UNDERSTANDING UPCYCLING AND CIRCULAR ECONOMY AND THEIR INTERRELATIONSHIPS THROUGH LITERATURE REVIEW FOR DESIGN EDUCATION

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ABSTRACT

Design and engineering are fundamental activities in shaping the world we live in. Educating new generations in design and engineering, therefore, is crucial to build a better and more sustainable world. The changes in education for the transition from a linear economy to a circular economy, in particular, has become a priority for many educators. Aligned with the circular economy, a promising umbrella concept and practice called 'upcycling' is emerging. The concepts and practices in the circular economy and upcycling overlap depending on the definitions of the terms in various disciplines and sectors in different parts of the world. This has caused some confusion and misunderstanding. For educators aiming to teach students about sustainable design, production and consumption, it is beneficial to distinguish between these two concepts. Understanding the relationships (or interrelationships) between them in theory and practice is important for the educators to offer clear guidance and recommendations to future designers and engineers. This paper provides literature review on upcycling and circular economy, compares these two concepts, and visualises their interrelationship as draft teaching materials for design education.

Keywords: Circular economy, Design education, Sustainability, Transition, Upcycling

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1 INTRODUCTION

Design and engineering are fundamental activities in shaping the world we live in: all the products we use on a daily basis (for personal care, cooking, cleaning, work, entertainment, transportation, etc.) and the built environment that we live and work in are the results of design and engineering. Educating new generations in design and engineering, therefore, is crucial to build a better and more sustainable world - economically, socially and environmentally. The changes in education for the transition from a linear economy (based on take, make, use and dispose) to a circular economy (based on material/resource circularity) (MacArthur, 2013; Stahel, 2016), in particular, has become one of the priorities for many educators especially in higher education institutions (Wandl *et al.*, 2019; van Dam *et al.*, 2020). Aligned with the circular economy (CE), a promising umbrella concept and practice called 'upcycling' is emerging. Upcycling incorporates a variety of material processes including various CE practices (such as 'creative' and/or 'innovative' repair, reuse, refurbishment, redesign, and remanufacturing) to create a product of higher quality or value than the compositional elements (i.e. used/waste materials, components and products) (Sung, 2017; Singh *et al.*, 2019). The concepts and practices in the CE and upcycling overlap depending on the definitions of the terms provided by academics and practitioners in various disciplines and sectors in different parts of the world (Sung, Singh and Bridgens, 2021). This has caused some confusion and misunderstanding by some academics and professionals, according to multiple anecdotal evidences. For educators aiming to teach students about sustainable design, production and consumption, it is beneficial to distinguish between these two concepts. Understanding the relationships (or interrelationships) between them in theory and practice is important for the educators to offer clear guidance and recommendations to future designers and engineers. Acknowledging such need for clarification and understanding, this paper reviewed literature on upcycling and CE, compared the two concepts, and visualised their interrelationships.

1.1 Project background

The starting point of this study was the British Science Festival (BSF) 2022 event, 'Upcycling Station', at LCB Depot (Leicester's creative hub) in the UK in September 2022 that the author was involved in organising. Nine global experts in upcycling and circular economy (CE) from academia and industry made short videos to explain what upcycling is and how it is related to CE to inform and educate the general public. These global experts are part of the International Upcycling Research Network (funded by UKRI - UK Research and Innovation - AHRC - Arts and Humanities Research Council) which is a two-year research project that started in June 2022. The network seeks to move upcycling from a niche area to the mainstream practice (scaling-up) in CE by establishing the world's first long-term platform to facilitate cross-industry, multi/interdisciplinary and international collaborative research and initiatives, developing theories and practices globally across industries and disciplines, and creating positive synergies between various international actors for collaborative endeavours to understand and promote upcycling (Moalosi and Sung, 2022). Informed and inspired by the BSF2022 Upcycling Station, and as part of AHRC-funded International Upcycling Research Network, a small collaborative project has been set up with the goal of delivering teaching and learning materials that could be used in any formal or informal educational programmes or training sessions regarding the upcycling and CE in higher education institutions and beyond. The project involves literature review, development of teaching materials, and a series of online questionnaires to refine and polish the teaching materials. This paper covers the initial literature review and draft teaching material development.

2 APPROACH

Theoretical, narrative review (Paré *et al.*, 2015) was conducted using one bibliographic database (Google Scholar) for search. Google Scholar was selected since it is known to provide sufficient coverage and publishers' contents (Halevi, Moed and Bar-Ilan, 2017; Harzing and Alakangas, 2016). As search keywords, "upcycling" and "circular economy" (not as a combination but as separate search keywords) were used. The inclusion criteria for screening were: first, English publication, and second, type of publication as journal article, conference proceeding, and PhD thesis. All the other criteria, for instance, publication year or particular disciplines, were not part of inclusion or exclusion criteria. For further screening, titles, abstracts, and main body of publications were checked for the content relevance. The

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review was mainly on the definition of the terms, and descriptions and examples of the relevant principles or practices. Due to the vast amount of data with limited time and resources, an arbitrary cut-off point (first 60 most relevant pieces of literature from the search outcome results) was applied to the search. The search, screening and review were done between October and November 2022.

In the first screening process (based on the inclusion criterion of type of publication), 2 book chapters were excluded from the identified upcycling literature, resulting in 58 publications (52 journal articles, 5 conference proceedings and 1 PhD thesis), and 4 books and 6 reports were excluded from the identified circular economy (CE) literature, resulting in 50 journal articles. In the second screening process (based on contents review), 6 journal articles were excluded from the upcycling literature due mainly to the technical nature of the papers lacking theoretical description or discussion on the concept of upcycling. For example, the technical papers were such as 'catalytic upcycling of high-density polyethylene via a processive mechanism' (Tennakoon *et al.*, 2020) or 'aminolytic upcycling of poly (ethylene terephthalate) wastes using a thermally-stable organocatalyst' (Demarteau *et al.*, 2020). From the CE literature, 8 journal articles were excluded due to the relative insignificance of the contents relevant to the definition, concept, and practices of CE. For instance, the excluded journals focused on CE indicator system in China (Geng *et al.*, 2012) or digitalising CE (Reuter, 2016). After the screening processes, 52 upcycling literature (46 journal articles, 5 conference proceedings and 1 PhD thesis) and 42 CE journal articles were considered for the review. The literature was listed according to, first, year of publication, second, alphabetical order of the first author's sir name, third, second author's sir name, etc. and then alphabetical order of the title. The contents were reviewed and narrated chronologically, incorporating similar contents from other relevant reviewed publications. Theoretical saturation (Low, 2019) was applied to the review narration (i.e. inclusion of contents based on new information added).

3 REVIEW RESULTS

3.1 Trends in reviewed literature

The reviewed upcycling literature (n=52) were published between 2011 and 2022 with the majority being published between 2019 and 2022 (n=39, 75%), while the CE literature (n=42) were published between 2006 and 2022 with the majority between 2016 and 2021 (n=33, 79%). More than half of the reviewed upcycling literature addressed plastic upcycling (n=28, 54%), followed by consumer upcycling (n=7, 14%), fashion and textile upcycling (n=5, 10%), and biowaste upcycling (n=3, 6%). The rest of them were about upcycling silicon photovoltaic waste, wood, and metal as well as policy interventions, general review, upcycling for interiors, upcycling for concrete, and upcycling integrated in industrial design practice. The largest portion of the reviewed CE literature were conceptual papers (n=16, 38%), followed by papers about CE in China (n=7, 17%) and review papers (n=5, 12%). There were three papers (7%) about CE application and evaluation, and another three on product design, product services and business models for CE. The rest of them were about consumption in CE, CE and industry 4.0, CE in chemistry, agriculture, and emerging economies, and CE indicators and measurement.

3.2 Upcycling (definition and concept)

Richardson (2011) described upcycling as a tool for effective design and waste management especially for designers to refashion and integrate discarded components and materials into a range of new products within open-loop cycles in order to reduce household solid waste, add value to waste, and save energy and water. Ali et al. (2013) defined upcycling as reuse of old objects in a new way that does not degrade the materials but increases the aesthetic and environmental values to the invented products. Sung et al. (2014) stated that upcycling is the creation or creative modification of products out of used materials for higher quality or value than the compositional elements. Han et al. (2015) regarded upcycling as a design-based waste solution to optimise the lifetimes of discarded products and create products with a higher retail value than traditionally recycled goods. The first systematic literature review on upcycling (Sung, 2015) identified number of definitions mostly originated from Braungart and McDonough (2002), and provided the collective description of upcycling as: (re)creation of new products with higher values and/or qualities and a more sustainable nature by converting or transforming waste or used materials/products, giving them second life and beyond, while reducing unnecessary resource expenditure. Wilson (2016) considered upcycling as a green practice within the

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realm of product management to transform old products into new products which could be deemed as a green product or green technology that has the goal of protecting the environment and resources by minimising waste and toxicity, conserving energy, and reducing pollution (Schoemaker and Day, 2011). Sung's PhD thesis on upcycling (2017) reviewed different definitions and provided the central idea of upcycling as converting or transforming waste materials or used products into high value or quality outputs, either as products or materials. Bridgens et al. (2018) explained that upcycling is reuse of discarded objects or materials to create a product of higher quality or value than the original. Paras and Curteza (2018) cited Fletcher and Grose (2012) (upcycling is giving new value to materials that are discarded or not being used anymore), Janigo and Wu (2015) (upcycling as repurposing of lower-value items to create a higher-value end of item) and many others to describe upcycling. Singh et al. (2019) defined upcycling as a process in which products and materials that are no longer in use, or are about to be disposed of, are instead repurposed, repaired, upgraded and remanufactured to increase their value. Sung et al. (2019a; 2019b) defined upcycling as the process to retain the high quality and value of used or waste materials, components and products in an open-loop industrial cycle, and to utilise such resources to create a product of higher quality or value than the compositional elements. In the context of plastic upcycling, many authors were talking about converting waste plastics into value-added products (e.g. high-performance fuels, chemicals and materials) using a variety of advanced recycling processes (e.g. Zhuo and Levendis, 2014; Celik *et al.*, 2019; Lewis, Wilhelmy and Leibfarth, 2019; Liu *et al.*, 2019; Rorrer *et al.*, 2019; Chen, H. *et al.*, 2021; Chen, X., Wang and Zhang, 2021). In fashion and textiles, the focus of upcycling has been on refashioning, resurfacing, recutting, redesign and reconstruction of second-hand clothing, and more essentially, recovering intrinsic value and closing the loop of the manufacturing system (James and Kent, 2019).

To summarise, upcycling is an effective design-based solution and green practice:

- utilising the materials, components and products that are discarded, no longer in use or about to be disposed of
- incorporating multiple material processes (e.g. 'creative' or 'innovative' reuse, repurpose, repair, upgrade, redesign, reconstruction, refashion, remanufacture, advanced recycling) involving minimisation of waste and toxicity, saving in energy and water, and reduction in emissions and pollution
- creating the outputs of new/modified products and materials with higher quality and values (economic, aesthetic, environmental) compared to the original/compositional elements.

3.3 Circular economy (definition and concept)

Yuan and Moriguichi (2006) explained that the core of a circular economy (CE) is the circular, closed flow of materials and the use of raw materials and energy through multiple phases, often with the 3R principles (reduce, reuse and recycle) as the approaches in practice (Yong, 2007; Lieder and Rashid, 2016; Heshmati, 2017; Winans, Kendall and Deng, 2017; Patwa *et al.*, 2021). Yong (2007) described CE mission as reducing the material flux and making the material flow balanced between the ecosystem and the socioeconomic system by restructuring the material flow from the linear to the circular approach, raising the efficiency of resource utilisation, and reducing the intensity of emissions. Ellen MacArthur Foundation (2013) defined CE as an industrial system that is restorative or regenerative by intention and design, aiming to rely on renewable energy, minimise, track and eliminate the use of toxic chemicals, and eradicate waste through careful design and management of material flows - allowing biological nutrients to re-enter the biosphere safely and making technical nutrients to circulate at high quality without entering the biosphere (Braungart and McDonough, 2002). Bonviu's (2014) view on CE was the production process designed in a circular way that waste becomes a resource and indefinitely recycled in the economic process. Stahel (2016) explained that CE would replace production with sufficiency by fostering reuse, extending service life through repair, remanufacturing, upgrading, retrofitting, and recycling, therefore closing loops in industrial ecosystems and minimising waste. Bocken et al. (2016), building on Stahel (2016) and Braungart and McDonough (2002), suggested three strategies toward the cycling of resources in CE: (i) slowing resource loops (through the design of long-life goods and product-life extension); (ii) closing resource loops (through recycling); and (iii) resource efficiency or narrowing resource flows (using fewer resources per product). Elia et al. (2017) proposed four categories of actions for CE: (i) circular product design and production (e.g. eco-design to reduce hazardous substances and facilitate product reuse, refurbishment and recycling); (ii) business models (e.g. product

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service systems rather than product ownership, collaborative consumption tools); (iii) cascade/reverse skills (e.g. innovative technologies for high-quality recycling); and (iv) cross cycle and cross sector collaboration (e.g. industrial symbiosis). Geissdoerfer et al. (2017) defined CE as a regenerative system in which resource input, waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops, achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. Kirchherr et al. (2017) and Morseletto (2020) emphasised the CE strategies from Potting et al. (2017): (i) smarter product use and manufacture including R0 Refuse (make product redundant), R1 Rethink (make product use more intensive), and R2 Reduce (increase efficiency in manufacturing); (ii) extend lifespan of product and its parts including R3 Reuse, R4 Repair, R5 Refurbish, R6 Remanufacture, and R7 Repurpose; and (iii) useful application of materials including R8 Recycle and R9 Recover (material incineration with energy recovery) - R0 is more circular and R9 is more linear. Murray et al. (2017) defined CE as an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed to maximise ecosystem functioning and human well-being. Korhonen et al. (2018) listed environmental, economic and social win with CE: (i) reduced virgin material and energy input, (ii) virgin inputs renewable from productive ecosystems, (iii) reduced wastes and emissions, (iv) multiple use of resources in production-consumption system, (v) reduced raw material and energy costs, (vi) minimised use of costly scarce resources, (vii) reduced costs from environmental legislation, taxes and insurance, (viii) responsible and green market potential, (ix) reduced value leaks and losses, (x) reduced waste management costs, (xi) reduced emissions control costs, (xii) new employment opportunities, and more. Saidani et al. (2019) and Grafström and Aasma (2021) mentioned three different levels of CE research and implementation: (i) micro level - enterprises and consumers; (ii) meso level - economic agents integrated in symbiosis; and (iii) macro level - cities, regions, and governments. Similarly, Geng et al. (2019) suggested four levels of CE operation: products, companies (new business models), networks (of companies and customers) and policies (to support markets).

To summarise, CE is an alternative economic model and industrial system (of production and consumption) designed to be restorative or regenerative:

- by (i) restructuring the material flows from the linear approach (take make use and dispose) to the circular one (e.g. slowing and closing resource loops, or narrowing resource flows); (ii) relying on renewable energy, (iii) minimising, tracking and eliminating the use of toxic chemicals, (iv) utilising applicable principles (e.g. refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover), and (v) actioning in circular product design and production, business models, technology development, cross-cycle and cross-sector collaboration, and supportive environment including policies conducive to CE
- operated in micro (enterprises and consumers), meso (economic agents in symbiosis), and macro (cities, regions and governments) levels
- resulting in environmental benefits such as increased resource/material efficiency and reduced wastes and emissions as well as socio-economic benefits such as reduced costs for raw materials, energy, waste management and emissions control, and new employment opportunities

3.4 Explicit overlap between upcycling and circular economy

In the reviewed upcycling literature, CE or material/resource circularity was mentioned frequently (27 out of 52, 52%), and upcycling was, in relation to CE, viewed as, for example: (i) a particular sub-CE practice (e.g. design-led, small-scale, creative reuse) (Bridgens *et al.*, 2018); (ii) a bottom-up social action towards CE (Coppola, Vollero and Siano, 2021) or CE enabler or facilitator (Shi, Huang and Sarigöllü, 2022) in the context of consumer upcycling; (iii) an enabling technology of CE (Liu *et al.*, 2019) or equivalent to advanced/improved recycling as part of CE (Korley *et al.*, 2021) in the plastic industry; (iv) a concept embedding multiple CE strategies (combining circular material flows with slower throughput of products and materials and slower cycles of consumption) (Singh *et al.*, 2019); and (v) one of the key concepts and practices embedded in CE (Sung, Cooper and Kettley, 2019a; 2019b). In the reviewed CE literature, on the other hand, upcycling was less frequently mentioned (6 out of 42, 14%), and it was addressed as: (i) a sub-CE practice (process of converting materials into new materials of higher quality and increased functionality) (MacArthur, 2013; Kalmykova, Sadagopan and Rosado, 2018; Morseletto, 2020); (ii) a concept of retaining or improving the properties of the material in CE (Bocken *et al.*, 2016); and (iii) a concept as opposed to downcycling

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in the context of metal and plastic recycling in CE (Winans, Kendall and Deng, 2017). It is indeed apparent that there are different perspectives and understanding (i.e. how people define each concept and relate one concept to another) coming from upcycling researchers and CE researchers, confirming the anecdotal evidences - confusion and misunderstanding by some academics and professionals about these two concepts especially around the (inter)relationship between them.

4 DISCUSSION

The review confirmed the different understanding by researchers especially regarding the relationship between upcycling and CE. As our project goal is to deliver teaching and learning materials for design education (either formal or informal) in higher education institutions and beyond, the following subsection proposes the draft materials.

4.1 Comparison between upcycling and circular economy and their interrelationships

Table 1 shows the comparison between upcycling and circular economy (CE), clearly distinguishing one from another. Using the comparison table, a draft diagram to show the relationship between upcycling and CE was created (Figure 1).

Table 1. Comparison between upcycling and circular economy

	Upcycling	Circular Economy (CE)
What	Effective, design-based solution and green practice	Alternative economic model and industrial system (of production and consumption) designed to be restorative or regenerative
Input materials	The materials, components and products that are discarded, no longer in use or about to be disposed of	Both virgin materials and the materials, components and products that are discarded, no longer in use or about to be disposed of
Principles or practices	'Creative' or 'innovative' reuse, repurpose, repair, upgrade, redesign, reconstruction, refashion, remanufacture, advanced recycling, and more	Refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover and more
How	- Minimising waste and toxicity - Saving energy and water - Reducing emissions and pollution	- Restructuring the material flows from the linear approach (take make use and dispose) to the circular one (e.g. slowing and closing resource loops, or narrowing resource flows) - Relying on renewable energy - Minimising, tracking and eliminating the use of toxic chemicals - Actioning in circular product design and production, business models, technology development, cross-cycle and cross-sector collaboration, and supportive environment including policies conducive to CE
Outcome	New/modified products and materials with higher quality and values (economic, aesthetic, environmental) than the original/compositional elements	* - New/improved policies, regulations, guidelines, or governance systems - New/improved partnerships or collaborations (industrial symbiosis) - New/improved business models - New/improved supply chain management systems - New/improved production or manufacturing systems - New products for long-life - New products for product-life extension - New biodegradable products - New products using fewer resources

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		- Sharing or leasing services (renting, pooling) - Product service system - New/improved reuse initiatives (e.g. second hand shops) - Incentivised product return service - Upgraded products - Remanufactured or refurbished products and parts - Repaired products - Recycled materials - Recovered energy - …
Operation	In micro (enterprises and consumers) and meso (economic agents in symbiosis) levels	In micro (enterprises and consumers), meso (economic agents in symbiosis), and macro (cities, regions and governments) levels
Benefits	- Environmental benefits such as increased resource/material efficiency and reduced wastes and emissions - Socio-economic benefits such as reduced costs for raw materials, energy, waste management and emissions control, and new employment opportunities	

* Possible CE outcomes were adapted from Bocken et al. (2016) and Lewandowski (2016).

As seen in Figure 1, upcycling is a clear sub-set of CE as a collection of practices based on existing materials (c.f. some of the CE design and production based on virgin materials) resulting in tangible outcomes (products and materials) (c.f. some of the CE innovation based on intangible outcomes such as services). Upcycling has overlap with CE design strategies, and is embedded in CE business and supply chain innovation and management. Upcycling is also supported by the CE policies, regulations, guidelines, etc.

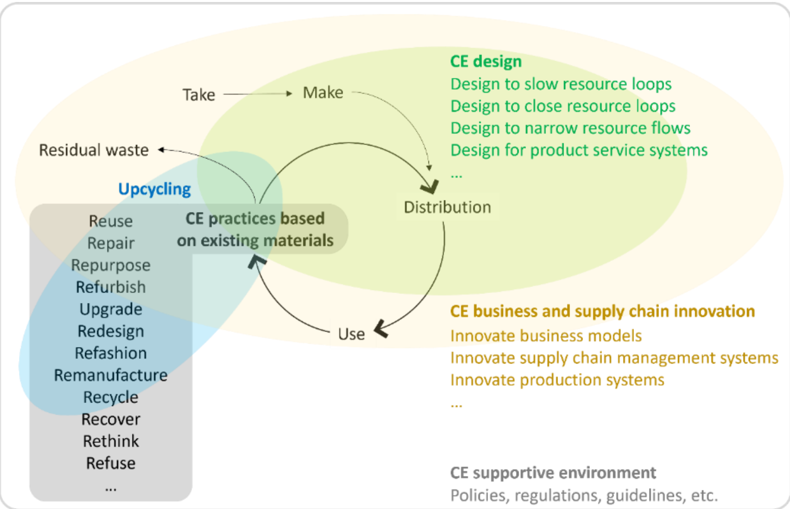

Figure 1. Upcycling as part of the circular economy (CE)

4.2 Limitations

I acknowledge the limitations in the approaches to this review. Theoretical, narrative review does not provide exhaustive results compared to systematic review. The bibliographic database was limited to only one platform. Narrow inclusion criteria were used. An arbitrary cut-off point was applied to the search. Systematic literature review utilising multiple databases including different languages and types of publications without the arbitrary cut-off point could have increased and diversified relevant literature significantly. Search keywords were also strictly limited to only two. Use of the variations of the keywords (e.g. upcycle, up-cycle and up-cycling) could also have made changes in the search results. Inclusion of related concepts such as 'product life extension', 'life cycle engineering', 'end-of-use treatment', 'end-of-life treatment', 'product value retention', and 'material value retention' could have

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yielded different outcomes. I regretfully accept that I did not reflect on these important issues/terms addressed in previous studies. As such, some may not agree with the definitions and descriptions used in this paper. Especially in the areas of engineering and manufacturing, the term, upcycling, has been rarely used. Therefore, discussing or comparing upcycling with CE in manufacturing industry may add more confusion than clarifying things to some people. It is possible that upcycling as a term, concept, or practice may live on in some specific areas but not in, for example, engineering and manufacturing. If that is the case, the value of this paper is not that significant in those areas without the use of the term.
Semantic comparison of two concepts is always a challenging and tricky activity because it may depend on the context or cultural differences between contexts of use of each term. The terms will sometimes have common points or differences depending on where they are manipulated. In this Discussion section, I started with a comparison table assuming that they are comparable (Table 1) but in fact upcycling is part of CE, shown in Figure 1, making these two concepts incomparable as they are not at the same level. Therefore, we now know that the comparison table is not the best way to present the two concepts.

5 CONCLUSION

Despite the limitations, this paper provided good understanding on both upcycling and CE with a summary of literature review results, distinguished between these two concepts with a comparison table, and visualised the interrelationship between them in a form of simple and straightforward diagram. We will test, expand, further develop, and refine the teaching materials (e.g. descriptions, diagram) through a series of online questionnaire with the global experts in upcycling and CE from the International Upcycling Research Network. By end of the project, we hope to deliver effective teaching and learning materials for sustainable design, production and consumption focusing on upcycling and CE that are suitable for design education in higher education institutions and beyond in a formal or informal way. Such materials used in educating new generations in design and engineering are envisaged to contribute ultimately to building a more sustainable world with CE as business as usual.

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