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Review Article

Packaging design for the circular economy: A systematic review

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ABSTRACT

The concept of circular economy has been ubiquitous over the past five years and has been steadily gaining a consensus as a new paradigm. Circular economy covers a wide spectrum of topics ranging from waste management, through materials to supply chain, amongst which packaging is an essential part for achieving a truly circular economy. It has been emphasised that resources should be kept in closed loops, thereby generating zero waste. However, largely due to the nature of packaging materials and designated usage, the packaging industry is built on a linear model where packaging is designed, produced, consumed and disposed of. This creates substantial amount of waste, which is now a growing concern for the earth ecosystem. To enable a smooth transition from a linear to a circular system, packaging design has been recognised as the fundamental stepping-stone towards a circular economy. In this study, an extensive literature review is performed, investigating the growing body of research on packaging design in relation to circular economy. This paper reviews the state-of-the-art research on packaging design, including design rules, guidelines, considerations and tools that can be applied in the design process for achieving a circular economy. A circular packaging design framework is then proposed, summarising the findings and showing (i) the factors that determine material selection, (ii) the design strategies, guidelines and considerations to be taken into account in the conceptual design and design development phases, and (iii) the tools and indicators to assist design validation and assessment of packaging circularity. Finally, future research trends in various aspects including material selection, design guidelines to facilitate recycling, design assessment tools, design education and policy making are discussed.

Contents

Abbreviations: BDE, brominated diphenyl ether; CE, circular economy; CEP, Circular Economy Package; CER, Corporate Environmental Responsibility; C2C, Cradle-to-Cradle; EVOH, ethylene vinyl alcohol; EU, European Union; HDPE, high-density polyethylene; LCA, life cycle analysis; LCD, liquid crystal display; MCI, material circularity indicator; NIR, Near Infrared; PBAT, poly(butylene adipate-*co*-terephthalate); PBS, poly(butylene succinate); PCL, polycaprolactone; PE, polyethylene; PET, polyethylene terephthalate; PGA, polyglycolide; PHA, polyhydroxyalkanoates; PLA, Polylactic acid; PP, polypropylene; PS, polystyrene; PVC, Polyvinyl Chloride.

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1. Introduction

Packaging has a long history along with the development of human civilisation, and the concept of packaging has merged since the first humans started making use of tools (Emblem and Emblem, 2012; Luijsterburg and Goossens, 2014; Silayoi and Speece, 2004). One of the very first examples of 'packaging' in the human history probably is using leaves to wrap food (Emblem and Emblem, 2012). In modern days, packaging usually refers to a form of object that encloses and protects products for distribution, storage, transport, sale, use and reuse (Coelho et al., 2020; Svanes et al., 2010). The most critical task of a package is to securely protect the product (Grönman et al., 2013). However, given the environment continuously deteriorating caused by ever increasing packaging wastes, there have been stronger voices requiring packaging to be designed, manufactured, consumed and recycled in a more sustainable way (Azzi et al., 2012).

In light of the pressing need for a healthier and sustainable ecosystem, the concept of the circular economy (CE) was proposed by policy makers from the European Union (EU) and China to tackle the global environmental issues via closing the loop of the product lifecycle (Charef et al., 2021; Korhonen et al., 2018). The transition to a circular economy requires a radical change in the linear model of economic activity (Nikiema and Asiedu, 2022; Zink and Geyer, 2017). The fundamental notion of a circular economy is the closed loop where resources are used, reused and recycled while creating additional values throughout the multiple lifecycles (Kirchherr et al., 2017). Goods towards their end of service life are turned into resources for others, forming a closed loop, whereby minimising waste (de Jesus et al., 2018; Prieto-Sandoval et al., 2018).

Development towards a circular economy requires synergic efforts from various industry sectors including but not limited to suppliers, manufacturers, recycling processers, distributors, retailers, end consumers and waste collection service providers (Batista et al., 2019; Iacovidou et al., 2017a,b; Jabbour et al., 2019; Li et al., 2018; Mahmoudi and Parviziomran, 2020). The packaging industry is a crucial and enormous economic generator with a gigantic growth rate every year. The turnover of the packaging industry in Western Europe represents around 2 % of GDP and the food industry is the main user of packaging with nearly 60 % of total packaging production (Coelho et al., 2020; European Committee for Standardization, 2020). The use of packaging has penetrated into almost every aspect of our daily lives. However, as a downside consequence, packaging waste has resulted in massive environmental issues (Grönman et al., 2013; Williams et al., 2020). This is due to the traditional linear consumption model where packaging is intuitively designed to be manufactured, transported, consumed and disposed of. Plastics are the most prevalent type of materials used in the packaging industry. There has been an exponential growth in the global consumption of plastic packaging since the 1950s (Rhodes, 2018). The packaging sector consumes 40.5 % of all plastics produced, which is the largest sector for plastic consumption in the EU (Fogt Jacobsen et al., 2022; Plastics Europe, 2022). However, the recycling rate is still at a low level, which is 34.6 %, and worryingly over 23 % of the plastic waste is still sent to landfill (Plastics Europe, 2022). In comparison to the EU, the recycling rates remain constantly low in China and the United States, which are 25 % and 9 %, respectively (Casarejos et al., 2018; Rhodes, 2019; Sarkar et al., 2022). This has caused significant pollution to the environment.

Packaging concerns a series of actors including raw material producers, packaging designers and manufacturers, transport, distribution, consumers, waste management activities and public authorities (European Committee for Standardization, 2020). Packaging design is generally considered as a decisive element in the packaging value chain as it determines the materials to be used, defines the manufacturing operations to be implemented and determines the end-of-life options, all of which are closely linked to the closed-loop model in a circular economy (Nemat et al., 2019). However, packaging design in the context of circular economy has not been systematically reviewed in the existing literature review studies. The majority of them only focuses on consumer behaviours (Fogt Jacobsen et al., 2022; White et al., 2019), plastic waste management (Chae and An, 2018; Sarkar et al., 2022), recycling techniques (Franz and Welle, 2022), and supply chain management (Silva and Pålsson, 2022). They mainly address how to deal with already produced packaging and packaging wastes, paying less attention on the design stage. However, the design stage is considered to have the greatest influence on packaging sustainability, determining around 80 % of environmental impacts (Ahmad et al., 2018; European Commission, 2018c). Although Silva and Pålsson (2022) discussed the industrial packaging development process with some basic design tools, the packaging design process and detailed design considerations were not thoroughly explored. There has not been a literature review that is specifically aimed at understanding packaging design for circular economy from the design perspective.

Therefore, this study is focused on packaging design in relation to circular economy. A review of the state-of-the-art research has been undertaken. The findings are summarised in a circular packaging design framework (in Section 4.5.1), which shows the typical factors and considerations to take into account during the packaging design process. The paper is organised as follows: Section 1 first introduces the background of CE and packaging, followed by an overview of the CE-related regulations and policies on packaging design by different levels of governments (in Section 2). Section 3 presents the literature review method used in this study. Academic publications on packaging design in the context of circular economy are systematically reviewed and the results are presented in Sections 4.1–4.4. This is followed by the discussions of the results and future research trends in Section 4.5.

2. Overview of regulations and policies on packaging in relation to circular economy

This section provides an overview of the regulations and policies introduced by governments in different levels for tackling packaging waste challenges and achieving a circular economy.

2.1. The European Union level

To address the significant challenges in environment protection, the EU enacted a number of regulations and policies. In the EU Waste Legislation (European Commission, 2018d), the targets and provisions for waste recycling are defined. The levels of reuse and recycling of municipal waste to be achieved are set to be 55 %, 60 % and 65 % by 2025, 2030 and 2035, respectively, as detailed in the Waste Framework Directive 2018/851 (European Commission, 2018a). As a large proportion of household waste is packaging waste, this means, in order to achieve the above goals, packaging should be designed in a way that facilitates multiple reuses and recycling target (Czarnecka-Komorowska and Wiszumirska, 2020; Faraca and Astrup, 2019; Grégoire and Chauvelot, 2019).

Amongst different types of wastes such as paper and glass, plastic packaging waste is highlighted in Directive 2018/852 (European Commission, 2018b). A strict target of recycling rate (by weight) for packaging waste is set, namely, a minimum of 65 % followed by a minimum of 70 % of all packaging waste must be recycled by the end of 2025 and 2030, respectively. In line with the EC waste policy and legislation (European Commission, 2018d), the first-ever European Strategy for Plastics in a Circular Economy (European Commission, 2018e) was published, which aims to improve design of plastic products, increase plastic waste recycling rates and improve quality of recycled plastics.

To achieve the long term targets set in the EU Waste Legislation (European Commission, 2018d), an action plan was proposed in the EU's "A new Circular Economy Action Plan for a cleaner and more competitive Europe" (European Commission, 2020). An essential part of the plan is to design and produce sustainable products and transform consumption patterns. The action plan focuses on a number of sectors, amongst which packaging and plastics sectors are identified as having a high potential for circularity. Packaging designers thus have an important role to play towards achieving a circular economy via designing sustainable packaging to change consumer's behaviour, ensure less waste in both product manufacture and consumption stages.

2.2. National level

To respond to the EU's Packaging and Packaging Waste Directive 2018/852 (European Commission, 2018b) and the EU Waste Legislation (European Commission, 2018d), many countries' governments have formulated relevant policies. For example, the UK government released the Circular Economy Package (CEP) policy statement (United Kingdom Government, 2020). Three essential requirements for packaging are defined in the CEP. They are: (i) packaging must be designed, manufactured and commercialised in order to permit reuse or recovery; (ii) the content of hazardous or noxious materials in packaging must be minimised; and (iii) the packaging weight and volume must be limited to the minimum amount while achieving the necessary level of hygiene, safety and acceptance for the consumer. In addition, France enacted a new law in 2020, which aims to reduce plastic consumption and promote reuse and recycling (French Government, 2020). It also extends producer responsibility and necessary information is required to provide to consumers to help to sorting packaging. Sweden also announced a national strategy for a circular economy (Swedish Government, 2020). Sustainable product and associated packaging design together with sustainable ways of using materials are highlighted as the two of the four main focus areas. For other countries' policies and strategies, readers are referred to (Ghosh, 2020; Lah, 2016; Nelles et al., 2020; Swiss Government, 2018; The Federal Government of Germany, 2018; United Nations, 2019).

2.3. Regional level

In line with the national governments' CE policies and legislations, local authorities published regional circular economy strategies and roadmaps, which were formulated based on local economies. Regional policies are heavily oriented by not only the environmental considerations but also the interests of the primary sectors in the region. The white paper titled "City governments and their role in enabling a circular economy transition" by Ellen MacArthur Foundation (2019) summarised the circular economy roadmaps that municipal governments developed. A sector-based approach was adopted, for instance, one of the key areas of Rotterdam's circular economy plan is focused on the bio-based materials sector (Gladek et al., 2019). In London Waste and Recycling Board's (2017) CE roadmap, measures are proposed to reduce the use of single-use plastic packaging bags. This is because the tourism is a major sector the local economy relies on but it also generates significant waste of single-use packaging waste. Paris intends to build drinkable tap water fountains, which aims to reduce the consumption of bottled water and the associated plastic waste (Mairie De Paris, 2017). In Glasgow's circular economy strategy (Clark and Gille, 2019), designers are urged to select environmental friendly materials, design out waste, and follow principles for design for disassembly and for adaptability. Other cities worldwide developed similar strategies and roadmaps such as Brussels Capital Region Government (2016), Vancouver Economic Commission (2017), Peterborough City Council (2017), Bristol City Council (2016) and Charlotte City (2018) etc. The white papers by C40 Cities Climate Leadership Group (2018) and Ellen MacArthur Foundation (2019) provided detailed description of current city-wide circular strategies across the world. In these municipality-led circular economy strategies, it is repeatedly highlighted that, in order to achieve the circular economy, designers and producers should hold further responsibility for waste resulting from their products after use, which however, they currently do not hold.

3. Methods

To identify academic studies that are concerned with packaging design in the context of circular economy, a systematic literature review was conducted, which was based on the methodology by Tranfield et al. (2003). It consisted of three steps: planning, execution and reporting. In the planning step, the keywords of interest were identified together with a protocol for conducting the review. The literature was searched from a number of reliable databases including ISI Web of Science, Scopus, Google Scholar and Ei Compendex, and subsequently subjected to initial and thorough analysis in the execution step. Finally, the findings were synthesised and reported.

Following the methodology, keywords and search terms were selected, which are listed in Table 1 below. To implement a thorough review, a combination of these keywords was used in multiple searches to locate the relevant literature. The search was conducted through the academic databases listed above to select suitable literature on packaging design for the circular economy.

The literature in the past 22 years was searched, starting at the year 2000 as the concept of circular economy started to emerge (Türkeli et al., 2018). This initial search led to a collection of 3016 studies, of which 489 was from Web of Science, 651 was from Scopus, 1022 was from Google Scholar and 854 from Ei Compendex. Then, the literature

Table 1
Keywords for academic literature search.

Search topics		Examples of search terms
Packaging design	Circular economy	
Packaging design, packaging, reusable packaging, refillable packaging, returnable packaging, product design, design, eco design, manufacturing, packaging design development, waste	Circular economy, sustainability, green, sustainable, environment, sustainable production, biodegradable materials, biomaterials, bioplastics, compostable materials, recycling, recyclability, cradle-to-cradle	"Packaging design" AND "circular economy", "manufacturing" AND "sustainability", "packaging design development" AND "recycling" OR "recyclability", "eco-design" AND "biodegradable materials"

which had little to no relevance to this research subject (e.g. forest conservation), duplicates and studies reported in other languages were removed. This reduced the total number of studies to 2194. This was followed by a screening process based on paper title, abstract, keywords and conclusions. By doing this, the number of relevant studies was narrowed down to 417. These articles were read in full and their relevance to this study was assessed. This resulted in 155 papers to be reviewed in this systematic review. The 'snowball' technique was then applied, leading to 23 additional publications in the form of research papers, books and reports that were added to the collection of the publications. Fig. 1 shows the method used in the literature selection. The final selection of literature included journal articles, conference papers and books. These publications were analysed and classed into four categories: (i) material selection, (ii) conceptual design phase, (iii) design development phase and (iv) design validation. The reason why the publications were classed into these four categories was because they are consistent with the typical design process where materials are selected, concepts are generated, design is further developed and validated.

Data extraction and analysis was conducted when reading the papers in full. Factors for circular packaging design were identified by searching each paper for word repetitions and keywords within the context of circular economy. Findings reported in the papers were summarised and interpreted by the authors of this article, which were also grouped into factors. The term "factors" include design rules, guidelines, considerations and tools which designers can apply in the design process to enable packaging design for circular economy. Upon identifying the factors, the next step was to identify when the designer should consider these factors. This was completed by directly searching each paper to understand the application areas of the factors. This method enabled the identification of circular packaging design factors and the understanding of how and when the factors should be considered. The factors were then classed into the four categories in accordance with the design process, as presented in the last paragraph. Finally, a

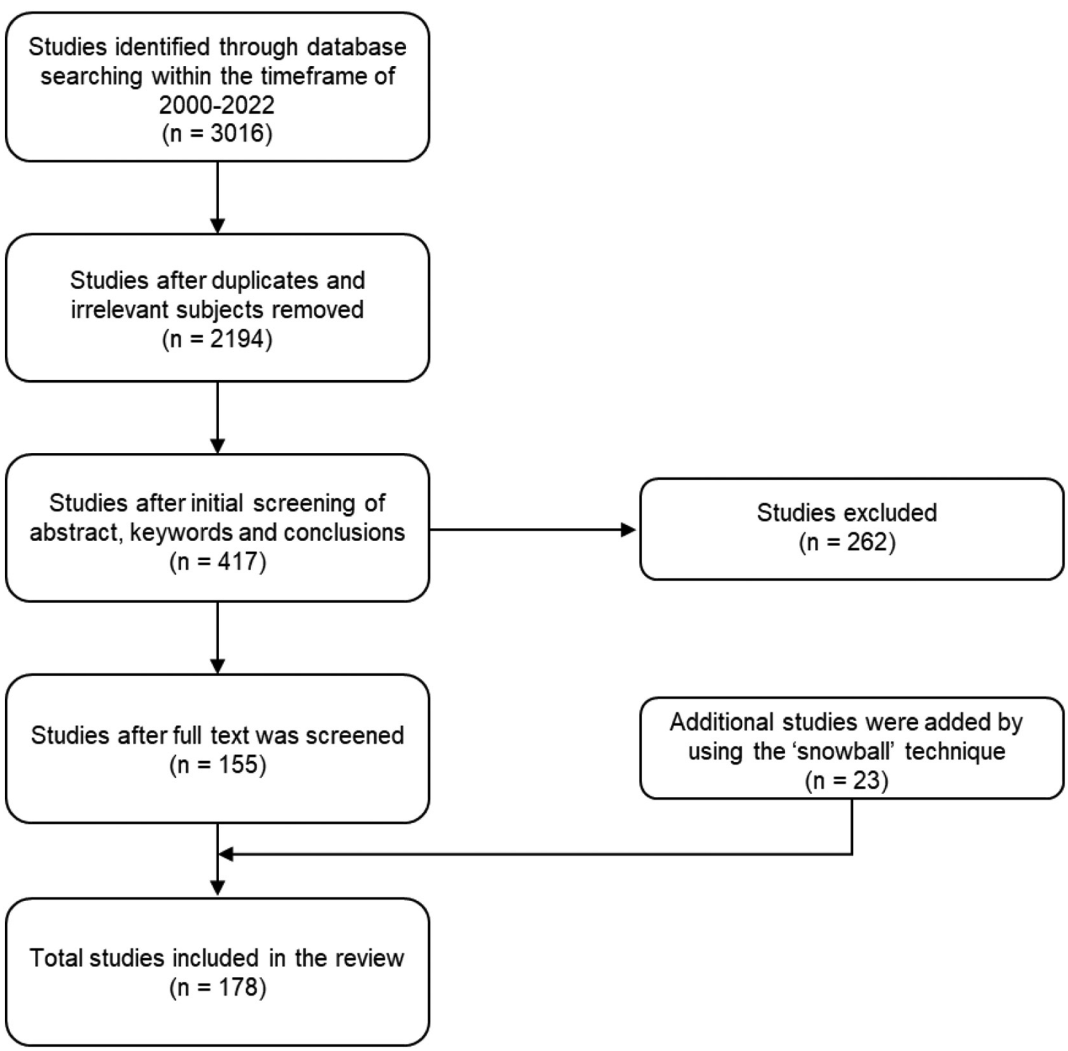

Fig. 1. Workflow of the academic literature review.

framework (in Section 4.5.1) was proposed to aid designers for implementing circular packaging design.

4. Results and discussions

This section focuses on reviewing the state-of-the-art research on packaging design within the context of circular economy. The results of this literature review are presented in Sections 4.1 to 4.4. Section 4.5 provides in-depth discussions on the results and identifies future research opportunities.

4.1. Material selection

4.1.1. Principles of material selection

Material selection is no doubt placed in the heart of the circular economy concept (Ghosh, 2020; Jones et al., 2022). The importance of using environmental friendly materials has been repeatedly emphasised in the literature and many governments' national strategies as well as public media (Geissdoerfer et al., 2017; Morseletto, 2020; Winans et al., 2017). Different types of materials can be used for packaging such as paper, glass, metal and plastics etc., amongst which plastic materials are receiving significant attention as plastic packaging waste accounts for the majority of packaging waste and has become a global issue that endangers the earth ecosystem (Dahlbo et al., 2018; Demetrious and Crossin, 2019; Luijsterburg and Goossens, 2014).

Due to the new and significant changes in legislation within the EU, polymer materials used in packaging should now be properly managed at every stage of the product life cycle. The two critical aspects towards achieving the goal set by the EU are the reduction of the formation of packaging waste and the improvement of the suitability of packaging materials for recovery via material recycling (Czarnecka-Komorowska and Wiszumirska, 2020). The reduction of formation of packaging waste can be achieved by minimising amount of packaging material via proper design (which will be presented in Sections 4.2 and 4.3), reuse of packaging and use of materials that are biodegradable so that they do not end up with landfilling or incineration (Babader et al., 2016). Material recycling can be achieved by means of using recycled materials or materials with a high content of recycled materials (da Cruz et al., 2014; Hopewell et al., 2009). If recycling is not possible, energy recovery (waste to energy) should be considered as an alternative (Jeswani and Azapagic, 2016; Šomplák et al., 2019). Two representative examples that have been adopted in practice are Dell's green packaging (Dell, 2018) and Adidas-Parley A.I.R. strategy (Adidas, 2017). For Dell's packaging trays, more than 93 % recyclable plastics by weight are used, of which the composition includes 25 % ocean-bound plastics and other recycled plastics such as high-density polyethylene (HDPE) used in bottles and food-storage containers. Additionally, the sea-foam running shoes by Adidas are partially made of polyethylene terephthalate (PET) fibre and nylon recovered from plastic bottles and gill nets, respectively (Romeo, 2017).

In addition to the material selection principles related to circular economy, other principles applied in traditional packaging design are also valid, including (i) enhancing functionality of the packaging materials in terms of protecting product quality; (ii) reducing cost; (iii) using materials that are clean and safe, non-hazardous to human and ecosystem (Abdul Khalil et al., 2016; Sanyang and Sapuan, 2015). The following subsections present the main considerations in choosing a material to use for circular packaging design.

4.1.2. Properties of reused and recycled packaging materials

4.1.2.1. Materials and mechanical properties of reused and recycled materials. The viability of closing materials loops greatly depends on the properties of the reused and recycled materials, namely, whether the materials, or the components and products made of these materials can be properly recovered, reprocessed and redistributed for reuse and recycling, given the remaining properties, characteristics and functionalities (Hahladakis et al., 2018).

Hahladakis and Iacovidou (2018) urged designers and engineers to understand the materials and mechanical properties of packaging plastics, which may gradually deteriorate after multiple uses or reprocessing. Solis and Silveira (2020) reported that plastics usually deteriorate and become unusable after undergoing recycling seven times. For example, Vilaplana and Karlsson (2008) found that the elastic modulus of polypropylene (PP) decreased after reprocessing, indicating the material becomes less elastic and more brittle. The quality of PP packaging was also found to be negatively affected by repeated washing (Coelho et al., 2020). In addition, processing of recycled PET increases the melt viscosity, leading to a reduced flowability of the material in blow moulding, resulting in poor quality of finished products (La Mantia et al., 2012). Whereas for HDPE, mechanical properties remain almost unchanged in multiple reprocessing cycles (Vallim et al., 2009), making it a better material than PP and PET in terms of recyclability. Masmoudi et al. (2020) investigated the mixture ratio of virgin and recycled PET, and the material in a ratio of 70/30 virgin/recycled showed good rheological, mechanical and thermal properties in extrusion and injection moulding. Eriksen et al. (2019) analysed the thermal degradation, processability and mechanical properties of reprocessed PET, PE and PP samples. PET waste is well suited for recycling (closed-loop) and can be recycled multiple times even with a high degree of heterogeneity in the waste. PP (mixed PP waste or individual PP waste packaging types) on the other hand is not suited for recycling. Degradation of PP during recycling was found to be substantial. Houssier et al. (2017) evaluated the effect of the content of ethylene vinyl alcohol (EVOH) in recycled multilayer HDPE food packaging used for out of home consumption products e.g. drinkable yoghurt bottles. Moreover, In Dell's (2018) packaging, as presented in Section 4.1.1, ocean-bound plastics and other recycled HDPE are mixed in a ratio of 1:3, which ensures that the chemical composition and the quality of the end plastic is not significantly influenced by the impurities in the recycled plastics. When comparing different materials for circular packaging design, designers should be aware of the later recycling processes. For example, recycling PET consumes a higher amount of energy due to its resistance to high temperature and the relatively high inertness (Welle, 2011). Jones et al. (2022) further investigated the economic and environmental impact of various polymers. It was found that PP, PE, Polyvinyl Chloride (PVC) and Polylactic acid (PLA) were preferred, because producing them had a lower fossil depletion and recycling them consumed less energy. In addition, due to polyolefin having a higher contaminant sorption rate than PET, recycling polyolefin polymers requires intensive cleaning, which causes increased recycling costs (Palkopoulou et al., 2016). For further information on recycling techniques and plastic waste management, readers are referred to the papers by Sarkar et al. (2022) and Jiang et al. (2022).

In addition, it is worth mentioning that, when the designer is selecting possible materials to use, product application should be one of the first things to consider as it largely restricts the material availability. For instance, refillable packaging for hand wash gels would require the packaging material to be rigid, durable and ideally translucent in certain areas. Whereas, for returnable drink bottles, the packaging material should be elastic, lightweight (for reduction of transport cost) and of good reprocessibility for multiple recycling.

4.1.2.2. Hazards of recycled materials. While using recycled materials is encouraged by the EU's Circular Economy Action Plan (European Commission, 2015, 2020) as an overarching gold rule, it should be warned that certain recycled materials are hazardous to some degree. Designers need to be well informed of potential risks of using these materials in specific applications such as food packaging and packaging for children's toys.

The reason why recycled polymers are hazardous is the presence of phthalates in plastics products from households and industry

(Eriksen et al., 2018; Pivnenko et al., 2016). Phthalates is a class of hazardous polymers to human health, which is usually added as plasticisers in plastics manufacturing. However, completely abandoning the use of phthalates is not always possible as it is a critical additive to help to form desired shapes of products. Additional phthalates may be added in reprocessing recycled plastics (Hahladakis et al., 2018) as well as in a later stage of production (e.g. labelling and gluing), which are generally not removed from recycling of household plastic waste (Wang et al., 2011).

Groh et al. (2019) developed a database of the chemicals used in plastic packaging and the chemicals that are hazardous to human health and the environment. Pivnenko et al. (2016) measured the phthalate content in different sources of plastics including virgin, recycled and waste plastics. It was revealed that more phthalates were introduced in the recycled plastics during recycling. Lee et al. (2014) further discovered that an increase in recycled PET bottles used in food packaging was linked to the increase in childhood exposure to phthalate. In addition to phthalates, Ionas et al. (2014) detected other additives such as flame retardants in children's toys, and it was believed that these additives entered the life cycle of the new products through recycled materials. Leslie et al. (2016) also reported that the banned brominated diphenyl ether (BDE) flame retardants were found at high concentrations in a variety of new and reusable consumer products and packaging including children's toys and automotive components. These bio-accumulative BDE and other persistent substances cannot effectively be separated from plastic waste streams, and hence stricter restrictions should be applied to the use of recycled plastics for certain products and applications.

4.1.3. Bio-based and agro-based materials

In recent years, biomaterials have become a popular packaging material option for packaging designers to pursue the circular economy concept. The rationale behind this is a circular material loop as shown in Fig. 2. Raw material, which can be from food waste, is processed into a form suited for packaging, which is then further processed enabling it to be back to nature and become the raw material again after customer consumption. This subsection summarises the innovations in the development of new biomaterials for the circular economy.

4.1.3.1. Biodegradable polymers commercially available. The concept of 'biodegradable materials' and 'biodegradable plastics/polymers' has always been a favourite for consumers as the perception is that they can be composted into the nature and thus has zero negative effect on the environment (Lambert and Wagner, 2017; Sudesh and Iwata, 2008). Some biodegradable plastics are made by animals, plants, or micro-organisms. In addition, they can also be produced synthetically (Havstad, 2020). Some commonly used biodegradable plastics in packaging industry include PLA, polyhydroxyalkanoates (PHA), polycaprolactone (PCL), polyglycolide (PGA), poly(butylene adipate-*co*-terephthalate) (PBAT) and poly(butylene succinate) (PBS). Civancik-Uslu et al. (2019) performed a case study on the environmental impact of using recycled materials. The virgin petrochemicals, which were the raw materials originally used for producing cosmetic tubes were partially replaced by mineral fillers and/or post-consumer recycled plastics. Results showed that the use of mineral fillers reduced the environmental impact by 12 % in average. The replacement of virgin petrochemicals by recycled plastic decreased emissions up to 29 %. Steenis et al. (2018) categorised design strategies into two groups, namely, biological strategy that uses biodegradable materials, and technical strategy where packaging is designed to be lightweight. The consumer responses to the packaging redesigned by these two strategies were compared. Results showed that consumers were more willing to purchase the packaging using biodegradable materials. In other words, the biological strategy received a higher level of acceptance.

However, there are barriers for adopting biodegradable materials. From the technical aspect, the processing window for biodegradable materials is far narrower than the petroleum-based counterparts, resulting in a lower productivity. From the design perspective, there is a lack of design tools to assist designers to fit packaging mass transfer properties of the biodegradable materials to packaging requirements (Guillard et al., 2018).

While the common sense is that packaging designers are strongly suggested to use more biodegradable plastics that do not cost the earth, there are misconceptions about biodegradable plastics and their impact on the environment, for which designers need to be alert. There has already plethora discussions on this topic (Harding et al., 2017; Lambert and Wagner, 2017; Rujnić-Sokele and Pilipović, 2017; Sudesh and Iwata, 2008). A consensus has reached, that is biodegradable plastics do not necessarily mean 'good for the environment'. Narancic et al. (2018) assessed the end-of-life options for biodegradable plastics and pointed out that biodegradable plastics are not the solution to reduce plastic pollution. While 'biodegradable' means the component polymer molecules can eventually break down under the continued

Fig. 2. An example of a circular loop for biomaterials (Karat Earth, 2018).

effect of microbial action, this biodegradation can only take place on prevailing conditions rather than naturally decompose at a home environment e.g. garden or trash bin. PLA is a popular biodegradable polymer used as tumblers for drinks, which is publically advertised as 100 % degradable and compostable. However, Rhodes (2019) reported that PLA does not show significant degradation for over a year by submerging in artificial seawater at 25 °C and do not decompose in a reasonable time scale. Industrial composting facilities are often needed for processing biodegradable plastics and specific conditions need to be met e.g. high temperature and humidity (Shen et al., 2020). Furthermore, a collateral impact is that, as highlighted by Dilkes-Hoffman et al. (2019), industrial composting can result in emission of methane, which is a greenhouse gas. It is also noted that there has not been established international standards to define home-compostable plastics (Filiciotto and Rothenberg, 2021). Having said that, some national standards have been established for home compostability, for example, Standard AS 5810 (Biodegradable plastics suitable for home composting) in Australia (Standards Australia, 2010) and French standard NF T 51-800:2015 (Specifications for plastics suitable for home composting) (French Standards, 2015). Packaging designers are obliged to conform to these established standards if the designed packaging products are to be sold in these countries.

4.1.3.2. New biomaterials. In comparison to not-so-easy degradable 'biodegradable polymers', microbial biodegradable biopolymers - which are made from food waste and allows nutrients to return to the soil - seems to be an eco-friendlier type of materials for a resilient food packaging economy (Guillard et al., 2018). In recent years, mycelium-based composite materials, which are an emerging category of biologically augmented materials, have drawn significant attention due to the production and use of these materials being circular by upcycling of lignocellulosic by-products and biodegrading at the end of life (Elsacker et al., 2020). They are made by natural growth of living mycelium-forming fungal micro-organisms on natural fibres rich in lignin, cellulose and hemicellulose (Abdul Khalil et al., 2016; Jones et al., 2017). These materials are of low density but exhibit excellent insulation properties and high stiffness (Dicker et al., 2014; Ramamoorthy et al., 2015). They can be produced into various shapes, which make them an ideal candidate not only for construction but also packaging materials (Girometta et al., 2019).

Elsacker et al. (2020) reviewed the state-of-the-art in the development of mycelium-based materials and the associated process parameters involved in a series of production stages that affect the characteristics and mechanical properties of the produced materials. Girometta et al. (2019) summarised the thermodynamic and physico-mechanical properties of mycelium-based composites, and the production methods of shaping them into packaging materials, bricks, insulating panels and new-design objects. Shanmugam et al. (2019) reported that recyclable and renewable nanocellulose materials exhibited excellent strength and water vapour permeability comparable to polyethylene (PE) and polystyrene (PS), which can be used as an alternative to polyolefin for food, pharmaceutical and electronics packaging.

In addition to biologically augmented materials, agro materials have also shown promising properties to be used as packaging materials for a circular economy. Andreola et al. (2020) showed some examples of recycling and processing of agro waste and post-consumer residues that were retrieved from vegetable and animal sectors such as spent coffee grounds. These residues are processed into a powder form, which is then subject to low temperature sintering. Lightweight aggregates are one of the typical finished products that can be used for tertiary or transit packaging (Sadh et al., 2018). Moreover, compostable packaging made from cassava starch shows promising environmental and societal impacts compared with petroleum-based packaging (Huntrakul et al., 2020). Engel et al. (2019) tested the viability of using foams made of starch and grape stalks for storage of foods in a low moisture content. Foams were found to completely biodegrade within seven weeks. Casarejos et al. (2018) evaluated the life cycle of cassava starch-based packaging materials. It was found that producing them usually requires more raw material as compared to plastic packaging. However, cassava starch-based materials can be composted and bio-digested, thus fostering raw material and enabling energy recovery.

It is noted that new packaging biomaterials are continuously emerging (Youssef and El-Sayed, 2018), such as use of wheat gluten for food packaging (El-Wakil et al., 2015; Shankar et al., 2019), edible chitosan and cellulose-based packaging material (Pinem et al., 2020), corn and rice starch-based biopolymer as an alternative to HDPE plastic bags (Marichelvam et al., 2019). Some of these materials are in an early development stage and some are towards commercialisation or have been commercialised. Packaging designers are expected to be aware of new biomaterials, and make use of them if applicable.

4.2. Conceptual design phase

Upon selecting appropriate materials, the next phase is to generate multiple packaging design concepts. It should be emphasised that this is an iterative process from material selection to conceptual design given their interconnected nature. This subsection reviews and summaries the factors that designers should consider during the concept generation stage.

4.2.1. Reusable packaging

Reusable packaging certainly fits the concept of circular economy and it is the first choice designers should endeavour to deliver if possible, as it does not incur additional cost in processing recycled packaging and subsequent remanufacture (Lofthouse et al., 2009). In general, reusable packaging can be classed into the following categories: refillable by bulk dispenser (reusable), refillable parent packaging (bottle and container), returnable packaging (container, bottle, cup and plate), and transit packaging (boxes and soft packages).

Mahmoudi and Parviziomran (2020) analysed the factors that affect the impact of reusable packaging on economics and environment. Return rates, transport distances, difficulties and costs in sorting, cleaning and maintenance were found to be negatively affect the benefits of employing usable packaging if either one of the above factors increases. Trade-offs need to be well-balanced between reusable and single-use packaging in terms of materials production, and disposal of single-use materials and increased transport of reusable packaging (García-Arca et al., 2017). In addition, designers need to understand the barriers to the introduction of reusable packaging if they are designing reusable packaging for a market where suppliers and customers traditionally use single-use packaging. Coelho et al. (2020) stated that the introduction of reusable packaging requires a system change not only for producers and retailers but also consumers. This is only possible when the reorganisation of supply chain and new investments in production lines are achieved. Below summaries the barriers for producers, retailers and consumers:

- Producers: increased complexity in logistics; reorganisation of supply chain to cope with the new scenario of packaging and stock; increased costs and delays in handling returned refillable packaging (e.g. containers) especially in global supply chains; significant investments in establishment of a new manufacturing system for reusable packaging (Zimmermann and Bliklen, 2020).
- Retailers: additional warehouse investment for extra space to store returned reusable packaging e.g. containers; additional cost for hygiene requirements for returned packaging (Gustavo et al., 2018); additional cost for regular cleaning and maintenance of equipment e.g. dispensers in sorting and storage of returned containers.
- Consumers: primarily inconvenience caused by (i) using the product (some refillable packaging is not easy to use for different age groups such as elderly people), (ii) taking empty packaging back to retailer

or designated station for refilling, (iii) possibility of refills or replacement being unavailable, and (iv) a higher packaging cost.

Gardas et al. (2019) identified and assessed 14 factors for reusable plastic packaging to be successful, of which reduction in packaging waste, reduced expenses of transportation, packaging and waste management, and effective utilisation of a warehouse space are directly linked to a successful packaging design. However, Gardas et al. (2019) specified that top management commitment, optimised inventory management and lean support are the top three most critical factors for the success of the business model of reusable plastic packaging. Lofthouse et al. (2017) identified some key aspects for a refillable package should have, which are good quality and value, easy to use, and significant reduction of the amount of packaging materials produced and distributed.

4.2.2. Multi-material usage

A general guideline for circular packaging design is that the number of materials used in the packaging should be kept as minimal (Eriksen et al., 2019). This is particularly important for plastic packaging of household products. Household plastic waste is usually heterogeneous and can contain contaminations. This results in recycled plastics being of lower quality, hindering the close-loop recycling process. Leissner and Ryan-Fogarty (2019) examined the plastic packaging waste of single-use infant formula bottles in Irish maternity hospitals. It was revealed that the bottle was usually designed to consist of a high variety of materials e.g. bottles, teats and packaging, which caused difficulties in identifying appropriate waste treatment options. The study suggested that the variety of materials used should be reduced to facilitate the recycling process.

In addition, the use of multi-polymers should be avoided wherever possible. Multi-polymers usually contain impurities, which affects material recyclability and contaminate other recovered plastic waste (Faraca and Astrup, 2019). Multi-polymers are rejected during reprocessing and will be incinerated, causing additional pollution. If multi-polymers have to be used, Eriksen and Astrup (2019) suggested to design individual and separable components, such as modular design, in which case, components made from multi-polymers can be separated and sorted during recycling.

4.2.3. End-of-life options

Radhakrishnan (2016) studied the environmental implications of reuse and recycling of packaging, and stated that the designer should consider and determine the end-of-life option for a product in the design stage. Environmental impact, legislation, packaging quality and cost (e.g. cost of manufacturing and remanufacturing packaging) should all be weighted, which will affect the return policy. Casarejos et al. (2018) suggested designers to rethink packaging, which should be considered as a product for consumers to purchase, own and disposing of. Consumers should purchase packaging products as services, and return the used packaging to the retailer and eventually the producer for credits that are used to purchase new packaging.

4.2.4. Design for logistics

Coelho et al. (2020) demonstrated the increased complexity in logistics and the increased costs associated with such an increased complexity, as presented in Section 4.2.1. For commercial companies, a balance between cost and environmental impact needs to be found. Moreover, the environmental impact is a complicated matter, for example, using reusable packaging reduces waste but increases CO_2 emissions in frequent transportation. Levi et al. (2011) compared two packaging and distribution systems for Italian fruit and vegetables distributed in Europe, which were one-way disposable corrugated containers and reusable plastic containers. Transportation distance and size of packaging were flagged out as the two most important factors.

This suggests that designers need to be mindful of logistics related factors when performing reusable and returnable packaging designs. While the transportation distances cannot be changed, packaging should be reconfigurable to maximum its capacity to accommodate more items in one transport (Farooque et al., 2019). Kuo et al. (2019) conducted a case study where the shipping boxes were redesigned to be reconfigurable. In this case, multiple liquid crystal display (LCD) panels with different sizes could be accommodated, reducing the need for additional containers to transport returned items. Dominic et al. (2015) developed a conceptual packaging model that integrates technical design, environmental factors and supply chain systems, which can be used to improve corrugated container design to reduce the impact of the packaging material on the environment in the supply chain. Gardas et al. (2019) further pointed out that the reduction of transportation cost could be achieved by modularity of packaging and standardisation of the practices.

Researchers have also raised concerns in the increased greenhouse gas emissions during multiple transportations of reusable packages. A typical example is demonstrated in the paper by Bernstad Saraiva et al. (2016). The environmental impact of the two materials, i.e. reusable composite and traditional cardboard, used in mango packaging industry in Brazil was compared. A higher amount of electricity used to produce the composite packaging and high fuel consumption in transports of the heavy composite packaging were identified as the major concerns. It was discovered that the CO_2 emissions of transporting the composite packaging for over four times became less environmental friendly in comparison to the single-use cardboard box. It is noted that this was due to Brazil being a large country that required long distance transportation. Furthermore, single-use cardboard is incinerated in Brazil, which helps energy recovery. Therefore, after four reuses of composite packaging, single-use cardboard was found to be a better option. Whereas, results also showed that, the break-even point was reached only after 35 reuses in the European scenario. This means that while designers are generally encouraged to design the packaging with more reuse times, the transportation distances and the resulting greenhouse gas emissions should not simply be neglected.

In addition, local return rate should also be factored into the design process if the product and associated packaging are specifically targeted for a local or regional market. Trošanová et al. (2019) evaluated the collection system of household packaging waste in Slovakia. The packaging waste recycling rate of some materials such as PET beverage packaging was much lower than the recycling target rate set by the EU. The recycling rates were also found to vary across two different cities. Kuo et al. (2019) further added that the recycling rate is a determining factor, which affects the total cost involved in logistics. A higher recycling rate usually incurs a relatively lower cost. Therefore, when there are a few material choices, designers need to be aware of the local return or recycling rates for these materials. Sensible decisions on material selection will need to be made in order to facilitate local waste recycling and thus reduce total cost.

4.3. Design development phase

4.3.1. Functionality of the packaging

While the primary role for packaging is to protect the enclosed product, there are other factors affecting the packaging quality and user experience which are also linked to waste generation (Bou-Mitri et al., 2021). Trollman et al. (2020) pointed out that current research heavily focused on extending product life or using waste as feedstock, however, less attention was given to address the actual cause of waste. Williams et al. (2020) investigated the food waste in relation to unsuitable packaging design. It was found that 'difficult to completely empty packaging', 'broken package', and 'food has quickly gone bad in re-sealable or opened packaging' were the main reasons that caused unnecessary waste. This indicates that food packaging should be designed to be easy to empty and to reseal or reclose, and provide sufficient physical-chemical protection. Schmidt Rivera et al. (2019) advised designers to consider two aspects for food packaging design: packaging increases the total amount of waste, in particular plastics-based packaging, but on the other hand, it reduces food waste as it protects food products and prolongs shelf life. The key indicators for food packaging design include shelf-life extension, food damage reduction and secondary packaging reduction (Khan and Tandon, 2018; Schmidt Rivera et al., 2019). Grönman et al. (2013) further addressed that the environmental impact of food packages were relatively small as compared to the food items contained in the package. Lofthouse et al. (2017) redesigned a refillable packaging for a body wash product and found that the critical factor to ensure success of the refillable packaging was that consumers should be able to easily understand how to refill the primary pack and how to use it. In addition to the durability that a refillable packaging is expected to have, functionality is equally important and should not be compromised.

4.3.2. Size, shape and colour

A general practice from the recycling perspective is to avoid using black or dark colour plastics for packaging. The reason is that the majority of sorting facilities employs Near Infrared (NIR) spectroscopy scanners, which are technically difficult to detect black or dark plastic (Brunner et al., 2015). However, nowadays 10–11 % of the PET, PP and PE plastics used in packaging is black (Eriksen and Astrup, 2019).

With respect to packaging size and shape, designers need to balance the size and cost of refills (Lofthouse et al., 2017). Refillable packaging is usually designed to be large to contain more content in order to maximise the economic benefit but a larger pack incurs a higher cost to be added to the packaging that is already more expensive than single-use packaging. Guillard et al. (2018) suggested that food packaging should be well adapted to the food content. Using well-dimensioned packaging was found to reduce food losses and waste as well as packaging waste. Williams et al. (2020) pointed out that oversized packaging is one of the main reasons that cause food waste, which should be avoided. Additionally, in order to further reduce packaging cost, Zhao et al. (2017) highlighted that the variety of packaging shapes and sizes should be reduced.

4.3.3. Modular design and labelling

Modular design is a design theory that subdivides a product or system into smaller constituent parts, which can be independently designed, modified, produced, replaced or exchanged within the product or between different products and systems (Tseng et al., 2008). Modular design should be adopted if possible for packaging products consisting of different materials and multi-polymers (Eriksen and Astrup, 2019). This facilitates different materials to be separated and sorted, particularly for multi-polymers which cannot be mixed and recycled with other polymers, to avoid the substantial degradation of recycled materials.

In the case study conducted by Niero et al. (2017) on the life cycle of Carlsberg's can packaging for beverage, it was found that designing the body and lids to be easily separated could increase the recyclability of the can, particularly in multiple closed recycling loops. The material compositions together with clear labelling of recycling guidance were also found to be essential to achieve high quality recycling. Radusin et al. (2020) proposed a three-layered PE structure for food packaging, which consisted of virgin outer layers and a mid-layer from recycled flexible PE films. Virgin PE was used for food contact purposes and the use of recycled PE in the mid-layer reduced the need for virgin material. This concept can potentially be applied to modular design where recycled materials can be utilised to produce some of the components. Hospitals were found to be the place where significant amount of plastic packaging and plastic products waste created (Lee et al., 2002; Sajjad et al., 2020). The study by Leissner and Ryan-Fogarty (2019) on the plastic packaging waste of single-use infant formula bottles showed that clearly labelling the recyclability for each component could reduce recycling complexity in waste management.

4.3.4. Embedding circular economy concept into design

The environmental benefit from circular packaging does not only depend on the characteristics of the packaging design (such as materials used and packaging appearance), but also on consumer's willingness to buy these products (Steenis et al., 2018; Wang et al., 2020). The study by Magnier and Schoormans (2015) showed that visual appearance and advertisement affected the perception of packaging sustainability to customers. Steenis et al. (2017) investigated the consumers' response to packaging design from two aspects i.e. packaging materials and graphics. It was found that consumers are willing to spend additional for sustainable packaging. Klaiman et al. (2016) studied consumers' motivation for plastic packaging waste avoidance and found that consumers were willing to pay extra for recycled and recyclable packaging materials, especially plastics. However, the term 'sustainability' itself is ambiguous to consumers and also they heavily rely on inaccurate and sometimes misleading lay beliefs to judge whether the packaging is sustainable. Lofthouse et al. (2017) strongly advised that the idea of circular economy such as using refillable packaging for body wash products should be clearly communicated to consumer, and also allows consumers to easily differentiate between the original and refill pack.

This suggests that it is critical to embed the concept of circular economy in the packaging design to advertise the positive consequences of the product and/or packaging to the circular economy. The review study conducted by Fogt Jacobsen et al. (2022) also suggested that the consumers' willingness on recycling plastic packaging waste is driven by their environmental concerns, and environmental-related messages can increase their motivation for recycling. Thus, designers need to consider how to best position and carry such messages through packaging design, which can help to increase consumers' motivation for recycling. However, Steenis et al. (2018) warned that designers should not over-utilise the concept of circular economy. Having multiple circular economic concepts embedded in a packaging design does not increase customer's willingness to buy or recycle due to very limited additional increase in the moral satisfaction that consumers can obtain from purchasing or recycling the product.

4.3.5. Design pitfalls

Apart from a number of design considerations that help improve the circular packaging design, there are pitfalls that are generally found in traditional packaging designs that designers should stay away. For example, lacquer has been vastly used in beverage packaging (e.g. using aluminium cans) industry. However, Niero et al. (2017) advised that the use of lacquer as well as other substances, even at a very low level (e.g. parts per million level), might have a negative impact on recyclability. The composition of the lacquer can introduce contamination to recycling, and thus affect the material reutilisation. The concept of design for zero contamination should be rooted in packaging design, allowing can-to-can recycling. In addition, as presented above, combining biological strategy with technical strategy or repeatedly use multiple circular economy design strategies neither significantly improves the packaging functionality nor raises the customer's willingness to purchase (Steenis et al., 2018). Furthermore, Lofthouse et al. (2017) proposed some considerations for designing refillable packaging for personal care products such as body wash products. It was drawn to attention that consumers were reluctant to pay extra expenses for the packaging that can be reused for more than 10 times despite the fact that it was functionally possible to refill and reuse the packaging for over 10 times. Customers would prefer to have access to a wide variety of fragrances and therefore refilling for the same fragrance was found to be less desirable.

4.4. Tools and indicators for design validation

Upon completing the detailed design, the designed packaging is subjected to rigorous assessment and validation. A handful number of tools such as life cycle analysis (LCA) tools can be used to facilitate this process. It is worth noting that these tools can be applied in all design phases. This subsection outlines the tools and indicators identified in the literature that has shown potential to assist circular packaging design.

Ligthart and Ansems (2019) and Ligthart et al. (2019) developed an LCA-based tool to assess the environmental impact, waste generation and resource usage. Sehnem et al. (2019) developed a list of indicators for the evaluation of environmental impacts of a packaging design, such as material toxicity, biodiversity, energy use and emissions to air. Lofthouse et al. (2017) presented an 'eco-indicator' table for evaluating the packaging concept from three aspects: production, transportation, and landfill & recycling. Zhao et al. (2017) developed a data mining model. It can reduce the variety of packaging sizes by clustering similar packaging shapes and sizes, which are then replaced by one package model with a size that suits them all. Zhang et al. (2010) proposed five criteria to assess circular packaging design, including (i) reduce, packaging reduction; (ii) reuse; (iii) reclaim, obtaining new energy sources by burning packaging waste without producing secondary pollution; (iv) recycle; and (v) degradability. Measures of circular packaging design were also proposed, requiring designers to enhance consumer's awareness of circular economy and sensibly use logistics package resources. Verghese et al. (2010) developed an LCA tool to assist designers to evaluate the environmental impacts of material production, cleaning of returned packages, transport and waste management processes. Yokokawa et al. (2020) developed an integrated LCA tool that analyses the trade-offs between packaging functionality and environment impact.

Niero et al. (2017) developed a framework consisting of LCA and Cradle-to-Cradle (C2C) certification programme. Niero and Hauschild (2017) examined the C2C design protocol, the framework for life cycle sustainability assessment and material circularity indicator (MCI). The C2C design protocol is based on three principles, which are 'waste equals food', 'using current solar income' and 'celebrate diversity'. The key criteria related to packaging design in C2C certification include material health and reutilisation, carbon management and renewable energy. MCI evaluates how restorative the material is from product production to recycling. The primary factors related in packaging design include the recycled content of the material, recycling rate as well as efficiency of recycling. de Koeijer et al. (2017) reviewed three types of packaging development models and tools, which are protocols, diagrams and evaluations. The evaluation-type models and tools (e.g. LCA) were found to be most useful in the later development stages, whereas protocol-type models and tools were considered lack of tangible descriptions, and thus they had limited effectiveness to assist circular packaging design.

4.5. Discussions and future research trends

4.5.1. The framework for circular packaging design

Based on the literature review presented in the above sections, a framework (Fig. 3) for circular packaging design is derived, which summarises the factors and design considerations that need to be taken into account during the design process. The design strategies as well as the tools and indicators that can be used to assist the design process are also included.

In the framework, the packaging design process is divided into four key phases in sequence, namely, material selection, early design phase (conceptual design), design development phase and design validation phase. The information included in each design phase shown in the framework is extracted from the papers presented in Sections 4.1 to 4.4. It should be noted that the design process is iterative, involving a number of design iterations and evolutions across different phases. The framework is further discussed in the next subsection together with possible future research trends, which is focused on the perspective of packaging designers.

The articles presented in this section are summarised in Table 2.

4.5.2. Discussions and future research opportunities

4.5.2.1. Discussions of current research and future perspectives. Based on the given design requirements, the first step of a packaging design

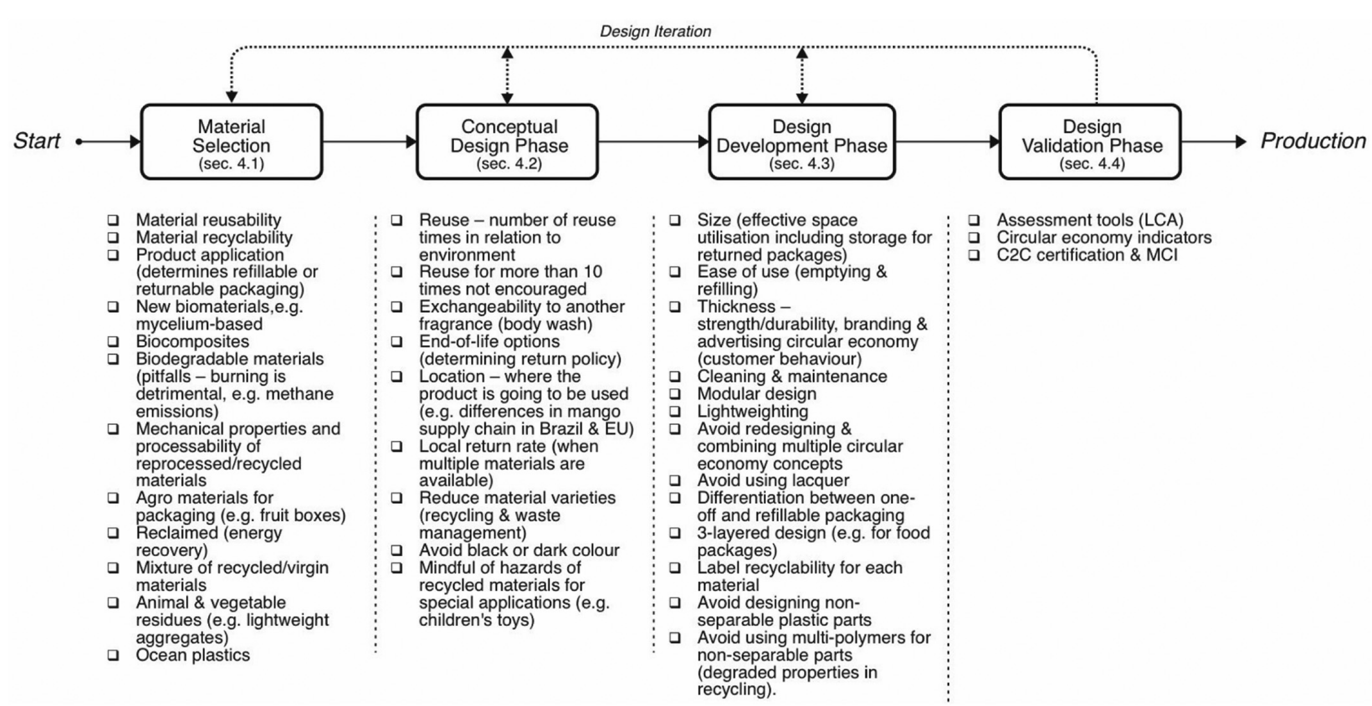

Fig. 3. The circular packaging design framework.

Table 2
Summary of the papers in category, ranging from material selection phase, through conceptual design, design development to design validation phase.

Material selection phase			Conceptual design phase	Design development phase	Design validation phase
Principles of material selection	Reused and recycled packaging materials	Bio-based & agro-based materials			
Abdul Khalil et al. (2016)	Coelho et al. (2020).	Andreola et al. (2020)	Bernstad Saraiva et al. (2016)	Bou-Mitri et al. (2021)	Bernstad Saraiva et al. (2016)
Adidas (2017)	Eriksen et al. (2018)	Casarejos et al. (2018)	Casarejos et al. (2018)	Brunner et al. (2015)	de Koeijer et al. (2017)
Babader et al. (2016)	European Commission (2015)	Civancik-Uslu et al. (2019)	Coelho et al. (2020)	Eriksen and Astrup (2019)	Ligthart et al. (2019)
Czarnecka-Komorowska and Wiszumirska (2020)	European Commission (2020)	Dicker et al. (2014)	Dominic et al. (2015)	Grönman et al. (2013)	Ligthart and Ansems (2019)
da Cruz et al. (2014)	Groh et al. (2019)	Dilkes-Hoffman et al. (2019)	Eriksen and Astrup (2019)	Guillard et al. (2018)	Lofthouse et al. (2017)
Dahlbo et al. (2018)	Hahladakis and Iacovidou (2018)	Elsacker et al. (2020)	Eriksen et al. (2019)	Fogt Jacobsen et al. (2022)	Niero et al. (2017)
Dell (2018)	Hahladakis et al. (2018)	El-Wakil et al. (2015)	Faraca and Astrup (2019)	Khan and Tandon (2018)	Niero and Hauschild (2017)
Demetrious and Crossin (2019)	Harding et al. (2017)	Engel et al. (2019)	Farooque et al. (2019)	Klaiman et al. (2016)	Sehnem et al. (2019)
Geissdoerfer et al. (2017)	Houssier et al. (2017)	Filiciotto and Rothenberg (2021)	García-Arca et al. (2017)	Lee et al. (2002)	Verghese et al. (2010)
Ghosh (2020)	Ionas et al. (2014)	French Standards (2015)	Gardas et al. (2019)	Leissner and Ryan-Fogarty (2019)	Yokokawa et al. (2020)
Harding et al. (2017)	Jiang et al. (2022)	Girometta et al. (2019)	Gustavo et al. (2018)	Lofthouse et al. (2009)	Zhang et al. (2010)
Hopewell et al. (2009)	Jones et al. (2022)	Guillard et al. (2018)	Kuo et al. (2019)	Lofthouse et al. (2017)	Zhao et al. (2017)
Jeswani and Azapagic (2016)	La Mantia et al. (2012)	Harding et al. (2017)	Leissner and Ryan-Fogarty (2019).	Magnier and Schoormans (2015)	
Jones et al. (2022)	Lambert and Wagner (2017)	Havstad (2020)	Lofthouse et al. (2009)	Niero et al. (2017)	
Lambert and Wagner (2017)	Lee et al. (2014)	Huntrakul et al. (2020)	Lofthouse et al. (2017)	Radusin et al. (2020)	
Luijsterburg and Goossens (2014)	Leslie et al. (2016)	Jones et al. (2017)	Mahmoudi and Parviziomran (2020)	Schmidt Rivera et al. (2019)	
Morseletto (2020)	Masmoudi et al. (2020)	Abdul Khalil et al. (2016)	Marinella et al. (2011)	Sajjad et al. (2020)	
Winans et al. (2017)	Eriksen et al. (2019)	Lambert and Wagner (2017)	Muranko et al. (2021)	Schmidt Rivera et al. (2019)	
Romeo (2017)	Palkopoulou et al. (2016)	Marichelvam et al. (2019)	Niero et al. (2017)	Steenis et al. (2017)	
Rujnić-Sokele and Pilipović (2017)	Pivnenko et al. (2016)	Narancic et al. (2018)	Radhakrishnan (2016)	Steenis et al. (2018)	
Sanyang and Sapuan (2015)	Rujnić-Sokele and Pilipović (2017)	NewPack (2021)	Bernstad Saraiva et al. (2016)	Trollman et al. (2020)	
Šomplák et al. (2019)	Sarkar et al. (2022)	Pinem et al. (2020)	Sehnem et al. (2019)	Tseng et al. (2008)	
Sudesh and Iwata (2008)	Solis and Silveira (2020)	Ramamoorthy et al. (2015)	Silva and Pálsson (2022)	Wang et al. (2020)	
Trošanová et al. (2019)	Sudesh and Iwata (2008)	Rhodes (2019)	Trollman et al. (2020)	Williams et al. (2020)	
	Vallim et al. (2009)	Rujnić-Sokele and Pilipović (2017)	Trošanová et al. (2019)	Zhao et al. (2017)	
	Vilaplana and Karlsson (2008)	Sadh et al. (2018)	Zimmermann and Bliklen (2020)		
	Wang et al. (2011)	Shankar et al. (2019)			
	Welle (2011)	Shanmugam et al. (2019)			
		Shen et al. (2020)			
		Standards Australia (2010)			
		Steenis et al. (2018)			
		Sudesh and Iwata (2008)			
		Youssef and El-Sayed (2018)			

usually starts with material selection. Development of new biodegradable materials and biomaterials is a primary enabler for achieving the prospect of a circular economy. The use of materials that is made from renewable resources such as agro waste, which can then decompose naturally has a profound implication to the environment. The EU as well as many national and regional governments around the world have enacted regulations and policies to promote the use of recyclable materials and reduce the consumption of single use plastics (European Commission, 2018d,e; The Federal Government of Germany, 2018; United Kingdom Government, 2020). In addition, the French Government (2020) published specifications for plastics suitable for home composting and the Australian government (2010) also published similar standards for biodegradable plastics. Therefore, designers are strongly encouraged to use biodegradable and recyclable materials, and follow the regulations by the local government e.g. which biodegradable plastics are preferred as well as the local infrastructure for recycling. An example is that, in Slovakia, the PET packaging recycling rate is lower than the EU standard whereas the recycling rate for PP is higher than the EU standard partially due to recycling infrastructure (Trošanová et al., 2019). This suggests that PP is a better option from the CE perspective in Slovakia. Thus, designers should have a proper understanding of recycling circumstances in local areas by checking the latest CE-related regulations and policies and strategies.

When conceiving of a new design concept, designing the packaging to be reusable is desirable. However, it might not always be the best option. The CO_2 emissions incurred in long distance transport for returning and redistributing reusable packaging may have a higher negative impact on the environment (Bernstad Saraiva et al., 2016). Therefore, designers need to carefully consider the trade-offs between return rates, transport distances, difficulties and costs in sorting and cleaning etc. In addition to the reusable packaging concept, packaging should also be designed to facilitate the recycling process and enable resource reuse (Silva and Pålsson, 2022). To achieve this, the number of materials, particularly plastic materials, needs to be kept minimal. If it is functionally necessary to use multiple materials, a preferable method is to design separate components that can easily be assembled and dissembled. Designers are advised to consider modular design, which has been demonstrated as a good strategy to fulfil the design task (Eriksen and Astrup, 2019; Niero et al., 2017). Moreover, a trend has been observed, that is consumers are willing to spend extra for packaging that is sustainable to the environment. This requires designers to embed the circular economy concept in the packaging design to enable effective communication with consumers. Although there are a number of factors in relation to CE that need to be considered in the packaging design, it should be noted that the most critical and essential factor is still the quality of the packaging, which provides sufficient protection to the enclosed product, which should never be compromised with other 'circular economy' factors.

While the studies have shown great potentials of circular packaging design to remit or solve some global environmental issues, its development is still in early stages and a number of challenges are yet to be addressed. Cost is one of the main barriers, not exclusive to circular packaging design but also traditional packaging design methods. The main drivers and motivations for business to perform environmental improvements is to gain economic benefit (Civancik-Uslu et al., 2019). This can be achieved by producing a more valuable product or attracting new customers. One way of gaining new customers is to design a packaging that is environmental friendly and at a low cost. Studies performed by Civancik-Uslu et al. (2019) and Trollman et al. (2020) showed that both customers and manufacturers are willing to work towards the circular economy but only if greater benefits are realistically achievable.

Therefore, looking towards the future, both cost reduction and environment friendliness should be achieved. The development of new biodegradable and biomaterials that can biodegrade quickly is needed. Many of the current so-called "biodegradable" plastics actually take over 200 years to naturally degrade. Moreover, the industrial recycling of them causes significant energy depletion and emissions of hazardous gases (Harding et al., 2017; Lambert and Wagner, 2017; Narancic et al., 2018). New advances in recycling techniques are also expected (Nikiema and Asiedu, 2022; Rahimi and García, 2017), which can reduce recycling costs. This should be coupled with better packaging design which facilitates the later recycling processes.

In addition to the technical advances, designers are expected to take more responsibility to promote the circular economy. An effective ways is to influence customer behaviour via design, whereby encourage customers to reuse existing packaging and/or to return and recycle the used packaging. New design strategies should be explored, which can better embed the CE concept into the packaging design and convey it to consumers. Challenges in consumer psychology should be addressed, embedding incentives in the packaging design to stimulate customers' willingness in the involvement of the consumption revolution from linear to circular.

This literature review showed that there is a lack of robust circular packaging design guidelines. While there are some general guidelines (e.g. reducing the number of materials used) developed in some studies reported in Sections 4.2 and 4.3 (Coelho et al., 2020; Eriksen et al., 2019; Lofthouse et al., 2009), a more complete and detailed design guidelines and rules are significantly lacking. It is thus expected that future research should explore feasible circular packaging design rules and guidelines that can assist designers throughout the design process. In the design validation phase, existing design models and tools in the form of protocols were found to be lack of tangible descriptions that can effectively assist designers to conceive of creative shape geometries and make reasonable decisions (de Koeijer et al., 2017). To meet the increasing demand for designing packaging for closed-loop circularity, efforts should be made to develop design tools such as LCA and establish unbiased and measurable indicators for evaluating circularity of a design and identifying areas for improvement.

In addition, attention should also be paid to education of designers. The circular economy requires a radical change of the way that products, manufacturing processes and supply chains are perceived and operated (Farooque et al., 2019). To embrace with the new packaging design opportunities and significant challenges, the next generation of designers need to be educated and equipped with new design mindsets. An education model should be established to inspire designers to rethink how future packaging products should be designed and to help improve the circularity of resources throughout the production chain (Sehnem et al., 2019).

4.5.2.2. Academic research and policy makers. The advancement of circular economy would not be possible without continued policy support by governments. The EU, member states and other countries have launched new laws, regulations and national strategies to cope with the ever-increasing environment crisis by addressing the importance of the circular economy in various aspects including plastic materials and packaging, recycling, waste management etc. Packaging designers should be aware of laws, policies and strategies relevant to packaging, plastics, waste management and circular economy. For example, the French law (French Government, 2020) requires producers to provide information to consumers to help sorting packaging. When designing packaging products specifically for a region or specific consumer groups in a region(s), the regional policies should be checked and understood.

A general trend is that EU and national governments tend to enact and enforce stricter regulations, which is certainly one way of promoting circular economy. However, governments are also anticipated to explore a more effective avenue to encourage and enable industry to proactively work towards the circular economy. Corporate Environmental Responsibility (CER) is the duty of a company to abstain from incurring detrimental impact to natural environments. Research showed that CER investment directly affected the collection rate (Wu et al., 2020). Governments should endeavour to build decentralised reverse channels that are manufacturer-led, retailer-led and third party-led collection, to reduce transport cost of recycled packaging products and increase average collection profits per used product. This will ultimately form a vibrant mechanism that enables packaging designers to design affordable circular packaging, stimulates distributors and retailers to sell refillable, returnable and recyclable packaging products, encourages consumers to purchase these packaging products and motivates waste management businesses to cost-effectively recycle used packaging products.

In terms of packaging materials, the above analysis of literature has shown that the current so-called "biodegradable" plastics do not always necessarily mean "good for the environment" and "have zero negative impact" (Harding et al., 2017; Lambert and Wagner, 2017; Rujnić-Sokele and Pilipović, 2017; Sudesh and Iwata, 2008). Given that vast majority of the regulations requires to use biodegradable plastics instead of single-use plastics, more support is needed from the policy makers to stimulate industries and academic institutions to develop better materials for designers to choose from. Some suggestions (e.g. reducing the number of material types used in packaging) proposed by Eriksen et al. (2019) and Leissner and Ryan-Fogarty (2019) are included in the EU's "A new Circular Economy Action Plan for a cleaner and more competitive Europe" (European Commission, 2020). Niero et al. (2017) proposed a labelling strategy for packaging where proper labelling can facilitate recycling and improve recycling efficiency. The above mentioned EU circular economy action plan (European Commission, 2020) also states that the Commission will look to promote the EU-wide labelling system that facilitates packaging waste separation at source. It is important that findings in academic research should be communicated to policy makers which can greatly help to form new regulations and policies. Moreover, although reusable packaging is desirable, packaging industry experiences high costs in cleaning and redistributing returned packaging, which has hindered the adoption of reusable packaging (Bernstad Saraiva et al., 2016). Investments should be made by the government on supply chains and infrastructure. The studies by Mahmoudi and Parviziomran (2020) and Muranko et al. (2021) revealed that consumers are sometimes reluctant to purchase products with refillable packaging. Therefore, some governments have introduced new policies to encourage consumers to use reusable and refillable packaging by providing incentives. A good example is the Deposit Return Scheme (Scottish Government, 2020; United Kingdom Government, 2019) where consumers pay a small deposit when they buy a drink and get the deposit back upon returning the empty container.

5. Conclusions

The traditional manufacture and consumption of packaging is linear, namely, packaging is designed, manufactured, consumed, disposed of and incinerated or buried in landfill. The circular economy aims to achieve zero waste and thus resources should be kept in a closed loop as long as possible rather than becoming waste that imposes negative impact on the earth's ecosystem. The introduction of the circular economy concept requires innovations in packaging design as it is estimated that around 80 % of environmental impacts are determined in the design stage (Ahmad et al., 2018; European Commission, 2018c), which largely defines what materials the packaging is made from, how the packaging is produced, consumed, reused and recycled. This is critical for achieving a circular economy. This study is the first academic review to understand the current research on packaging design and circular economy from the design perspective.

This paper reports a systematic literature review on the latest development of packaging design in relation to circular economy. The state-of-the-art research undertaken in various aspects has been reviewed, including material innovation, manufacturing processes of recycled materials, new design strategies for reusable packaging, logistics characteristics, public awareness, design tools and indicators for validating packaging designs. The findings of this review have been presented in Section 4, which are further summarised in the circular packaging design framework, as depicted in Fig. 3. The findings are classed into four categories which are consistent with the design process including material selection, concept design phase, design development and validation phases. The framework shows the design process with the key factors to consider during the process, which can facilitate packaging reuse or recycling. The material selection guidelines and associated considerations for material recycling are presented in Section 4.1. A wide range of design considerations and strategies that can be applied in the design concept generation phase (e.g. considering CO_2 emissions in transportation) are described in Section 4.2 and summarised in the framework. In the design development phase, more tangible guidelines are included such as designing separable parts to facilitate sorting and recycling of waste. Finally, the design evaluation indicators and tools for packaging circularity that have been developed and reported in the literature are collected.

This literature review is largely focused on academic research, however, it was also noticed that industry is actively practicing circular packaging such as Sidel Limited (2020), The Body Shop Internationall Limited (2021), Lush Retails Limited (2021) and Dell (2018). Industrial advances in circular packaging should be reviewed and summarised in the future, which can provide guidance to a wider community of packaging practitioners. Moreover, the research outcome of this study could be beneficial to designers, R&D managers and packaging industry practitioners for developing circular economy oriented solutions. The design considerations identified in this study can be taken as a reference for them when developing circular packaging designs. Educators could also benefit from the findings in this study for education of new generation of talents.

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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