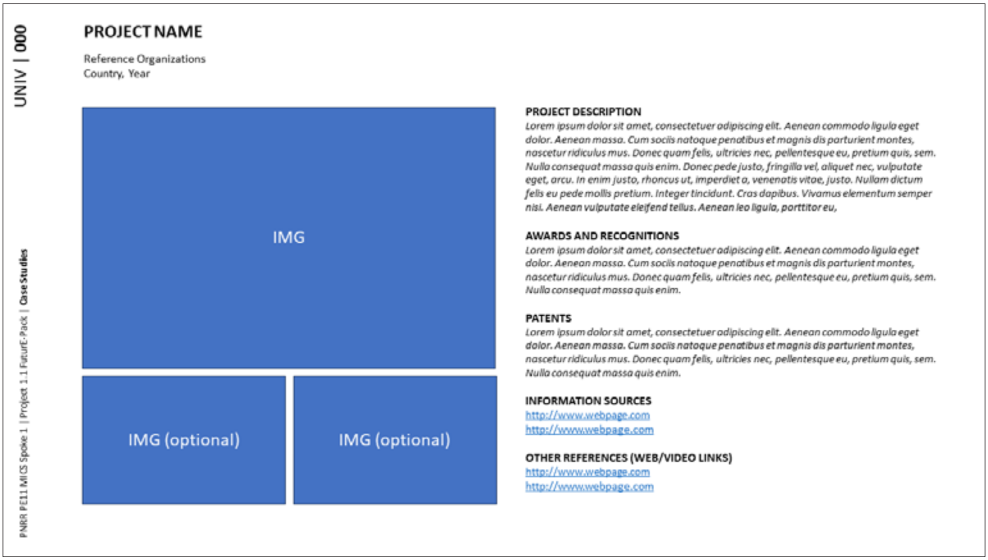
Following the methodology of the Packaging Innovation Observatory (Ciravegna, Pletto, & Pasini, 2024; Giardina, 2024), the research process involved the investigation, mapping, interpretation, and collection of sector innovations. This was achieved through a design-driven approach, integrating knowledge and expertise from different scientific and technological disciplines. Additionally, relevant documentation, including scientific publications, technical reports, and media related to packaging design, was analyzed to identify current trends.

The monitoring process covered not only packaging solutions but also digital technologies, logistics solutions, and communication projects. While not exhaustive, the case studies on digitally enhanced packaging provide valuable insights into the innovative dynamics at play. To expand the sample and gain a more comprehensive perspective, case studies from the fashion sector that were not directly related to packaging solutions were also included in the analysis. These case studies focused on labels and accessories, identified as key elements among the analyzed products.

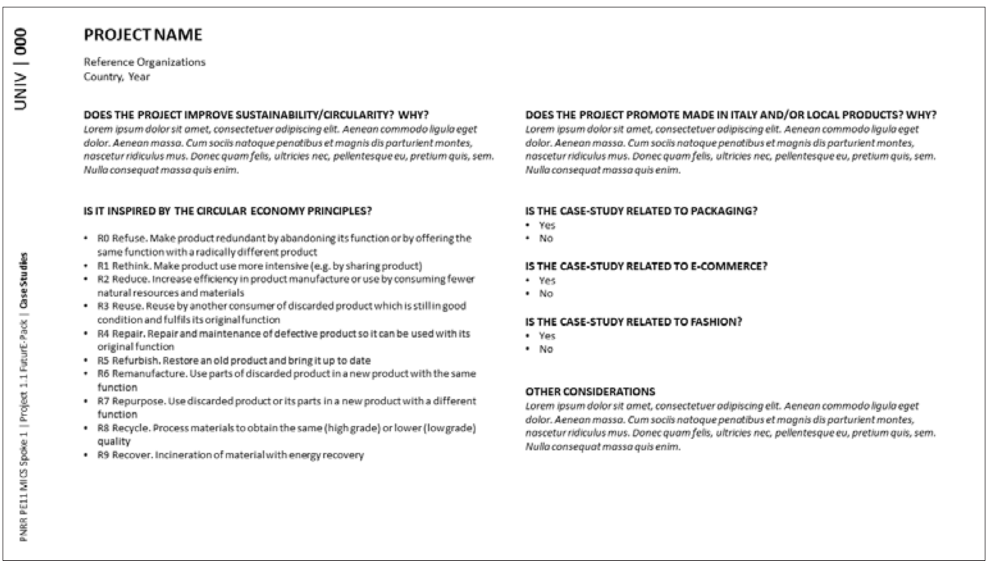
To ensure consistency in the collection and analysis of projects across the three partners, a unified filing system, incorporating a standardized case study template, was developed based on shared criteria. The template includes elements such as the digital systems and technologies employed to perform specific functions, the relationship (direct or indirect) with the promotion of Made in Italy or local products, and the principles of the circular economy addressed in each case study.

The case study template is structured into three main sections. The first section (fig. 4) provides a comprehensive overview of the basic information of the project, including a description, details of any awards and patents, and additional resources for further exploration of the case study.

The second section of the case study template analyzes the project's connection to the project's key themes. It is divided into two parts: the first provides an overview of the case study's sustainability aspects, emphasizing the so-called *9Rs* of the circular economy (Ellen MacArthur Foundation, n.d.); the second examines how Made in Italy is promoted and whether the case study directly relates to packaging, e-commerce channel, or fashion industry.



4. Initial section of the case study template for the filing system.



5. Second section of the case study template for the filing system.

UNIV | 000

PNRR PE11 MICS Spoke 1 | Project 1.1 FuturE-Pack | **Case Studies**

PROJECT

Project Type
- Concept/Prototype
- Pilot Project
- Commercialized Solution

Product/Service Target Market
- B2C
- B2B
- B2B2C

Reference Sector
- Fashion
- Food
- Beverage
- Pet Care
- Childcare
- Stationery / School and office
- Sports / Hobbies
- Arts and Culture
- Tobacco
- Games / Toys
- Cosmetics / Personal Care
- Pharmaceuticals / Health
- Home Care / Household Accessories and Appliances
- Gardening
- Consumer Electronics
- Furniture
- Publishing
- Services
- Construction
- Automotive
- Logistics, Shipping and Delivery
- Industrial Processes and Automation
- Waste Management

DIGITAL SOLUTION

Digital Solution Aim
- Decision-Making Intelligence
- Production and Converting Optimization
- Logistics, Transport and Storage Optimization
- Shelf Planning and Replenishment Facilitation
- Sales Simplification and Dematerialization
- Re-Sales Facilitation
- Waste Disposal Optimization
- User Accessibility Improvement
- User Engagement, Gamification and Reward System
- User Social and Environmental Awareness
- Instructions for Use, Reuse and End-of-Life Management
- Product Characteristics Information / Digital ID
- Brand System Information
- Product Impacts Information
- Environmental Conditions Monitoring
- Product Conditions and Quality Monitoring
- Tracking and Traceability
- Theft Protection
- Counterfeiting Protection

Digital Solution Target Audience
- End-Users
- Companies and Other Supply Chain Actors

DIGITAL SYSTEM

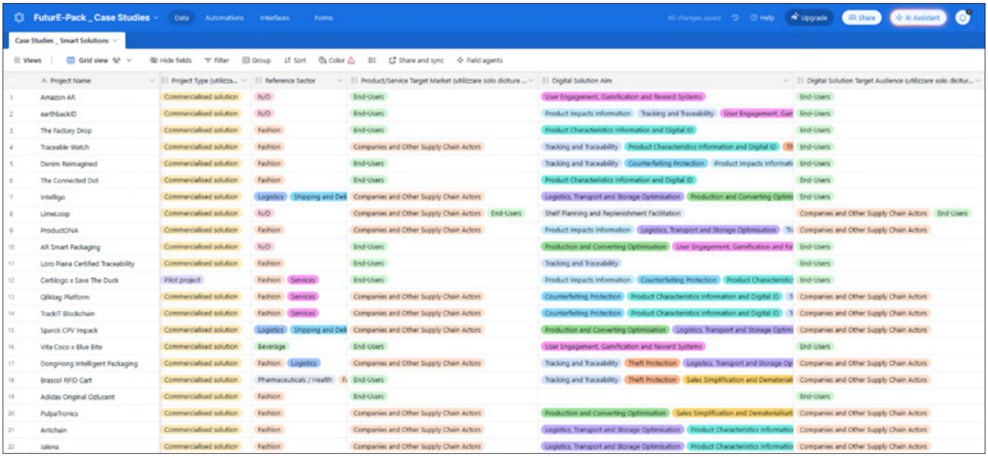
Data Carrier
- Barcodes
- QR-Codes
- RFID Tags
- NFC Tags
- Digital Watermarks
- AR/WebAR Codes
- VR Codes

Indicators
- Time Temperature Indicators (TTIs)
- Freshness Indicators
- Gas Indicator / Gas Leakage Indicators
- Integrity Indicators

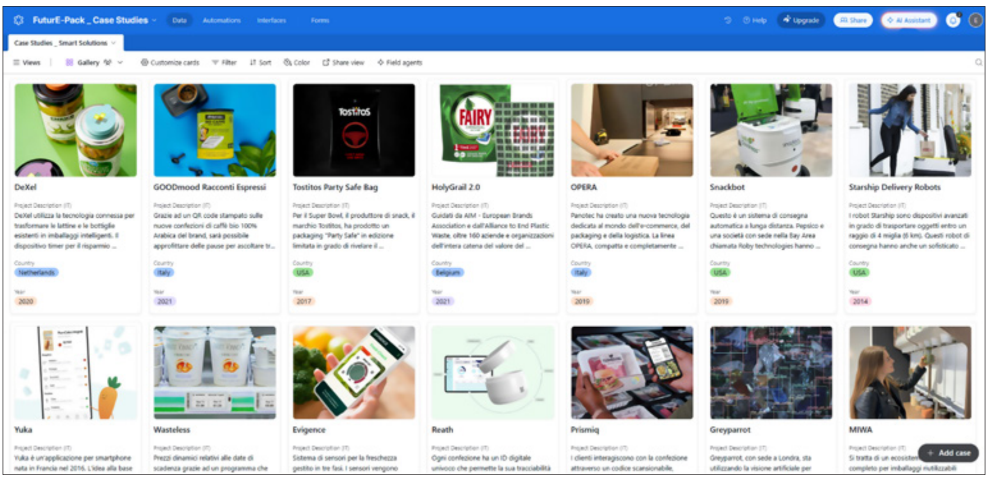
Sensors
- Gas Sensor
- Biosensor
- Chemical Sensor
- Umidity Sensor / Relative Umidity Sensor
- Temperature Sensor / Thermochromic Inks
- Movement Sensor

Other Solutions
- Electronic / Conductive Inks
- Display (LED, E-Paper)
- UHF (Ultra High Frequency)
- GPS / Geolocation
- IoT
- AI / Machine Learning
- Cloud Computing
- Blockchain
- Bluetooth
- RVM (Reverse Vending Machine)

6. Third and final section of the case study template for the filing system.



7. Screenshot of the grid view of the online database (AirTable).



8. Screenshot of the gallery of the online database (AirTable).

9. Totality of the case studied collected and analyzed so far.

The third section provides a comprehensive overview of the digital system central to the case study. It clarifies the system's objective and underlying technological solutions and components. Additionally, it specifies the type of project analyzed, the target market, and the reference product sector.

The collected case studies were organized within an online database (*AirTable*), enabling modular and dynamic data structuring for enhanced management and exploration (figs. 7-8). Cases were also tagged to highlight their innovative aspects and value drivers, which are the key factors contributing to value creation within the project.

The approach prioritizes objective and quantifiable data while incorporating qualitative and narrative elements for a multidimensional analysis, utilizing conceptual grids and tools tailored to the specific analytical needs. The collection process yielded 185 case studies, categorized as follows: 122 related to packaging, 53 to fashion, 55 to e-commerce, 26 to products associated with Made in Italy or local territories, and 64 to environmental sustainability and circularity. These cases were cataloged and underwent in-depth analysis using a research team-developed taxonomy, enabling detailed classification and a deeper understanding of the variables involved.

In-depth analysis and systematization of the case studies resulted in an updated and expanded taxonomy of smart packaging solutions, organized by digital system. Each system includes a reference technology and several subcategories (numbers in parentheses denote distinct typologies within each technology):

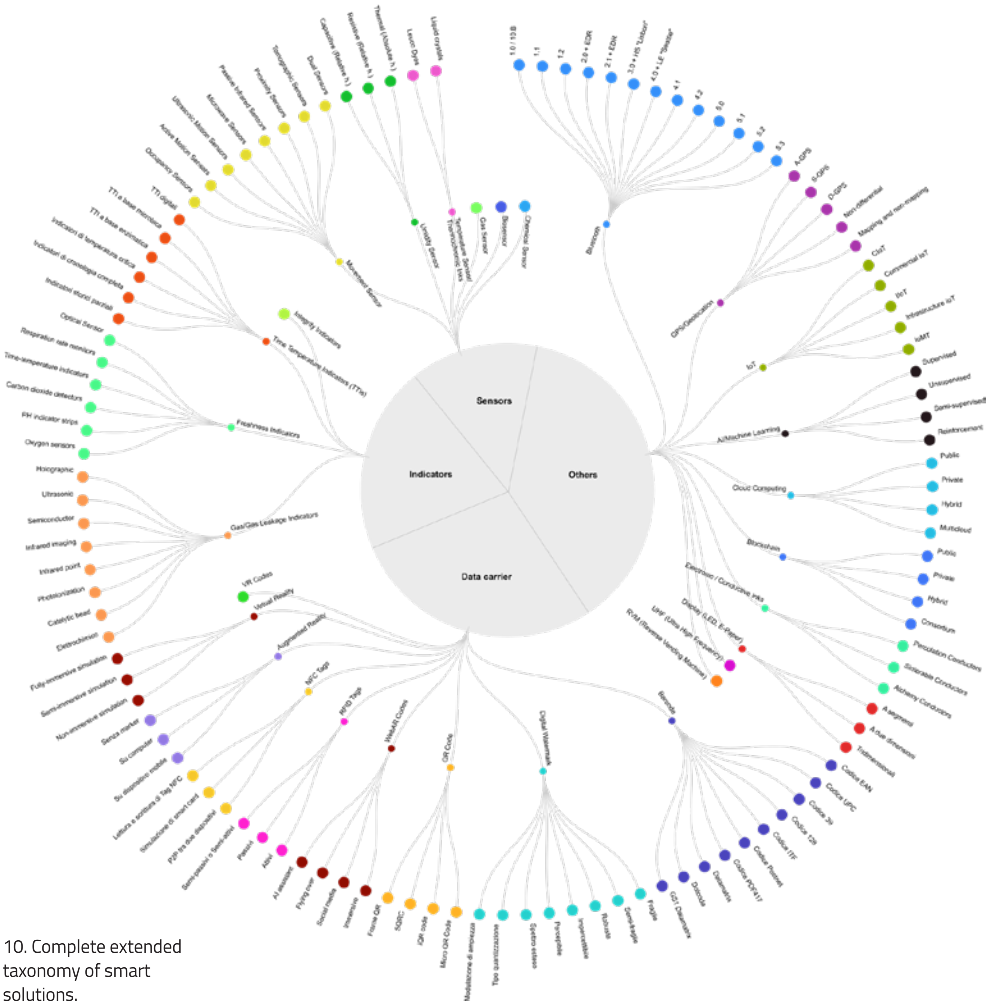
- *Data Carriers*: Barcodes (12); QR-Codes (44); RFID Tags (20); NFC Tags (41); Digital Watermarks (7); AR/WebAR Codes (13); VR Codes (4);
- *Indicators*: Freshness Indicators (12); Gas and Gas Leakage Indicators (1); Integrity Indicators (7); Time Temperature Indicators (7);
- *Sensors*: Gas Sensor (1); Biosensor (2); Chemical Sensor (5); Humidity Sensor (4); Movement Sensor (10); Temperature Sensor / Thermochromic Ink (13);
- *Other Solutions*: Electronic / Conductive Ink (1); Display (LED, E-Paper) (4); UHF (2); GPS / Geolocation (8); RVM (3); Cloud Computing (14); AI / Machine Learning (20); Bluetooth (1); Blockchain (15); IoT (12).

The details of all categories and subcategories are shown in figure 10.

In addition, in response to the requirements identified during case study selection, a *digital solution aims* list was defined, describing the needs and requirements that the solutions aim to satisfy: Decision-Making Intelligence; Logistics, Transport, and Storage Optimization; Shelf Planning and Replenishment Facilitation; Re-Sales Facilitation; Production and Converting Optimization; Sales Simplification and Dematerialization; Waste Disposal Optimization; User Accessibility Improvement; User Engagement, Gamification/Reward System; User Social and Environmental Awareness; Instructions for Use, Reuse, and End-of-Life Management; Product Characteristics Information/Digital ID; Brand System Information; Product Impacts Information; Environmental Conditions Monitoring; Product Conditions and Quality Monitoring; Tracking and Traceability; Theft Protection; Counterfeiting Protection.

4. Conclusions

The integration of smart solutions into advanced packaging presents both significant opportunities and challenges across



10. Complete extended taxonomy of smart solutions.

multiple dimensions. These dimensions include material considerations, device longevity, and wider economic, social, and environmental impacts. While these technologies offer great promise, they also bring with them complexities that require careful consideration, particularly in terms of sustainability.

The material composition and lifespan of smart packaging play a crucial role in determining its overall sustainability. While there are general guidelines for sustainable packaging design (Sustainable Packaging Coalition, 2023), such as minimizing the number of materials used (Coelho et al., 2020;

Eriksen et al., 2019; Lofthouse et al., 2009 cited in Zhu et al., 2022), there remains a distinct lack of comprehensive and detailed design rules. This gap becomes even more pronounced apparent when considering the inherent complexity of integrating technologies into packaging (Barbero & Pereno, 2020). For example, while multi-material packaging is advantageous due to its enhanced functional benefits such as moisture and oxygen barriers, it poses significant economic and technical challenges when it comes to recycling (Sokka et al., 2024). Even when downcycling is possible, it often leads to substantial losses in both material quality and economic value, thereby limiting the potential for a truly sustainable material cycle (Sokka et al., 2024).

Economic viability is another critical factor, especially for small and medium-sized enterprises (SMEs). The significant financial burden associated with developing and implementing intelligent packaging can be a major hurdle. Packaging costs can potentially account for 50% to 100% of the total product cost (Müller & Schmid, 2019). This is a particular challenge in the food industry, where packaging costs are expected to remain below 10% of the total product value (Dainelli et al., 2008). These economic challenges raise concerns about the widespread adoption of intelligent packaging, as smaller companies may struggle to invest in such technologies. This could lead to a widening gap between large corporations and SMEs.

In addition, intelligent packaging presents several social implications, including potential changes in consumer behavior and the widening of the digital divide. While data carriers like QR codes are widely used due to their low cost and ease of use, more sophisticated sensors and indicators are not yet as widespread due to their higher costs (Müller & Schmid, 2019). Such technologies may also negatively impact consumer perceptions, potentially leading to increased food waste if consumers avoid products displaying discolored freshness indicators, even if the product remains safe for consumption (Müller & Schmid, 2019). Moreover, concerns regarding privacy and data generation by intelligent packaging may deter consumers who are increasingly wary of digital surveillance implications.

Another significant concern is the environmental impact. Although smart packaging can potentially reduce food waste by optimizing inventory management and extending product shelf life, it also presents challenges related to material use and waste generation. The production of smart packaging often necessitates additional materials, potentially compromising sustainability goals by increasing resource consumption and waste generation (Müller & Schmid, 2019). Furthermore, the recyclability of these materials, particularly in multi-material packaging, poses a significant challenge, as it is often not economically viable to recycle (Sokka et al., 2024). The most significant applications of smart packaging technologies are evident in the pharmaceutical and food industries, as demonstrated by the collected case studies. These sectors have adopted smart packaging primarily for its clear advantages, including enhanced product safety, reduced waste, and improved supply chain traceability. However, despite these benefits, challenges persist regarding cost, material complexity, and consumer perception (Müller & Schmid, 2019; Dainelli et al., 2008). Nevertheless, this concentrated application within specific industries also highlights a significant opportunity for broader adoption of digital packaging technologies across other sectors. Integrating smart packaging could prove highly beneficial for sectors such as cosmetics or clothing, ensuring product integrity, enhancing the user experience, and providing real-time data on product conditions. The expansion of smart packaging into these novel domains has the potential to stimulate innovation and generate new business models, especially for companies looking to differentiate their products and contribute to a more sustainable and efficient global supply chain.

References

Barbero & Pereno, 2020
Barbero, S., & Pereno, A. (2020). *Packaging design in the digital age: A systemic approach to e-commerce*. Franco Angeli.

Brockgreitens & Abbas, 2016
Brockgreitens, J., & Abbas, A. (2016). Responsive food packaging: Recent progress and technological prospects. *Comprehensive Reviews in Food Science and Food Safety 15*(1): 3–15. https://doi.org/10.1111/1541-4337.12174

Ciravegna, 2010
Ciravegna, E. (2010). *La qualità del packaging*. Franco Angeli.

Ciravegna, 2017
Ciravegna, E. (2017). Diseño de packaging. Una aproximación sistémica a un artefacto complejo. *RChD: Creación y Pensamiento*, *2*(3), 1–17. https://doi.org/10.5354/0719-837X.2017.47825

Ciravegna, Pletto & Pasini, 2024
Ciravegna, E., Pletto, D., & Pasini, V. (2024). Desarrollo de métodos y herramientas para la industria del envasado: El papel mediador y facilitador del diseño. *Cuadernos del Centro de Estudios de Diseño y Comunicación*, *233*. https://doi.org/10.18682/cdc.vi233.11424

Coelho et al., 2020
Coelho, P. M., Corona, B., Ten Klooster, R., & Worrell, E. (2020). Sustainability of reusable packaging–Current situation and trends. *Resources, Conservation & Recycling: X*, *6*, 100037. https://doi.org/10.1016/j.rcrx.2020.100037

Dainelli et al., 2008
Dainelli, D., Gontard, N., Spyropoulos, D., Zondervan-van den Beuken, E., & Tobback, P. (2008). Active and intelligent food packaging: legal aspects and safety concerns. *Trends in Food Science & Technology*, *19*, S103–S112. https://doi.org/10.1016/j.tifs.2008.09.011

Ellen MacArthur Foundation, n.d.
Ellen MacArthur Foundation. (n.d.). *Circular economy introduction*. Ellen MacArthur Foundation. https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Eriksen et al., 2019
Eriksen, M. K., Damgaard, A., Boldrin, A., & Astrup, T. F. (2019). Quality assessment and circularity potential of recovery systems for household plastic waste. *Journal of Industrial Ecology*, *23*(1), 156–168. https://doi.org/10.1111/jiec.12822

European Commission, 2020
European Commission. (2020). *A new circular economy action plan for a cleaner and more competitive Europe*. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

European Commission, 2022
European Commission. (2022). *Proposal for a regulation of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0677

Giardina, 2024
Giardina, C. (2024). *Advanced design for the extended packaging system. Piattaforma di servizi R&I per supportare una innovazione circolare e sostenibile negli imballaggi*. [Doctoral dissertation, Alma Mater Studiorum - Università di Bologna].

Kirchherr, Reike & Hekkert, 2017
Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kruijf et al., 2002
Kruijf, N. D., Beest, M. V., Rijk, R., Sipiläinen-Malm, T., Losada, P. P., & Meulenaer, B. D. (2002). Active and intelligent packaging: applications and regulatory aspects. *Food Additives & Contaminants*, *19*(S1), 144–162. https://doi.org/10.1080/02652030110072722

LaBerge et al., 2020
LaBerge, L., O'Toole, C., Schneider, J., & Smaje, K. (2020, October 5). *How COVID-19 has pushed companies over the technology tipping point–And transformed business forever*. McKinsey & Company. https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever

Lao, Etrati & Narsalay, 2022
Lao, M., Etrati, A., & Narsalay, R. (2022, March 3). *Reinventing packaging*. Accenture. https://www.accenture.com/in-en/insights/industry-x/reinventing-packaging

Lichtenthaler, 2021
Lichtenthaler, U. (2021). Digitainability: The combined effects of the megatrends digitalization and sustainability. *Journal of Innovation Management*, *9*(2), 64–80. https://doi.org/10.24840/2183-0606_009.002_0006

Lofthouse, Trimingham & Bhamra, 2017
Lofthouse, V., Trimingham, R., & Bhamra, T. (2017). Reinventing refills: Guidelines for design. *Packaging Technology and Science*, *30*(12), 809–818. https://doi.org/10.1002/pts.2337

Lydekaityte & Tambo, 2020
Lydekaityte, J., & Tambo, T. (2020). Smart packaging: Definitions, models and packaging as an intermediator between digital and physical product management. *The International Review of Retail, Distribution and Consumer Research*, *30*(4), 377–410. https://doi.org/10.1080/09593969.2020.1724555

Marrone & Raimo, 2021
Marrone, A., & Raimo, N. (2021). *Sostenibilità e digitalizzazione, un approccio economico-aziendale*. Giuffrè.

Moghrabi et al., 2023
Moghrabi, I. A. R., Bhat, S. A., Szczuko, P., AlKhaled, R. A., & Dar, M. A. (2023). Digital transformation and its influence on sustainable manufacturing and business practices. *Sustainability*, *15*(4), 3010. https://doi.org/10.3390/su15043010

Müller & Schmid, 2019
Müller, P., & Schmid, M. (2019). Intelligent packaging in the food sector: A brief overview. *Foods*, *8*(1), 16. https://doi.org/10.3390/foods8010016

Nandanwade Priyanka & Nathe Parag, 2013
Nandanwade Priyanka, C., & Nathe Parag, D. (2013). Intelligent and active packaging. *International Journal of Engineering and Management Sciences*, *4*(4), 417–418. http://scienceandnature.org/IJEMS-Vol4(4)-Oct2013/IJEMS_V4(4)2013-2.pdf

NILSSON et al., 2012
Nilsson, H.-E., Unander, T., Siden, J., Andersson, H., Manuilskiy, A., Hummelgard, M., & Gulliksson, M. (2012). System integration of electronic functions in smart packaging applications. *IEEE Transactions on Components, Packaging and Manufacturing Technology*, *2*(10), 1723–1734. https://doi.org/10.1109/TCPMT.2012.2204056

OZCAN, 2020
Ozcan, A. (2020). New approaches in smart packaging technologies. In *Proceedings of the 10th International Symposium on Graphic Engineering and Design, GRID* (pp. 21–37). https://doi.org/10.24867/GRID-2020-p1

PALAZZO, VOLLERO & SIANO, 2023
Palazzo, M., Vollero, A., & Siano, A. (2023). Intelligent packaging in the transition from linear to circular economy: driving research in practice. *Journal of Cleaner Production*, *388*, 135984. https://doi.org/10.1016/j.jclepro.2023.135984

PURVIS, MAO & ROBINSON, 2019
Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. *Sustainability Science*, *14*(3), 681–695. https://doi.org/10.1007/s11625-018-0627-5

SCHAEFER & CHEUNG, 2018
Schaefer, D., & Cheung, W. M. (2018). Smart packaging: opportunities and challenges. *Procedia Cirp*, *72*, 1022–1027. https://doi.org/10.1016/j.procir.2018.03.240

SOKKA et al., 2024
Sokka, L., Välimäki, M., Väisänen, K. L., Keskinen, J., Hakola, E., Mäntysalo, M., Ollila, J., Happonen, T., Hakola, L., & Smolander, M. (2024). Life cycle assessment of a new smart label for intelligent packaging. *Flexible and Printed Electronics*, *9*(1), 015007. https://doi.org/10.1088/2058-8585/ad2279

SUSTAINABLE PACKAGING COALITION, 2023
Sustainable Packaging Coalition. (2023). *Definition of sustainable packaging*. https://sustainablepackaging.org/wp-content/uploads/2024/01/SPC_Definition-of-Sust-Packaging_Landscape.pdf

ZHU, 2022
Zhu, Z., Liu, W., Ye, S., & Batist,a L. (2022). Packaging design for the circular economy: A systematic review. *Sustainable Production and Consumption*, *32*, 817–832. https://doi.org/10.1016/j.spc.2022.06.005