



Review

Sustainability in e-commerce packaging: A review

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ABSTRACT

Online purchasing, and hence e-commerce packaging production and use, have grown steadily in recent years, and so has their environmental impact as a result. This paper reviews the evolution of packaging over the last century through a compilation of scientific literature on e-commerce packaging focusing on its environmental side. The primary aims were to identify research gaps in e-commerce packaging and to propose new research lines aimed at reducing its environmental impact.

A systematic search of abstracts was conducted to identify articles dealing with sustainability in e-commerce packaging in order to better understand changes in materials and formats, identify problems such as oversizing and allow prospective readers to become acquainted with the latest innovations in materials, sustainability and logistics.

Based on existing research, packaging materials and technology evolved rapidly until the 1990s. Later, however, it has become increasingly difficult to further reduce their cost and environmental impact. Also, some packaging products continue to be made from non-renewable materials and thus restrict growth of e-commerce. Further research is needed with a view to producing new packages from renewable sources such as cellulose-containing materials, which are widely available in nature, or from recycled cellulose-based materials such as cartonboard. Improving distribution processes with new, more effective tools could additionally help alleviate the environmental impact of packaging. Similarly, new production processes such as additive manufacturing and 3D printing might help optimize package volume and shape, thereby facilitating more sustainable production through, for example, reduced CO₂ emissions. Currently available technology can be useful to rethink the whole e-commerce packaging paradigm, which has changed very little over the past few decades.

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Abbreviations

APS	Automated Parcel Stations
PP	Pick-up Points
FFP	Frustration-Free Packaging
ISTA	International Safe Transit Association

Materials

PET	Polyethylene terephthalate
HPDE	High-density polyethylene
EPS	Expanded polystyrene
PP	Polypropylene
NC	Nanocellulose

Technology

AI	Artificial Intelligence
IoT	Internet of Things

1. Introduction

E-commerce continues to grow every year in many developed countries. Analysts have recently predicted that its market penetration will have increased by up to 25% by the year 2026 (Taylor, 2019). This prediction is consistent with the fact that the proportion of online purchases rose from 32% ISO, 2015, where 20 billion packages were shipped, to 43% in 2018 (Eurostat, 2018; Monnot et al., 2019; Zhou, 2016). As shown by some consumer studies (Pålsson, 2017; Rizet et al., 2010), this trend has had an adverse impact on the environment in the form of increased CO₂ emissions and energy use. Although an increasing number of customers now prefer online buying because it is more convenient, the favourable or adverse effects of e-commerce on the environment remain uncertain. Thus, the Covid-19 pandemic has boosted online shopping (Kim, 2020) by, for instance, forcing many physical stores to start selling online—a trend that is unlikely to be reversed in the future. There have been substantial changes in the purchasing behaviour of consumers, many of whom have bought something online for their first time during the pandemic. Many are expected to continue shopping online—at least until an effective vaccine for SARS-CoV-2 is found—through fear of being infected at large malls (Organization, 2020).

Research into the environmental impact of e-commerce and traditional in-store shopping have revealed that, for example, brick and mortar retailing (i.e., buying at physical stores) can reduce CO₂ emissions by up to 70% (Cairns, 2005; Liyi, 2011; Van Loon et al., 2015; Wiese, 2012) or even 84% in some cases (Carling, 2015). Based on available data, e-commerce is an effective choice for non-urban delivery over long distances (Morganti et al., 2014; Moroz,

2016; Wang and Zhou, 2015) as it avoids using private means of transport to reach urban areas, which is where malls are usually located. The main problem as regards delivery in urban cities arises in the 'last mile', where a number of factors including package type, material and size, and consumer behaviours, are all major contributors to carbon emissions (Manerba et al., 2018; Van Loon et al., 2015; Visser, 2014; World Economic Forum, 2017).

The fact that packaging materials have a direct impact on energy use—and hence on logistics and waste production—is arousing increasing concern (Fichter, 2003; Pålsson, 2017, 2013; Shvarts, 2019; Sivaraman, 2007; Wikstrom, 2010). As can be seen from Fig. 1, producing the amount of packaging needed for one person's weekly consumption of food (viz., 10% of the supply chain energy) requires using a large amount of energy (Kooijman, 2009). Package weight and volume are also important because they influence energy use for transport.

Overall, existing studies highlight the need to develop packaging solutions based on alternative materials to ensure that energy is efficiently used and waste reduced. Overpackaging continues to result in overuse of materials and energy, and thus influences the impact of production and transportation processes (Lu et al., 2020; Monnot et al., 2019).

Customer satisfaction is the last link in the e-commerce chain (Elgaaied-Gambier et al., 2018; Yu, 2016). According to García et al. (2019), 71% of e-customers would shop online again if they were awarded premium packaging. Companies should therefore improve consumers' experience through functional, aesthetic presentation of packages, and preservation of their brand image. Moreover, they should strive to control the direct and indirect environmental impacts of their packages through green messages. For example, Tu

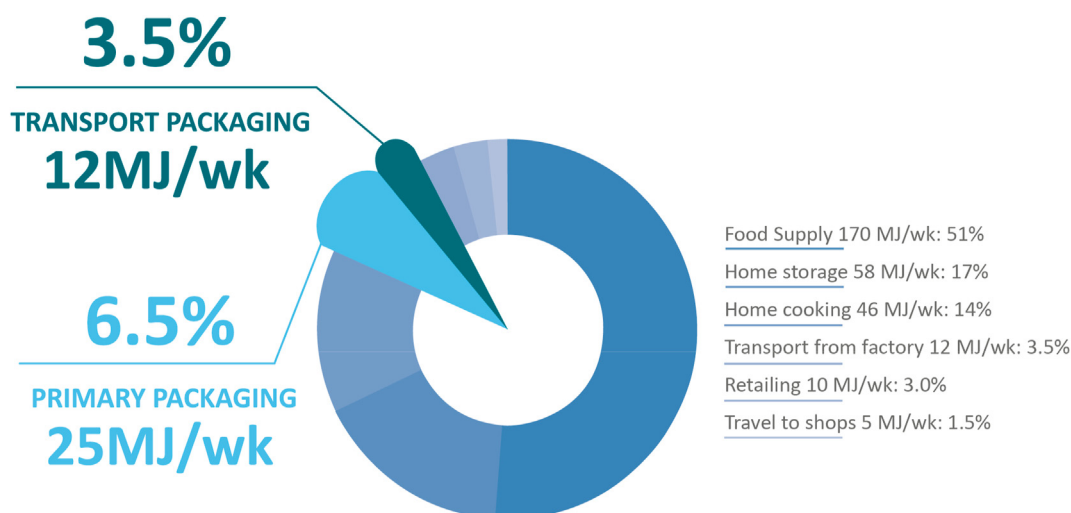


Fig. 1. Amount of energy needed, in MJ, for one person's weekly consumption of food. Adapted from (Kooijman, 2009).

et al. (2018) found 67.75% of manufacturers to provide incorrect recycling information and Choice (2010) found 98% of labels to be false or the result of greenwashing practices intended to deceive customers. Some authors (Breugelmans, 2007; Monnot et al., 2019) have examined changes in online consumer behaviour and attached less importance to the visual graphics of products. Marketing mix strategies (particularly communication and advertising approaches) are gaining increasing ground because dealers are increasingly perceiving the needs to provide adequate, accurate product information and to grant prospective buyers access to previous customers' opinions. A shift in focus from information about physical products to information about online products is clearly in order if designers and manufacturers are to reduce the need for packaging materials.

This paper is organized as follows: Section 2 describes the methodology used. Section 3 deals with the evolution and state of the art in packaging by first examining primary sources of literature on its history and economic changes, and then analysing sustainable packaging and how specific materials and new ways of thinking can advantageously replace current choices. Section 4 depicts today's e-commerce scenario and e-commerce packaging alternatives. Some points are illustrated with specific cases to help readers understand the advantages and disadvantages of existing approaches. Section 5 discusses the most salient representative innovations in e-commerce packaging on a global scale for easier understanding of the new paradigms in its materials and logistics. Finally, several conclusions are drawn and suggestions for future research made.

2. Methods

This work is a systematic review based on the suggestions of Ferrari (2015), Nsanzumuhire and Groot (2020), Tranfield et al. (2003), and Vom Brocke et al. (2009). It is based in the following steps:

2.1. Identification of relevant literature

A methodical database search was performed to compile a body of articles based on the relevance of their abstracts and the reputation of their authors.

As shown in Fig. 2 and Table 1, the main databases searched were Google Scholar and Elsevier Scopus, which are among the

largest directories of scientific papers, books and congress reports. The academic database DiscoveryUPC¹ Server, which is a content search engine of all the databases to which UPC is subscribed and includes UPC's own resources (books, magazines, articles, doctoral theses, conferences, videos), was also searched. This process allowed ethical downloading of articles, and the software Mendeley facilitated their filtering and organization. The criteria established to select the published articles were based on the following strategies: (1) relevant issues (e-commerce, history of packaging, circular economy, packaging materials, new paradigms, last innovations); (2) chronological order (from late 19th century to 2020); (3) issues and challenges.

Keywords included in this search were: e-commerce and consequences, packaging, sustainability, cellulose based-materials, circular economy, additive manufacturing and robots. See more details attached in Table 1.

2.2. Screening and selection of studies included

From the first selection of relevant literature, the abstracts were evaluated and read to order full articles assessed for eligibility. Studies on any type of packaging (food, cosmetics, cleaning products, etc.) and studies dealing with the latest innovations in e-commerce technology and sustainability were included irrespective of author name and whether the journals were indexed. There was no exclusion in terms of geographical area. Articles whose abstracts were irrelevant to points such as packaging evolution (materials, innovation, shapes, sustainability) or whose contents were redundant, were excluded. Papers written in a language other than English or Spanish were excluded.

After excluding the number of references a total of 305 articles were assessed for eligibility.

163 articles were finally deemed especially relevant to the target subject matter as it indicates in Fig. 2, the flow chart of the search procedure. The following 'Results' section introduces the results from these publications.

2.3. Data extraction

The authors extracted data from the articles included in the

¹ DiscoveryUPC: www.discoveryupc.edu.

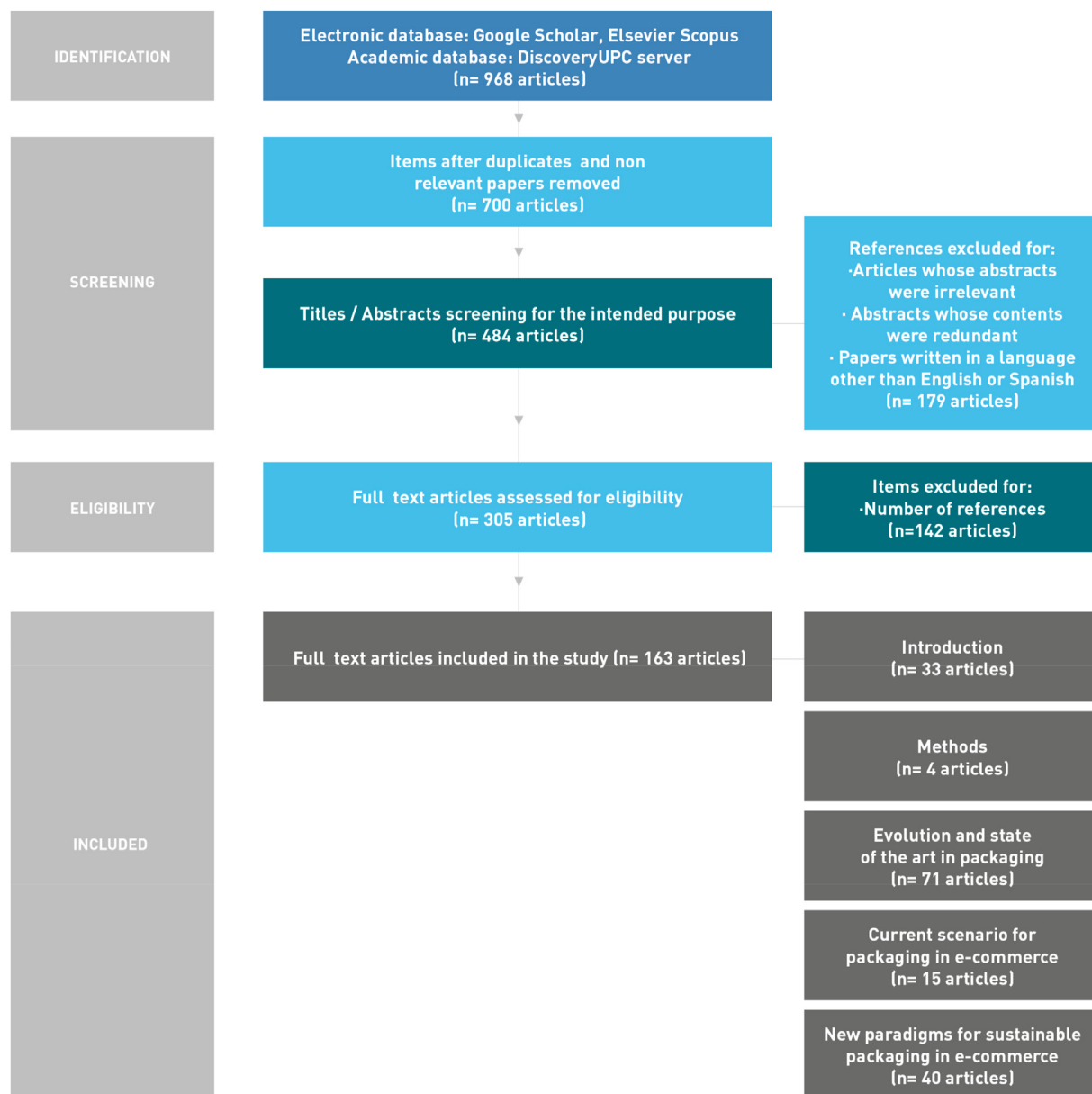


Fig. 2. Flow chart of literature review process.

study, showed in Fig. 2, identifying: (1) e-commerce and consequences (GHG emissions, last mile, e-commerce vs. physical stores, waste material after package use, returns); (2) packaging evolution through the last times (60's, 90's, 00's, materials and shapes, new innovations in packaging sector); (3) packaging and e-commerce (references framework, green packaging, materials efficiency in packaging for e-commerce; (4) new paradigms and new challenges (new logistics systems as customers pick up, drones and robots, and cellulose-based materials).

2.4. Quality assessment

This review is based on the following qualitative criteria:

- To ensure the quality of the articles, searches were performed for particularly relevant authors publishing in high ranked journals (Q1 and Q2).

- The consistency of the results of this study is based on the solid evidence found in high quality works. Common data and perspectives found in 70–80% of the revised papers were considered to be reliable.
- From each article read, the most relevant data were extracted, critical assessment and saved in a document for easy identification: title, abstract, date, keywords, relevant data and contribution to the study (quality of results, limitations, methods, interpretations of the results, impact of the conclusions for the study)

Furthermore, the following questions were used to select the publications:

- Does the publication discuss the problems, obstacles or challenges of e-commerce and sustainability?
- Does the publication analyse in detail the evolution of packaging, both in terms of materials and form?

Table 1

Methodology: key words, period considered, and academic databases of the three core sections in the manuscript.

	Section 3. Evolution and state of the art in packaging	Section 4. Current scenario for packaging in e-commerce	Section 5. New paradigms for sustainable packaging in e-commerce
Keywords	'Packaging' 'modern packaging' 'history of packaging' 'packaging and materials' 'sustainability and packaging' 'edible packaging' 'packaging and last mile' 'sustainability' 'circular economy'. A total of 314 papers were selected of which 71 are cited. The keywords were used to ensure that articles dealing with the target topics would be identified.	'Global e-commerce' 'e-commerce and market distribution' 'disruptive packaging' 'e-commerce packaging materials'. This search retrieved 98 papers. The aim was to identify papers dealing with these subjects from their title and abstract. A total of 15 articles among those retrieved were finally cited.	'New paradigms in logistics' 'new paradigms in 3d printing' 'last innovations in logistics' 'last innovations in cellulose materials' 'last innovations in additive manufacturing'. This search retrieved 57 potentially relevant papers judging by their title and abstract of which 40 are cited here.
Period considered	Late 19th century to 2019	XXI century (2000–2020), where e-commerce has gained increasing importance.	2014 to 2020 to illustrate the latest innovations in logistics and materials.
Academic databases	Google Scholar, Elsevier Scopus and Academic database DiscoveryUPC server.		
Timeline of investigation	October 2018 to October 2019	January 2019 to May 2020	The scarcity of articles on referenced logistics journals prompted a search for papers published in non-indexed journals from June 2019 to May 2020.

- Does the publication analyse individuals or companies that contribute new developments in materials or packaging?
- Does the publication discuss if these developments are really positive contributions to the problems of e-commerce?
- Does the publication analyse new opportunities in logistics and new materials?

Additionally, the applied methodologies were analysed. All articles with unreliable data were excluded as unsuitable for quality reasons.

2.5. Data synthesis

The core of this paper comprises the following sections: (3) Evolution and state of the art in packaging; (4) Current scenario and packaging in e-commerce and (5) New paradigms for sustainable packaging in e-commerce. Table 1 summarizes the methodological aspects of the investigation including keywords, periods of time and databases used to acquire the information. The table includes the content analysis procedure followed to extract relevant information of the qualitative type (e.g., quartile ranking of the journals) and quantitative type (basically, the topics dealt with in the articles).

3. Results

3.1. Evolution and state of the art in packaging

This section examines changes in packaging since 1880 with emphasis on the materials used in recent decades, and on their economic and environmental impact. Also, it shows how sustainable packaging has improved, not only as regards aesthetics, in the meantime. In addition, it uses several case studies to assess the strengths and weaknesses of sustainable packaging initiatives following Circular Economy.

3.1.1. Evolution of packaging: materials, formats and latest innovations

The timeline in Fig. 3 summarizes the history of packaging since the late 19th century. Design historians have deemed the period from 1880 to 1900 the beginning of modern packaging. This period brought about new concepts such as mass marketing and mass production, which ran in parallel with the opening of the earliest supermarkets with their associated low prices and high volumes, as

well as with the notion of strategic advertising in the same pack (Twede, 2012). According to some authors (Piselli, 2016; Schleger, 1968), this revolution changed consumption habits, promoted new ways of mechanizing production, facilitated the spread of supermarkets and even brought economic benefits to packaging manufacturers and consumers. The packaging materials largely used in the period 1880–1900 were paperboard folding carton, tin and glass, mechanization of which allowed vast amounts of packages to be produced (Piselli, 2016; Twede, 2012). The advantages cartonboard boxes provided to customers gradually increased the market share of many industrial sectors. In fact, according to Davis (1967), patents on up to 800 different types of boxes were filed in this early period.

The scarcity of materials during the Second World War (1939–1945) led to their preferential use for making war-related products that were sent to soldiers in battle. This left the general population lacking in resources. Packages were then largely made from steel (shipping containers), tin (cans), glass (bottles), paper (containers), kraft paper (bags), cloth (bags) or wood (boxes) (Risch, 2009; Schleger, 1968; Sheldon, 1944). In that time of shortage, people preferred to pay few cents more for products held in high-quality, reusable containers such as glass bottles.

The 1950s witnessed a boom in marketing and communication through packaging; however, they also started an age of waste-related problems and shorter product life cycles (so-called 'planned obsolescence'; Jorgensen, 2013). Packaging was then almost more important than the products themselves —so much so that James Pilditch called it 'the silent salesman' (Cheskin, 1957; Maffei and Schifferstein, 2017; Opie, 1991; Pilditch, 1963; Piselli, 2016; Vilnai-Yavetz, 2013). A new age of self-service in supermarkets then began that allowed consumers to stock up products faster and without waiting to be served (Quinn, 2001). At that point, it was necessary to understand consumers' needs and to apply marketing mix techniques such as market research, merchandising and advertising to better fulfil them (Cheskin, 1957; Kotler, 2010; Quinn, 2001; Silayoi and Speece, 2007; Vilnai-Yavetz, 2013).

Until the 1960s, packaging materials had remained essentially unchanged because marketing departments and designers had focused on shape, colour and size to ensure optimal viewing of products on the shelves (Cheskin, 1957; Silayoi and Speece, 2007; Vilnai-Yavetz, 2013). Louis Cheskin, an innovative marketing person and psychologist, coined the concept 'sensation transference' and provided experimental evidence for the need to arouse people's emotions through the aesthetics of packaging design. This meant



Fig. 3. Packaging timeline.

that packages should not focus on aesthetic values such as shape, size, colour or graphics to attract customers' attention, but rather on assigning values of the products to their packages so that customers would be able to discriminate between the two (Cheskin, 1957).

The 1960s, 1970s have been deemed the golden age for advances in technology and space travel. The advances included the production of new materials such as vapour- and water-proof plastics, aluminium and adhesives to cater for the needs of the packaging industry. Although the earliest plastics (e.g., John Wesley Hyatt's celluloid) were discovered in the 19th century, they were not used for packaging until the 1960s and 1970s (Wudl, 2014) because of their high combustibility and short lifetime. At the time, plastic was the main material for all types of packaging because it was easily pliable in different shapes, durable, hygienic, flexible and inexpensive. Polyethylene and polyethylene terephthalate (PET) were the most widely used materials in water bottles and plastic bags (Opie, 1991; Risch, 2009).

Scientific and technological advances fortunately led to a more humanistic approach. Thus, materials can now be scrutinized at deeper levels such as those afforded by nanotechnology. In fact, scientists have shown that some nanoscale materials can adapt themselves to many other materials and enhance their properties to unbelievable levels as a result (Doordan, 2003; Leydecker, 2008; Watson, 2001). The term 'nanotechnology' was coined by the Japanese scientist Norio Taniguchi at a conference of the Japanese Precision Engineering Society in 1974. Nanotechnology can be very useful to understand the physical, chemical and biological properties of materials at a very small scale (Leydecker, 2008; Martín-Gago et al., 2014).

The concept of sustainability emerged in 1980. For humans to continue to enjoy nature, it was deemed essential to be aware that the amount of fossil resources available for manufacturing materials was limited, and also that greenhouse gas (GHG) emissions from transport and other human activities had adverse effects (Doordan, 2003; Jorgensen, 2013; Lyla and Seevakam, 2018; Manzini, 1994; Rizet et al., 2010; Shvarts, 2019; Watson, 2001). In 1997, Pira International devised new rules for packaging in the 21st century. Previously, the EU Directive on Packaging and Packaging Waste (94/62/EU) (European Parliament, 1994) had taken several steps to control packaging waste and foster the recycling concept (Sturges, 2000). The goal was to recover 50–65% of all packaging waste and recycle 25–45% of all packaging by 2001. This directive was amended in 2008 (European Parliament, 2008) to add 'new recycling and recovery targets to be achieved by 2020: 50% preparing for re-use and recycling of certain waste materials from households and other origins similar to households, and 70% preparing for re-use, recycling and other recovery of construction and demolition waste' (European Commission, 2008).

Based on a survey conducted by Cone Communications in 2014, 77% of consumers were being more environmentally conscious and taking action with better choices when shopping at supermarkets. In fact, many consumers were willing to pay an additional 10% over the usual price for a sustainable container (Hitchin and Bittermann, 2018; Kotler, 2018; Lindh, 2016). On the other hand, customers buying online were unaware of the need for sustainability; rather, they prioritized other, more appealing variables such as price, volume and time of delivery (Monnot et al., 2019; Shvarts, 2019).

European Commission, 2015 the European Union revised the legislation again under the concept 'Circular Economy Package' and made new proposals that all member countries of the European Commission were to adopt by 2030, namely: at least 65% of municipal waste and 75% of packaging waste should be recycled, and municipal landfill volume should be reduced by at least 10%.

The packaging sector clearly needs research and production of

emerging materials as alternatives to plastic and fossil-based materials. One form of evidence is the presentation of existing choices such as edible and cellulose-based materials on the market (Janjarasskul and Krochta, 2010). Classified edible materials as proteins, polysaccharides, lipids and resins. Proteins from wheat, soy, milk and corn are used to improve optical and mechanical properties, while polysaccharides such as cellulose derivatives, starch, chitin, pectin and alginate are meant to improve gas-barrier and mechanical properties. Lipid materials such as glycerol, wax and resins added to composite materials act as moisture-protective films (Janjarasskul and Krochta, 2010). For instance, Notpla's Ooho is a seaweed-based material used as edible bubbles of water intended to replace plastic bottles. Kombutcha, which is obtained by fermentation of tea sugars, is one other alternative edible material. Because it generates no waste, the biodesign company MakeGrowLab has deemed it very useful for packaging (Shvarts, 2019).

According to Carlin (2019), sustainability in e-commerce can be accomplished by favouring the use of paper and paperboard materials for packaging. In this line, Mirjam de Bruijn has developed the unconventional package called 'Twenty'. This product reduces the water content of home care, beauty and personal care products by 80%, thereby allowing smaller cardboard packages to be used. In fact, Twenty reduces the use of packaging materials and avoids the need for plastic bottles, which decreases transportation costs (Solanki, 2018) to an extent that may cause a shift in consumers' behaviours.

Packaging materials should not only be environmentally friendly, but also pose little problem over 'the last mile', which is the greatest hindrance to e-commerce expansion at present. Companies are struggling to deliver lighter packages as expeditiously as possible, but obviously at a cost. For example, IKEA charge a high price for home delivery of its products, but it is their customers' decision to pay it (Yu, 2016). On the other hand, to keep their customers satisfied the online supermarket Ulabox has not levied last-mile charges even though this obviously detracts from the company's turnover (García et al., 2019).

Some studies have examined potential solutions to the last mile problem. Such solutions include locker-based automated parcel stations (APS), pick-up points (PP) and parcel machines allocated in various areas for customers to collect their purchases (Morganti et al., 2014; Moroz, 2016). Amazon and Google are extensively using the parcel locker solution. For other companies, the click-and-collect concept allows consumers to buy products online and collect them at a physical store (Roger and Batty, 2017). One limitation of this concept is that companies still use the same types of packaging for their e-commerce channels (Carrillo, 2014; Ruesch et al., 2016). As can be seen from Fig. 4, both shapes and folding in cardboard boxes for transportation have remained almost unchanged. This subject is addressed in greater detail in Section 5.2 through several case studies which show that the same form and divider concept, and similar materials, continue to be used.

3.1.2. Sustainable packaging following circular economy

When (Papanek, 1973) wrote *Design for the Real World*, he demanded that the role of product designer should be played with a more analytical and self-critical attitude. He insisted that products should be efficient and sustainable rather than merely aesthetically pleasing. In contrast, however, concepts such as 'eco-design', 'green design', 'design for environment' and 'sustainable design' have become the norm even though they do not respond to Papanek's ideal and remain more akin to the linear model of the 'take-make-use-dispose' process (Moreno, 2016; Oxman, 2015). The earliest notions leading to the concept of Circular Economy (CE) arose in the 1970s (Stahel, 2013) and, especially, with Pearce and

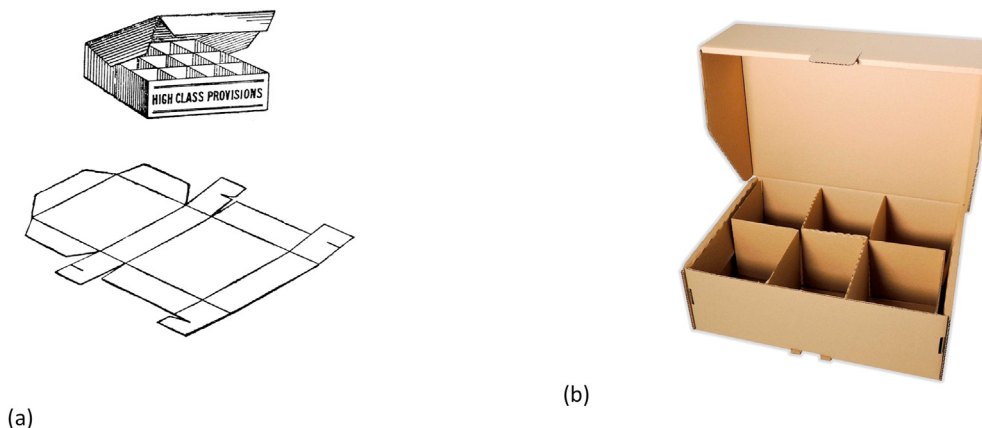


Fig. 4. (a) Cardboard folding box from the 1896 catalogue of the Britannia Folding Box Co. (Davis, 1967),(b) Contemporary design (Brildor, 2019).

Table 2
Circular Design strategies as applied to packaging.

Product/Case study	Strategy	Concept	Materials	References
Huhtamaki	Recycle	Flexible packaging made with recyclable materials	PP, PE and paper	Huhtamaki (2019)
Coca-Cola	Recycle	The company produces rPET from recyclable PET bottles and ocean waste plastic to minimize wastage of bottles they sell	rPET	Gibbs (2019)
	Renew		Plastic from ocean waste plastic	
Revolv	Reuse	Reusable cups used by all cafés and restaurants in the city. Participants recover the money they left on deposit when they bought the drink	Glass and silicone	MacArthur (2019); Revolv (2018)
Repack	Reuse	Bags for e-commerce. Reusable and returnable to avoid cardboard box waste	Recycled materials	Hellgreen (2014)
Unpackaged	Recycle	Refill system inside stores to avoid packaging and food waste	Glass or recycled plastics	Conway (2006)
	Rethink			
Kaffee Form	Renew	Coffee cups made from coffee grounds	Coffee grounds	Lechner (2018)
Feltwood ecomaterials	Renew	Valorize waste from agriculture and the disposal of vegetables as packaging materials	100% plant fibre (e.g., lettuce)	Feltwood (2019)
Feel the Peel	Renew	Circular juice bar. Bioplastics made from orange skin that can be 3D printed on a glass to serve the juice	Bioplastic made from oranges	Ratti (2019)
Gourds packaging	Renew	Redesign the shape of gourds from moulds	Gourds	Aizaki (2017)
This too shall pass	Renew	Rice packaging solution based on biodegradable beeswax	Beeswax	Billqvist and Glansén (2019)
Edible water by Notpla	Rethink	Packaging made with seaweed and plants that can disappear easily	Renewable sources: seaweed and plants	Garcia et al. (2019)
Apeel Sciences	Rethink	Thin skin to cover fruits and vegetables. The idea is to keep oxygen away and food inside in order to retain moisture for greater, longer freshness and to reduce waste	Edible plant material	Apeel Sciences (2012)
Mushroom packaging	Rethink	Wholly compostable packaging solutions made with mycelium and hemp that are wholly compostable	Mycelium and hemp	Evocative Design (2007)
Biodegradable water bottle	Rethink	Water bottle made with algae that easily breaks down unless refilled with water	Seaweed: algae	Morby (2016)
Twenty	Rethink	Redesign the packaging of cleaning products for home or personal use. In powder form rather than liquid to save 80% of water	Cartonboard	De Bruijn (2017)
Adaptive packaging (Puma + MIT)	Rethink	Use of live, biodegradable materials that can be programmed to adapt to the product	Bacteria and yeast	Lim (2018; Winston (2018)
Lush Cosmetics	Rethink	Naked products: no packaging needed because the soaps are solid instead of liquid. Recycling of black plastic material (one only)	Black Plastic	Dancey-Downs (2019); Lush (1995)
	Recycle			

Turner in 1989 (Evans and Bocken, 2014; Ghisellini, 2016; Gregorio et al., 2018). Manzini (1994) focused on the environmental consciousness on the manufacturing process of new products such as packages, and also to consumers’ attitudes in the 1980s and 1990s. The emerging political, economic and design awareness led to the development of new products that were intended to be more ethical and positive towards the environment.

Circular Economy (CE) is a business model based on a closed-loop system that uses biological and technical inputs separately (Bocken, 2016; Ghisellini, 2016; MacArthur et al., 2013a, 2014). CE adds value to existing materials and avoids overexploiting natural resources, which helps to reduce waste. The ‘butterfly diagram’ developed by the Ellen MacArthur Foundation (MacArthur et al.,

2013b) encourages companies to rethink their manufacturing processes by following CE methodology. A sizeable number of studies on CE for packaging have addressed the role played by business models and stakeholders, existing packaging strategies for materials, logistics, and legislation and policies, among others (Gregorio et al., 2018; Meherishi et al., 2019; Moreno, 2016).

The Delft University of Technology, where the 4R strategy was developed (Klooster, 2002), has conducted extensive research into CE as applied to packaging. Table 2 summarizes the 4R approach, the four Rs standing for ‘recycle’, ‘reuse’, ‘renew’ and ‘rethink’. In this context, recycling is using materials from packaging waste to produce new materials for making new packages; reusing is harvesting, washing and using packaging products once more;

renewing is using biodegradable, compostable or renewable materials for packaging; and *rethinking* is finding new design methods to improve existing packaging solutions socially and environmentally.

The current trend is to recycle and to search for biodegradable, compostable or renewable packaging materials that can be easily disposed of with no waste. Rethinking packaging design is being considered to depart from conventional uses.

3.2. Current scenario and packaging in e-commerce

3.2.1. Global e-commerce market distribution

At present, global e-commerce is being led by Amazon, eBay and Alibaba/Aliexpress (Fernández, 2018). Amazon dispatches more than 10 billion packages each year (an estimated 27 700 000 packages each day) and have recognized that their carbon footprint in 2018 was 44.40 million tons (Amazon, 2019; Shieber, 2019). Covid-19 increased the number of virtual visits to Amazon in March 2020 to 4.06 billion visitors (Baltrusaitis, 2020). This is a huge amount of material and a massive wastage of energy. For this reason, Amazon is considering reducing secondary packaging in all deliveries in the future; however, they will have to rely on manufacturers to achieve this ambitious goal, and not all are willing to spend money and time in innovating and redesigning secondary packaging.

3.2.2. Packaging design strategies for a better environment

This section examines various strategies companies are currently using to reduce CO₂ emissions and energy wastage in e-commerce packaging. Amazon is currently working on the concept of 'material reduction' with their FFP programme. The secondary packaging they use must protect the product, minimize the amount of material used in each pack and maximize its recyclability in order to reduce waste production (Amazon, 2018). Amazon's certification requirements include using rigid hexahedral boxes of the following minimum dimensions: 228.6 mm (length) × 152.4 mm (width) × 9.5 mm (height). Amazon makes its boxes with corrugated cardboard and other cellulosic materials—or plastics such as PET, HPDE and PP. All must be 100% recyclable and airtight sealed with a long enough piece of masking tape so that no material will be wasted during shipment. Amazon even recommends using technology for measurements. Also, packages must be labelled with appropriate information, the volume of each product should not exceed the holding capacity of its container and packages must be easy to open by customers.

Packages should be made from as little material as possible. 'Dematerialization' is a widespread approach to reducing material and energy use, production of solid waste and CO₂ emissions. Victor Papanek illustrated the concept briefly back in 1971 in describing a particular anecdote in his book *Design for a Real World* (Papanek, 1973). There, he proposed making toilet paper an inch less wide to reduce the wastage of millions of litres of water each day.

Based on Circular Economy principles, the manufacturer of the Saica Pack (Saica, 2017) uses waste as a secondary raw material to produce eight different cardboard boxes (seven for small items and one big box for shipping deliveries) for Amazon Spain under the FFP program. Although Amazon's warehouses can recycle 75% of their own material and return it to Saica, they cannot control the fate of everything they deliver.

Mondi Group (2019) produces recycled paper and sustainable flexible plastic for packaging. As material manufacturers, they are continuously working jointly with recycling companies and sustainable material suppliers to broaden their range of solutions. Although they have competitive prizes, they only manufacture packages in standard sizes. Pro Carton is a cartonboard

manufacturer that has grown 2.5% each year over the last decade as a supplier of a sustainable alternative to plastics. Cellulose in their cartonboard comes from sustainable forests (FSC) and is mixed with recycled material. One should be aware, however, that some recycled materials such as cardboard do not have the same properties as the pure materials. This is so because recycled materials have shorter fibres and these are less resistant to handling than are long fibres. The greatest advantage of recycled fibres is that they save trees from felling in addition to 1% of water and 30% of electricity per ton of paper (Piselli, 2016).

One problem with online purchases is that most products are packaged in the same type of material: corrugated paper (Carlin, 2019; Pålsson, 2017). By contrast, food e-commerce has introduced more complex variables into packaging that require new, effective developments. Packaging Regulations have established three different layers of packaging. The person who unwraps a package at any level is deemed the end user of the material. It is therefore important to understand which level of packaging a company is bracketed at in order to determine its total obligation tonnage and total cost. There are three main tiers here, namely:

- *Primary packaging*, which encompasses the wrapping or containers handled by the consumer or end user and serves to protect and advertise the product (e.g., foil wrapped around a chocolate bar).
- *Secondary packaging*, usually in the form of large cases or boxes that are used to group quantities of primary packaged goods for distribution and for display in shops (e.g., cardboard boxes containing large numbers of foil-wrapped chocolate bars).
- *Tertiary packaging*, which comprises the containers used to gather packaging groups into larger loads for transport in order to facilitate loading and unloading of goods (e.g., wooden pallets and plastic wrapping).

Online grocery retailers typically use corrugated board packages and paper or plastic bags (mostly biodegradable plastics). Why are they still using those materials if new alternatives are needed in e-commerce? In fact, a clear demand for new materials exists in this



Fig. 5. Flat wine bottle for e-commerce deliveries (Garçons Wines, 2019).



Fig. 6. Winepack solution (Total Safe Pack, 2016).

area. Standard stores are increasingly using paper bags instead of corrugated board packages for home delivery (Carlin, 2019; Pålsson, 2017), thereby saving 80% on energy. The question thus arises as to how e-commerce materials for reducing this impact can be obtained. Although e-commerce can reduce CO₂ emissions in non-urban areas—and also in urban sectors under APS or PP—the impact of packaging materials and energy requirements should be the main consideration here.

3.2.3. Disruptive sustainable packaging solutions and materials for e-commerce

This section is concerned with existing alternatives to standard packaging designs. Very little attention has to date been paid to the original flat wine bottle redesigned by Garçons Wines (Garçons

Wines, 2019), shown in Fig. 5, which can be delivered in a letter-box. The bottle is manufactured from 100% recycled PET, so it will not break in freight deliveries; also, it is 100% recyclable after use. At only 63 g, it is 87% lighter than a standard glass bottle, so the environmental impact of its transportation is much smaller. However, this new form of packaging can alter consumers' perception and lead them into believing that the wine it contains is of lesser quality.

The Winepack (Total Safe Pack, 2016) was developed jointly by Itene and Cartonajes Font to protect wine bottles. This packaging system (Fig. 6) has a special folding that reduces bottle breakage by 95%. The outer box consists of a double layer of 8 mm thick corrugated cardboard and the inner piece of a single layer of 3 mm thick corrugated cardboard. The package has a double thickness flange at the top and bottom. The Winepack uses a fair amount of material and is thus expensive for e-commerce. Because it is single-use, it increases environmental impact and material wastage—consumers tend to have a negative perception when they receive an overpacked product they have purchased online. In fact, according to Monnot et al. (2019), saturation with materials generated once a package is disassembled can be the source of bad experiences for consumers. In any case, the Winepack provides improved protection for bottles and reduces product losses as a result.

Fig. 7 compares a standard package for wine transport with the Winepack, which is a corrugated cardboard box with dividers (Olivares, 2019), in terms of bottle safety, and Table 3 shows the final additional cost of packaging 100 bottles. As can be seen, the Winepack provides substantial savings in bottle handling. Thus, it avoids bottle breakage, which reduces losses and their associated costs; also, it affords transportation of bottles in greater numbers without breaking. As a result, the Winepack is a cost-saving, environmentally friendly solution. Cost savings do not offset packaging price relative to standard packaging, however. Moreover, the actual benefits of using the Winepack over a conventional wine package are still to be demonstrated. For example, the Winepack uses 4 times more corrugated cardboard, which means increased transport costs and CO₂ emissions. One should bear in mind that the environmental tax for cardboard is 0.068 €/kg (Ecoembes, 2009).

Although not intended for e-commerce food purchases, the Scudopack is another choice for diminishing the environmental



Fig. 7. Standard package (Rajapack, 2019).

Table 3

Comparison of costs between the premium package and the standard package for 1 bottle.

*L Length, W Width, H Height. Transport price = average for a bottle of about 1.5 kg delivered to an address in the Iberian Peninsula.

	1 BOTTLE PREMIUM PACKAGE	1 BOTTLE STANDARD PACKAGE
SIZE OF 1 BOTTLE PACKAGING	Outer box: 140 × 140 × 425 mm Inner part: 90 × 90 × 330 (L × W × H)*	136 × 136 × 385 mm
TOTAL WEIGHT FOR 1 BOTTLE PACKAGING	442.84 g	120.5 g
PACKAGE PRIZE FOR 1 BOTTLE PACKAGING	1 UNIT = 2.43 € 100 UNITS = 243 €	1 UNIT = 1.2 € 100 UNITS = 120 €
AVERAGE BROKEN BOTTLES PER 100 UNITS	0.04 BOTTLES	7 BOTTLES
DISAGGREGATED COST OF BROKEN BOTTLES PER 100 UNITS	New bottles: 0.04 × 5 € = 0.2 € New premium package: 0.04 × 2.43 € = 0.097 € New transport added: 0.04 × 7.70 € = 0.30 € Total = 0.597 €	New bottles: 7 × 5 € = 35 € New premium package: 7 × 1.2 € = 8.4 € New transport added: 7 × 7.70 € = 53.90 € Total = 97.3 €
TOTAL COST FOR 100 BOTTLES INCLUDING EXTRA COST OF BROKEN BOTTLES	Total 243 € + 0.597 € = 243.597 €	Total 120 € + 97.3 € = 217.3 €



Fig. 8. Scudopack solution to protect furniture with a minimum amount of cardboard (Scudopack, 2017).

impact of packaging and reducing the amount of material used. As shown in Fig. 8, Scudo systems are typically used to protect furniture, windows, marble and doors, and recommended for all types of electronic products including radiators and photovoltaic panels, because they are easy to apply and highly resistant to impacts. Thus, they have been found to decrease breakage by up to 70% and to reduce packaging volume —and transport costs as a result. Their advantages over conventional packages include a substantial reduction in material volume, costs and product breakage —a Scudopack can withstand 30 consecutive impacts without damage, so it fulfils ISTA regulations.

Metsä Board (2018) recently detected a high consumption of bubble wrap and mini-polystyrene foams (so-called ‘packing peanuts’) to secure products in e-commerce packaging. Although conventional expanded polystyrene (EPS) packing peanuts are light and durable, they are not degradable, so they can be the source of health problems for production workers. Alternative biodegradable



Fig. 9. ‘Stretching Inner Part’ as designed by Iiro Numminen, winner of Metsä Board’s prize (Metsä Board, 2018).

starch-based peanuts are more expensive than are EPS packing peanuts (Cheng Kwee et al., 2013). Iiro Numminen found cutting a pattern in cardboard packaging to provide a secure package with the same amount of material and less cost (see Fig. 9). This idea won him Metsä Board’s ‘Better With Less’ prize, which is awarded to innovative packaging solutions (Metsä Board, 2018).

In Finland, Repack offers a bag for reusable packaging that reduces CO₂ emissions by up to 80%. Instead of bio-based material, which is not reusable, Repack is made of polypropylene (PP). This polymer is long-lasting, recyclable and lightweight, and has a reasonable impact on cost saving. In any case, the manufacturer is open to using other biomaterials that might be found on the market. Repack’s proposal is that customers themselves should return their empty bags through a post office (see Fig. 10). The service, however, is unsuitable for fragile contents such as liquid foods.

Fig. 11 compares the previous alternative packaging solutions in terms of cost savings, material volume and function. As can be seen, the Scudopack is the most cost-effective solution, as well as the most functional and best performing, and the one using the least



Fig. 10. Repack as reusable packaging (Repack, 2019).

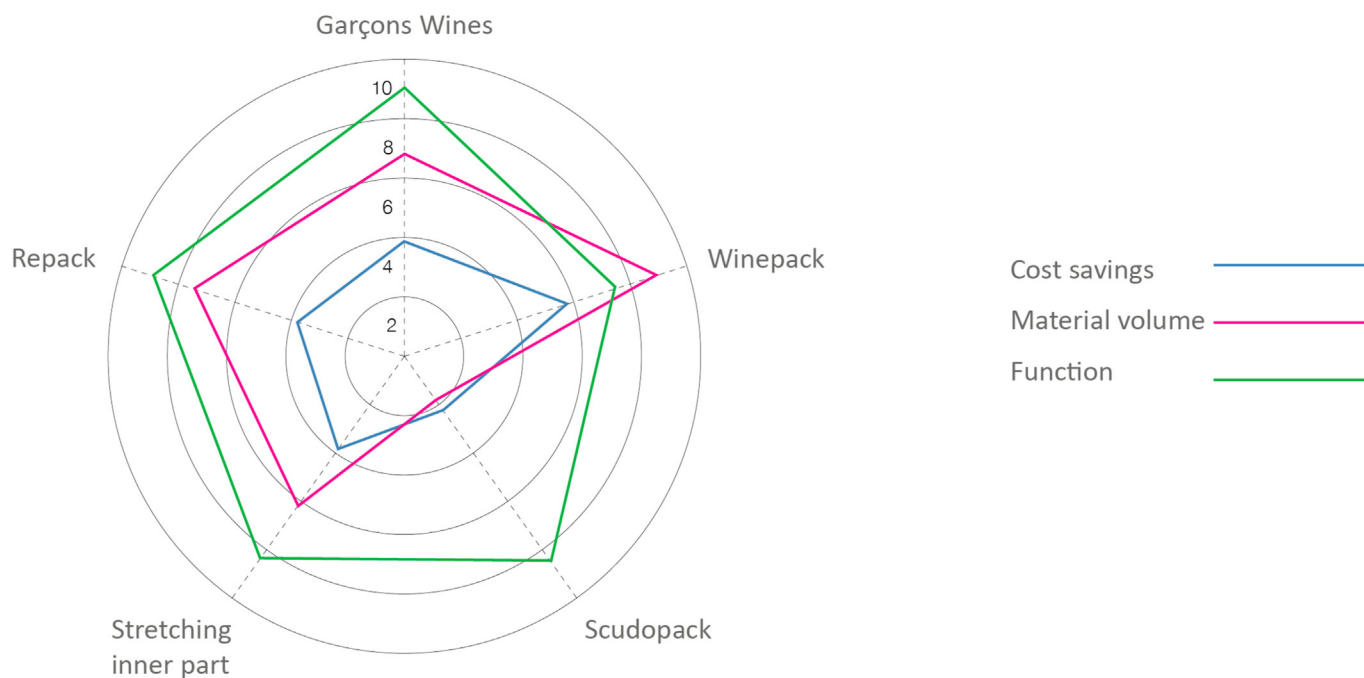


Fig. 11. Comparison of the five solutions examined in terms of cost saving, material volume and function on a scale from 0 to 10.

material. On the other hand, the Winepack and Garçons Wines solutions are effective in terms of material volume and functionality, but not in cost, which is high relative to the Scudopack. Finally, Repack and the Stretching Inner Part fall in between the previous two extremes, with acceptable cost savings, and good material volume and functionality properties.

Fig. 12 compares the previous solutions in terms of reusability, returnability, recyclability and adaptability to product volume. As can be seen, the Garçons Wines and Repack solutions are the indisputable winners in these respects. Repack is reusable, made from recyclable material and returnable, but cannot easily adapt to any type of product because it is only available in a standard shape. Garçons Wines have focused on adapting their solution to particular products and even specific circumstances of the sector (e-

commerce in this case), whereas the Winepack, Scudopack and Stretching Inner Part have been conceived for product adaptability and recyclability.

In summary, the Garçons Wines and Repack solutions are the best choices for e-commerce but are made from non-biodegradable materials obtained from non-renewable sources. The other three solutions are made from cardboard, which is biodegradable and comes from a renewable source (cellulose fibre). This topic is dealt with in greater detail in Section 5.2.

3.3. New paradigms for sustainable packaging in e-commerce

Today, the world is at a very special time in history. In fact, the early 21st century is witnessing substantial changes through the

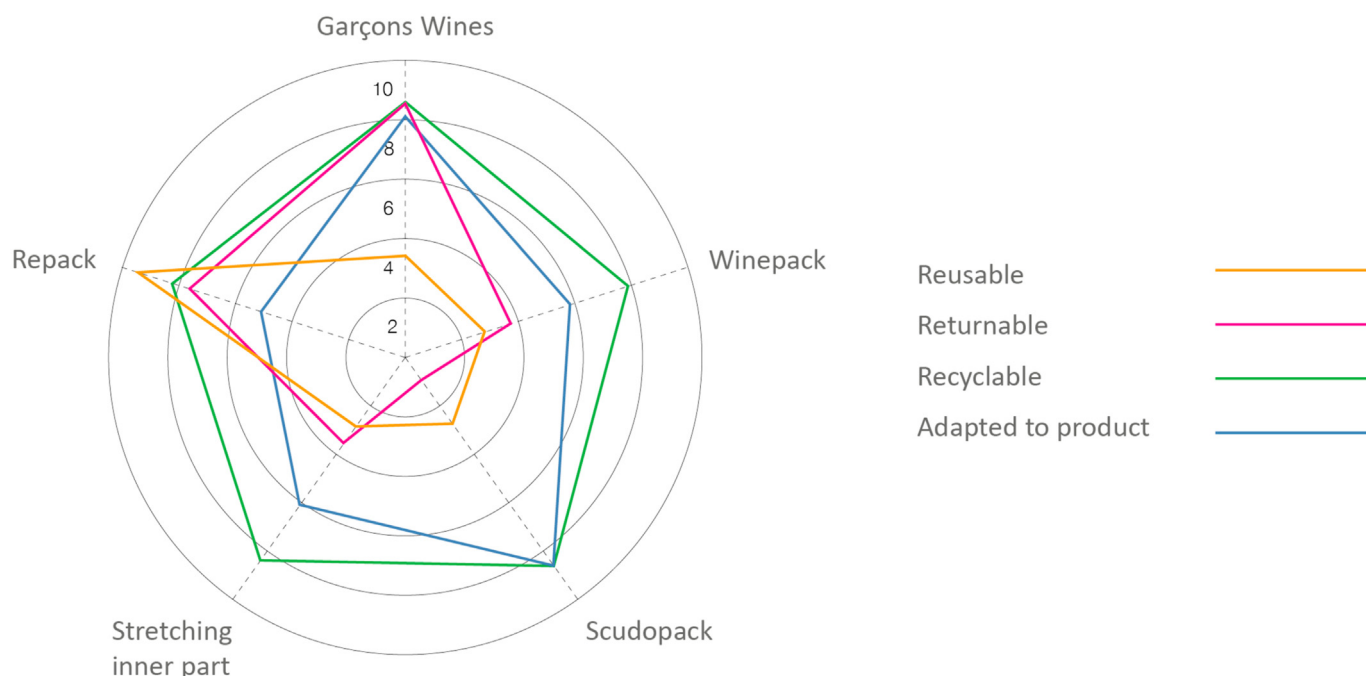


Fig. 12. Comparison of the five solutions examined in terms of the indicators reusable, returnable, recyclable, and adapted to product shape and volume.

fourth industrial revolution, also known as 'the digital revolution'. The changes include the development of exponential technologies such as Artificial Intelligence (AI), Autonomous Vehicles, 3D Printers, Drones, Virtual Reality, Brain–Computer Interfaces and Genetic Engineering. 3D printers, for example, are allowing new materials to be applied with better resolution and in less time. This has enabled DIY printing of products at home instead of buying them (Salim et al., 2014).

In Japan, technologies such as Internet of Things (IoT) connectivity, 3D vision sensors and robots are allowing workers to improve package manufacturing processes (Carlin, 2019). This is the right time to stop thinking in a linear manner, and to switch to exponential and circular thinking as new paradigms for the human being. The following sections discuss various technological improvements and material enhancements that are expected to lead to a renewed society.

3.3.1. Logistics

By using cost-effective algorithms, US carriers such as UPS can save 85 million miles of driving each year (Salim et al., 2014), thereby considerably reducing CO₂ emissions—each day, the company delivers around 16 million shipments. The traditional concept of transportation is being challenged by the advent of autonomous cars and the new information paradigm. Autonomous cars avoid having drivers—and the aggressive behaviours of some—on the roads; also, they help reduce fuel consumption. Recent studies on transportation strategies for reducing greenhouse gas (GHG) emissions have shown that using appropriate sensors and algorithms can reduce logistic activity and increase the efficiency of autonomous cars. In any case, the fuel market for cars should provide more options such as electricity, hydrogen or bio-fuels and electrofuels for hybrid cars in order to further reduce carbon dioxide emissions. As suggested by their high environmental impact and the apparent lack of viable alternatives, a thorough Life Cycle Assessment (LCA) of electric car batteries is also in order (Belvedere, 2017).

Using robots and small drones to deliver packages can reduce

emissions on the 'last mile'. This would imply rethinking package shapes and making use of new, light, sustainable materials. To solve this problem, the company Matternet (2017) uses a combination of vans and drones to make shipments more efficient in accordance with the size of the package to be delivered, thereby reducing GHG emissions (Condliffe, 2017). The company itself is revolutionizing transport standards and considering introducing drones as an effective delivery option for developing countries in Africa. They intend to use technology to make the leap to new ways of transport in much the same way as the mobile phone improved communication (Salim et al., 2014). Amazon gave the option to send shipments with drones in 2016 under the 'Prime Air' concept (Amazon, 2016); the project, however, was abandoned because it was not as effective as predicted (Vincent and Gartenberg, 2019). UPS went further in this direction thanks to its being authorized by the Federal Aviation Administration (FAA) to use drones for hospital deliveries (Ray, 2017). This was made possible by the digital and technological revolution leading to increasingly powerful devices at increasingly low prices (Ray, 2017); for the moment, however, the system can only be used by commercial airlines and is subject to stringent regulations. In any case, adopting drones should be the concern of citizens, governments and air forces as it might lead to collapsed skies unless their use is strictly regulated. For this reason, alternative technologies are currently being sought one of which involves using pneumatic tube systems invented in the late 19th century (Woodford, 2019). Such systems are still used by banks, hospitals, supermarkets and logistics centres, among others, in the United States. Elon Musk's Hyperloop relies on this concept, and the situation is highly likely to improve in the long term and allow new methods of fast, efficient transport to be developed (Dudnikov, 2017).

In any case, progress towards reducing the impact of the last mile could be furthered by a change in consumers' attitude. For instance, if most customers collected their orders at specific places, a number of transport problems could be solved and packaging wastage reduced. As stated above, Amazon is already installing automated parcel machines and establishing pick-up points for

personal collection in urban areas. In fact, they have established several supermarkets in the USA where Artificial Intelligence is used to avoid the need for staff and to allow customers to purchase their products easily and conveniently (Favors, 2017).

3.3.2. Packaging materials and processes

As shown by existing literature, cellulose-based materials have a very low environmental impact relative to other choices (Suhas et al., 2016). Cellulose is one of the most naturally abundant materials (Abitbol et al., 2016; Bharimalla, 2017; Klemm, 2018; Li, 2015; Nechyporchuk et al., 2016; Osong et al., 2016; Perepelkin, 2004; Rajinipriya, 2018; Tayeb, 2018; Vilarinho et al., 2018; Yang et al., 2019) and one of the most important renewable materials (Brinchi et al., 2013; Cusola, 2015; Hischier et al., 2005; Osong et al., 2016; Piselli, 2016).

Cellulose can be found in woody and non-woody plants (grass, algae), and bacteria, as well as in waste from forestry and timber industries, agricultural practices and industries, and even from pulp and paper industries (Li, 2015; Rajinipriya, 2018; Ramesh, 2017). Plant cells are the main raw material for paper and cardboard production. The interesting properties of cellulose as a macro structure could be explored for use in disposable packages, but has some limitations as regards barrier properties.

By virtue of its exceptional mechanical, physical, thermal, optical and even barrier properties, nanocellulose (NC) appears to have a high potential for a wide variety of uses. Recent studies suggest that the food packaging industry is searching for efficient ways to produce this strong, lightweight bio-based material. Because it has antimicrobial properties, and is transparent and water- and oxygen-permeable, NC is highly suitable for packaging to be in contact with food (Itzela et al., 2013; Li, 2015; Nechyporchuk et al., 2016; Osong et al., 2016; Rajinipriya, 2018; Vilarinho et al., 2018).

A young generation of design students at Aalto University in Finland has worked collaboratively with chemists to explore biomaterials from cellulose and develop new approaches for the future. There are some indications that the properties of NC can be further improved. Thus, although the crystal structure of cellulose confers it strength, three students (Arto Salminen, Steven Spoljaric and Jukka Seppälä) have found a way to enhance it before spinning (Fig. 13) in order to increase its water stability and expand its range of uses (Kääriäinen et al., 2015).

Another student (Martha Yessen) has developed an interesting reaction for converting dissolved cellulose acetate into solid cellulose (Lindberg et al., 2017). The high versatility of cellulose has enabled the production of new biodegradable materials through a

combination of chemistry and technology that expands the scope of cardboard and paper in e-commerce packaging.

ISO 17296–2:2015 (ISO, 2015) defines the principles behind material extrusion for Additive Manufacturing. However, 3D printing in one of its seven forms can be used to produce packages by material extrusion, vat photopolymerization, powder bed fusion, material and binder jetting, sheet lamination and directed energy deposition. These processes can be applied to various materials but are especially suitable for plastics, bioplastics, other polymers, metals, ceramics, glass or even edible viscoelastic ink for food (Braslavsky et al., 2017; Jordan, 2019; Keating, 2016). The Finnish initiative known as 'Design Driven Value Chains in the World of Cellulose' (DWoC) uses Direct Ink Writing (DIW) and Fused Deposition Modelling (FDM) to print solid and liquid cellulose-based materials (Kääriäinen et al., 2015; Kataja and Kääriäinen, 2018).

In the Netherlands, 3D printing has allowed the industrial designer Beer Holthuis to print objects with recycled paper in order to reuse material that would otherwise have been wasted. According to Holthuis (2018), each person generates about 80 kg of paper waste each year. 3D printing enables customized, more sustainable package production and facilitates Circular Economy. Its actual potential, however, should be assessed by comparing life cycles with those of existing conventional choices.

Tomorrow Machine is a Swedish packaging studio, product and food concept that has worked on a series of proposals with Innventia, a research company, for Ekoportal2035. Ekoportal2035 is a futuristic project of the Swedish Forest Industries Federation seeking new outputs for cellulose in the near future. One of the proposals, presented in 2013, was a plastic made with cellulose and printed with 3D technology. This solution has gained ground as a tool for producing flexible objects that can even self-manufacture and self-destruct (Billqvist and Glansén, 2013; Innventia, 2019; The Swedish Forest Industries Federation, 2019).

Neri Oxman, the renowned architect and founder of the Mediated Matter Group at the Massachusetts Institute of Technology (MIT), has been searching for several years new biopolymers from renewable sources and considering their return to nature as waste (Pangburn, 2019). This is what Oxman calls 'Material Ecology'. New ways of manufacturing biopolymers have also been devised. The concept of 'designing for decay', inspired by nature, has been used to obtain organic materials such as cellulose, chitosan and pectin—the most abundant natural polymer—and transform them into objects that will break down over time (Lipps et al., 2019). Once the materials have been obtained, they are used to feed a 3D printer operated by a water-based robot for additive manufacturing of extruded hydrogel composites (Mogas-Soldevila et al., 2014). According to Oxman, the industrial revolution abandoned nature and led to mass production, repetition and practical design, but handicapped imagination (Latza et al., 2015; Lipps et al., 2019); however, emerging technologies and new materials are opening up new horizons for creativity.

4. Conclusions and suggestions for further research

The packaging industry has scarcely changed the structure of folding boxes since the 19th century even though the recent growth of e-commerce has considerably increased packaging usage and raised the need for effective solutions to the ensuing environmental problems. This paper reviews the state of art of packaging in e-commerce with the aim of depicting the current scenario, identifying gaps in past research and proposing new lines to revitalize the evolution of packaging, which has been stuck since the 1990s.

The current scenario for the packaging sector can be easily understood if one considers the following facts:



Fig. 13. Cellulose-based filaments from hydrogel suspensions (Kääriäinen et al., 2015).

- Packaging evolved substantially by effect of the production of new materials until the 1990s. At present, however, it has reached a standstill owing to the need for effective ways of reducing costs and environmental impacts. Unlocking this situation will call for new design paradigms to be built.
- Overpackaging is increasingly common and should be among the concerns of policy makers.
- Although packaging made from non-renewable materials such as plastics continues to be widely used on the grounds of its recyclability, too strong a dependence on these sources should be avoided at any rate.
- Package distribution remains one of the main contributors to the environmental impact of packaging and is hence in need of more effective solutions.

Based on the foregoing, work aimed at reducing the environmental impact of packaging should somehow be guided by the following considerations:

- The abundant waste generated by e-commerce—usually in the form of cardboard—can end up being degraded and returned to nature. Also, such a widely abundant natural biopolymer as cellulose can be obtained from renewable sources and biodegraded or upcycled after use.
- Effective guidelines and policies to avoid overpackaging are very much needed.
- Circular packaging should be promoted by developing sound specific design guides.
- Production with new technologies such as additive manufacturing and 3D printing should be further explored to devise new packaging solutions (e.g., packages more closely fitting the shape and volume of the products they are to hold and made from lesser amounts of material). High-performance 3D printers afford cleaner manufacturing and can alleviate CO₂ emissions. The new production technologies are being increasingly used at the industrial scale on account of their low production costs and high throughput.
- New logistic strategies such as those based on drones, electric cars or pick-up points should be evaluated in order to identify the best performers as regards environmental impact reduction and ways of using them in different scenarios should be found.
- Life Cycle Assessment (LCA) studies should be fostered to ensure that the previous research lines will improve on previous choices (e.g., to confirm that a new solution reduces carbon footprint relative to the existing packaging product it is intended to replace). Package design should also be subjected to LCA in order to ensure that the ensuing solutions are more environmentally friendly than the original ones.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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