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031

Early Warning, Emerging Issues and Futures

Sustainable production and consumption: Design for disassembly as a circular economy tool

Background

The Foresight Briefs are published by the United Nations Environment Programme to highlight a hotspot of environmental change, feature an emerging science topic, or discuss a contemporary environmental issue. The public is provided with the opportunity to find out what is happening to their changing environment and the consequences of everyday choices, and to think about future directions for policy. The 31st edition of UNEP's Foresight Brief explores global adoption of design for disassembly, transitioning it from a mere good practice to a widespread solution in an effort to tackle environmental challenges.

Abstract

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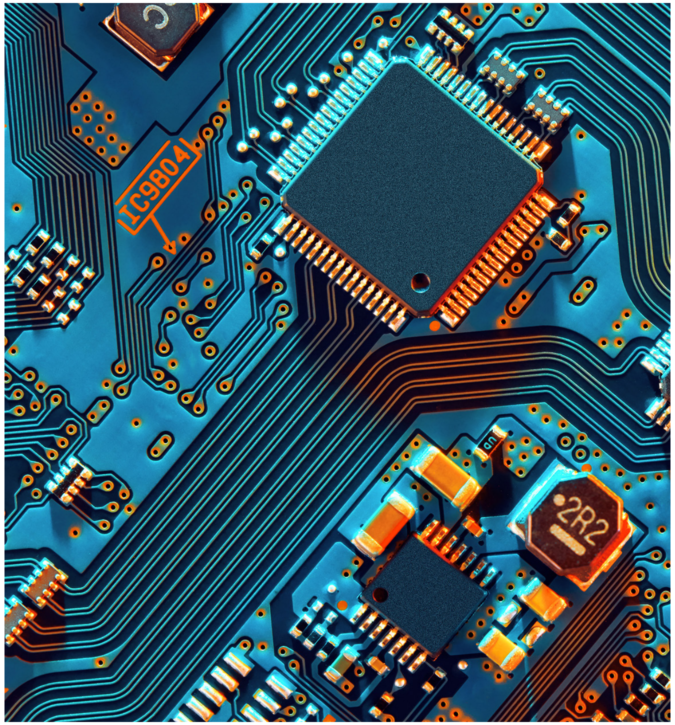
Circular economy practices are increasingly framed as one of the solutions in overcoming the triple planetary crisis. Options, such as design for disassembly, can extend opportunities for developing business models beyond simply creating new products, cutting the carbon footprint of produced goods and therefore limiting greenhouse gas emissions. Limiting the need for new, virgin materials may limit the pressure on ecosystems, maintain biodiversity, and keeping materials in the value cycle longer may lead to cutting pollution.

Introduction

The trend towards integrating different policies that take into consideration gender perspectives relevant to mitigating and adapting to the climate crisis involves wider acceptance and spread of circular economy practices (UN Women 2019). Circular economy is intended to ensure that resources are kept in the economy and at the highest possible economic value for as long as possible. It therefore enables a more efficient use of embedded materials after their end of life in a certain product, service or investment. Several practices enable this result, including design for disassembly.

This Foresight Brief showcases the definition and main principles behind this practice, as well as the challenges and opportunities it brings. It also gives practical examples of its implementations in sectors such as the built environment, electronics and textiles, along with a set of concerns and policy recommendations that could enable shifting the design for disassembly from good practice to common use practice across the globe.



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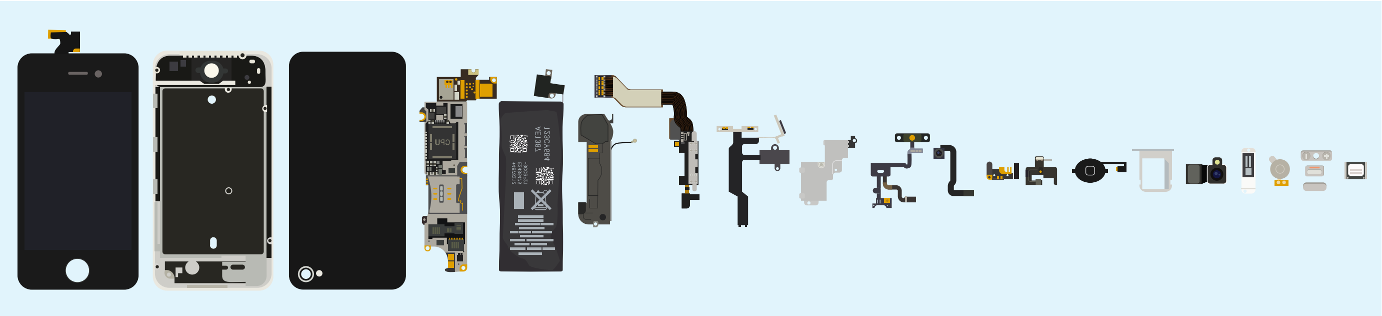

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Why is this an important issue?

According to UN data on the Sustainable Development Goals, global resource use is on the rise, still largely driven by extraction of raw materials (UN 2020). The International Resource Panel (IRP) states that extraction and processing of natural resources contributes to 90% of biodiversity loss and water stress, around 50% of climate change impact and a third of air pollution (IRP 2019). Furthermore, the world's poorest populations especially women are disproportionately affected by the environmental factors, both sustainable and unstainable production and consumption patterns yet, they play significant roles in management of natural resources, acting as key agents of change as consumers and decision makers in both private and public sectors (OECD 2022).

Effective resource use, including (but not limited to) using waste streams from one economic process as a valuable resource for another is portrayed as one of the methods allowing for limiting greenhouse gas emissions from lifecycles and therefore the rise in the average global temperature. According to the IRP emissions from the production of materials increased from 5 gigatons (Gt) of CO_2-equivalent in 1995 to 11 Gt in 2015, with their share of global emissions rising from 15 per cent to 23 per cent. This assessment covers only a limited scope of solid materials, such as metals, wood, construction minerals and plastics (IRP 2020).

The influence that the linear economic model has on biodiversity loss is also becoming more clear with years of scientific research. In recent decades we have seen how the rise in economic capital leads to the decline in natural capital. Exploitation of virgin materials leads to rising pressure on the planet, for example, in the form of extraction of materials, encroaching on natural habitat and threatening further species loss (Dasgupta 2021).

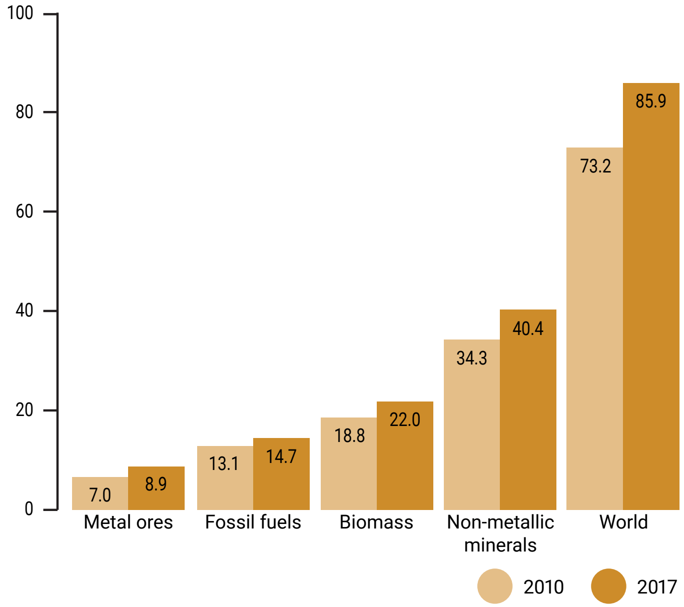


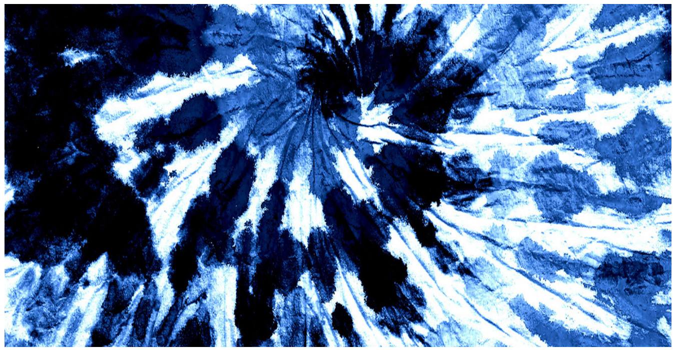
Figure 1: Material footprint by type of material, 2010 and 2017 - billions of metric tons (Source: United Nations, 2020)

In the coming years and decades we will need to simultaneously limit GHG emissions, halt and reverse ecosystem degradation and build the infrastructure needed for achieving the goals of global development, social equity and the green transition. In this context it becomes obvious that a shift from a linear economy, characterized by the "take-make-dispose" mentality, to a more circular one will be of utmost importance.

Integrating gender equality and circular economy practices into climate, biodiversity and pollution policies is an important trend in promoting a holistic view of planetary challenges and the need for sustainable approaches, integrating environmental, social and economic concerns (OECD 2020). In short - a circular economy is intended to ensure that resources are kept in the economy and with the highest possible economic value for as long as possible. It therefore enables a more efficient use of embedded materials after their end of life in a certain product, service or investment.

One circularity practice involves design for disassembly (DfD). Such a practice is defined as achieving the objective of retaining the value of resources (shared by all circularity practices) by ensuring - through proper design - that the product can be easily disassembled, enabling further usage of materials, products and their parts. DfD is seen as one of the building blocks of coherent circularity practices (Hansen 2017).

Its importance is rising in prominence due to e.g. the rising popularity of Life-Cycle Analysis (LCA) or taking a broader view on producer responsibility for the GHG emissions to which they are tied to (Scope 3 measurement showcasing responsibility for the wider value chain). What does DfD look like in practice? Let us look at the examples from three different sectors: building, electronics and textiles.



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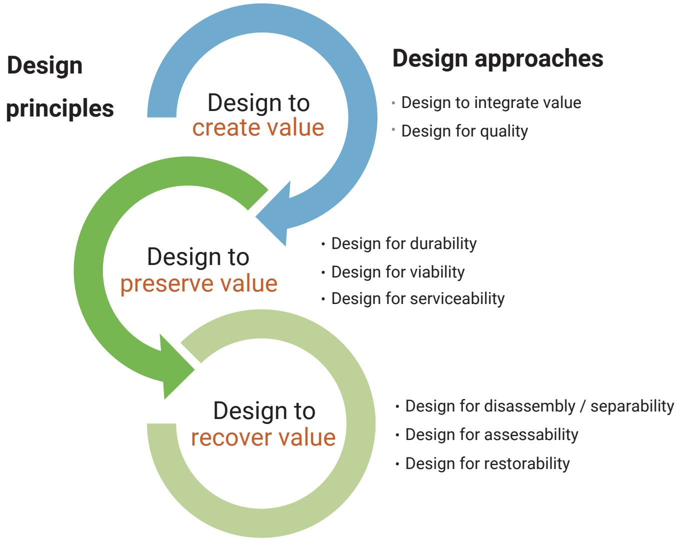

Figure 2: Design for disassembly as part of value retention practices (Source: IRP 2018).

Emerging practices: Main Findings and What is being done

The choice of these sectors stems from the intersection of their impact on climate, resource use and biodiversity, as well as the maturity of ideas and practices implemented within them. They regularly form an integral part of research on circularity, such as the "Circularity Gap Report", as well as being important spheres of contemporary social and economic debates on how to limit the negative influence of humanity on the environment. While the selection of illustrative examples is - due to the brief character of the Foresight Briefs format - subjective, the authors' goal is to give a global overview of the topic.

Building industry

Current trends of population growth, along with the prevailing style of consumption, mean that we face a serious risk of exceeding the limits of most of our global resource stocks by 2050 (UN 2012). An industry that particularly contributes to the growth of this risk is the construction industry, which historically holds a huge proportion of all extracted materials. Moreover, the sector is also the world's largest consumer of raw materials (Cutieru 2020). This trend will likely increase as the majority of buildings standing in 2050 have not yet been built (UNEP 2020a). In Africa, 70% of floor area existing by 2040 remains to be built (IEA 2019). Those figures highlight the opportunity we have to design and therefore build better from the start, with DfD in mind. The current practices prevalent in the industry are responsible for a good share of this negative impact. For example, the most popular connection techniques such as staples or pneumatically driven nails, makes the process of disassembly very difficult and complicated (Guy and Ciarimboli 2003). Furthermore, due to the increasing changes in the intended use of buildings, their expected operational lifespan is also being shortened, even though the materials from which they are constructed are still serviceable (Crowther 2018).

Design for disassembly has great potential to reduce the negative impact of the industry. Researchers indicate that the construction industry has the greatest potential to support circular economy principles. Crowther (2018) states that through the use of DfD, recovery of about 25-50% of total life cycle energy is possible. Finally, Eberhardt, Birgisd and Birkved (2019) conclude that the use of DfD in this industry is necessary to reduce its negative environmental impact. We can also see the importance of this method for the construction industry in EU regulations. In the EU Taxonomy[1], one of the criteria for buildings is the design and construction of buildings to ensure a high degree of removability and adaptability (Broniewicz and Dec 2022).

We can see a consensus in the academic community that the design stage is the most important for reducing project waste (Kanters 2018; Akanbi *et al.* 2019;

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O'Grady *et al.* 2021). Cutieru (2020) advocates the use of readily available and easily disassembled joints to avoid having to use too many, or too sophisticated, tools during disassembly. Bogue (2007) provides extensive guidelines stressing that choosing the right materials and minimizing the number of materials is key. Guy, Shell and Esherick (2006) suggest that materials and components used in construction, following the example of consumer goods, should have special labels that describe their characteristics and composition. Arisya and Suryantini (2021) also suggest that it is very practical to use modularity. By using modules, it is possible to more quickly identify components and materials with potential for reuse.

As is often the case in circularity practices their modern applications have a connection with traditional social and cultural practices. Nomadic built environment has for many centuries been designed with its disassembly and possibility for easy re-use in a different location.

[1] Established in 2020 to clarify which investments are environmentally sustainable, in the context of the European Green Deal

Mongolian yurts can be seen as a case in point, using resources in a way that does not limit the mobility of its users or the longevity of the construction.

One modern example of the use of design for disassembly - in a different setting - may be the city hall of the Dutch city of Venlo. Completed in 2016, the building is a symbol of modern construction and DfD. The materials used in the construction (including furniture) were provided on a buy-back basis, which means they will be able to be sold back to the manufacturer. The building also has its material passport, which describes the material composition of all components, as well as instructions on how to disassemble, recycle and return them to the manufacturer (Ellen MacArthur Foundation 2022). Finally, to facilitate future disassembly and return, no paint or adhesives were used in the furniture.

Examples of Design for Disassembly applications are also present in larger projects than individual buildings. Another project located in the Kingdom of the Netherlands is Park 20|20, located near Amsterdam. The buildings in the complex were designed with circular economy principles in mind. They feature passive design and integrated energy, water and waste management systems. Moreover, each of the buildings has been designed according to DfD principles, which means that they can be dismantled at the end of their lives and the materials used in their construction can be sold. To further reduce the project's carbon footprint, the materials used in construction were recycled (Park 20|20 2022).

Electrical and electronic appliances

The Electrical and Electronic Equipment (EEE) industry creates products that improve our standard of living through their functionality. It includes larger household appliances like a refrigerator or TV, but also smaller personal devices like a phone or headphones. These devices are everywhere and are entering more and more areas of our lives. Already, waste from the EEE (WEEE) is

Dutch city of Venlo; Photo credit: Shutterstock / Ralf Liebhold

one of the most abundant in the world, producing about 45 million tons of waste annually (Bressanelli *et al*. 2020). It is the fastest-growing source of waste, with an annual growth rate of 3-5%. Only about 20% of this volume is properly collected and recycled (Baldé *et al*. 2017). It is projected that as a result of economic progress, the size of the middle class will double by 2030, reaching 4 billion people (Kharas 2017). The increased affluence of such a large population will drive increased consumption of EEE products, which, without drastic changes in their production, will further increase the amount of WEEE. The total weight (excluding photovoltaic panels) of global EEE consumption is estimated to increase annually by 2.5 million metric tons (Mt) (Forti V. *et al*. 2020).

Researchers on the topic note that there are a number of factors that put pressure on the application of DfD in the industry. Such factors include the growing number of waste management regulations, public opinion requirements regarding environmental impact, and increasing competition (Ijomah and Chiodo 2010). Peeters *et al*. (2017) add that the growing middle class will result in limited availability of raw materials, requiring changes in production methods. Using DfD has great potential, as studies show that disassembly-based end-of-life treatment achieves the highest results in the number of precious metals and non-commodity plastics recovered (Peeters *et al*. 2017). (See **Figure 4,** A Systems Thinking Perspective.)

Smartphones are one of the most popular EEE devices. It was forecasted that an additional 1.4 billion smartphones would have entered the market by the end of 2022, bringing their total number to 3.1 billion (Lee *et al*. 2021). Approximately 83% of the total emissions of these devices in 2022 will come from manufacturing, shipping and usage of these new products yet to hit the market (Baldé *et al*. 2022). What's more, smartphones account for 10% of WEEE, and the resources of the six key raw materials that are essential to their production will run out in the next 100 years (Chatterji 2021). Nevertheless, only 17% of all EEE devices are recycled (Baldé *et al*. 2022).

One company that noticed the industry's problems and decided to act differently is Dutch smartphone manufacturer Fairphone. Its products are designed in a modular fashion to maximize their longevity (Fairphone 2022a). The design of the phones allows the user to disassemble them themselves and, using instructions available on the Internet, replace a damaged or obsolete module such as a camera or screen. Furthermore, the company also relies on recycling - in 2020 alone they

Photo credit: Shutterstock / Maxx Studio recycled 17,000 devices in this way. 40% of the recycled devices are repaired and re-sold and the remaining 60% are sent to recycling facilities for recovery of resources (Fairphone 2022b). Fairphone and its operations may represent a new paradigm - not only for other smartphone manufacturers, but also for other EEE product categories.

Copenhagen-born AIAIAI Audio, which specializes in headphones, is pursuing a similar strategy. To maximize the useful life of its products, the Danish company uses design for disassembly during development. The design of the AIAIAI TMA-2 headphones allows users to easily disassemble them so they can replace welded parts, or customize them themselves. In addition, the disassembly of the headphones, along with special instructions available on the company's website, is intended to help users accurately dispose of their components in accordance with circularity practices (AIAIAI Audio 2022).

Textiles

Every second, the amount of clothing that could fill a garbage truck ends up in a landfill (Beall 2020). Poor product quality and low resale value means that clothes are often sent abroad, but there they are often discarded resulting in facilities like the Dandora Dumpsite in Kenya. It is a landfill that would take up a third of the Vatican with its surface area, and its negative impact on women's and men's health of the surrounding population is so significant that a special ward has been opened at a local hospital dedicated to its victims (Textile Mountain 2022). The global apparel and footwear industries account for an estimated 2-8% of the world's greenhouse gas emissions (Quantis 2018; Sadowski, Perkins and McGarvey 2021) and due to inadequate design, only 1% of clothing does not degrade during the recycling process (European Union Parliament 2022). DfD is commonly referred to as 'circular design' in the textiles sector, and may ensure that designers think about how a garment will be reused or recycled from the initial stages of production (Sherburne 2009) (see also 'reduce by design', **Figure 3**).

Textiles consist of materials that are closely interconnected, often on microscopic scales. According to Forst (2020), this complexity of products is the main reason for the low uptake of DfD in the industry. In order to use this practice effectively, three things must happen: consumer preferences must shift towards circular design and reduced overconsumption, designers must create textile products with DfD in mind, and infrastructure must support DfD, including reverse logistics for reuse and textile recycling. The designer needs to combine the standard creative process with simultaneous thinking about how the product will be reused or recycled at the end of its life (Sherburne 2009). Academic research has also identified a number of tips for designers to help implement DfD, and the most important seems to be to refrain from mixing incompatible materials (Sherburne 2009; Forst 2020).

This has been echoed in an Ellen MacArthur Foundation project with the fashion sector to redesign denim jeans for circularity (Ellen MacArthur Foundation 2021), where other identified priorities include take-back schemes

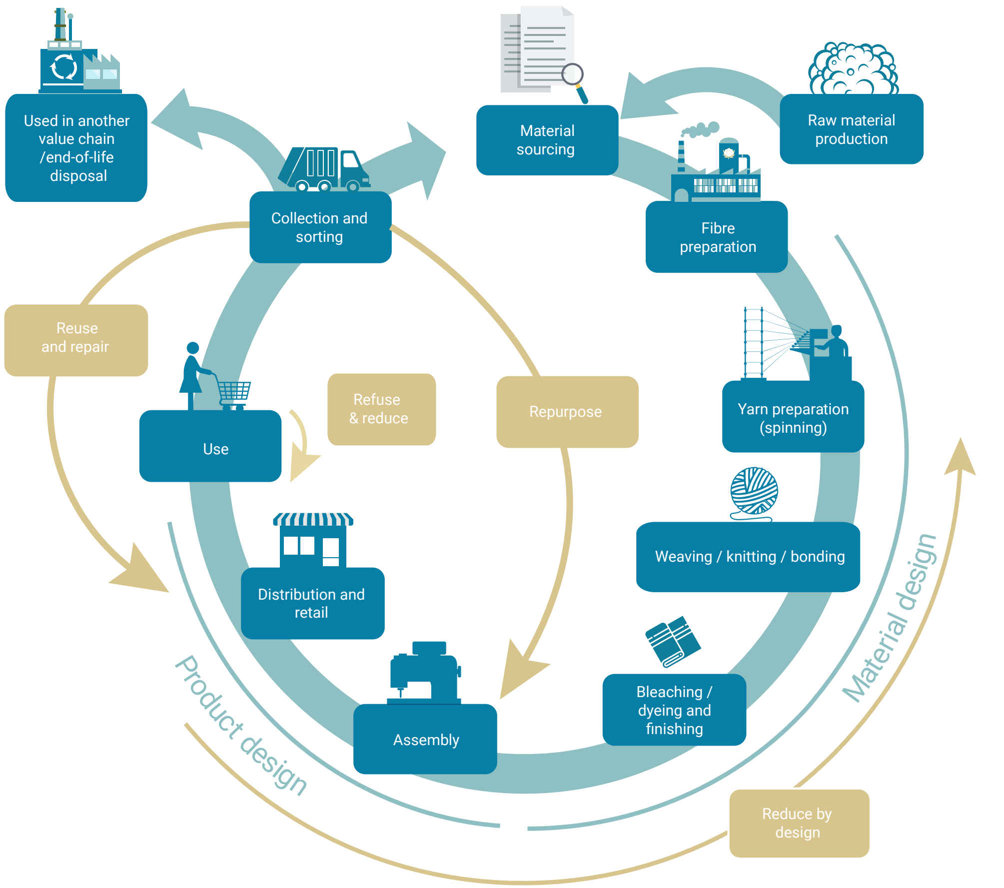

Figure 3: A circular textile value chain (Source: UNEP (2020). Sustainability and Circularity in the Textile Value Chain - Global Stocktaking. Nairobi, Kenya)

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for DfD-compatible products, design component choices (including fabric, thread, zippers, and care labels) and cross-value chain collaboration (e.g. brands collaborating on solutions with fabric mills and manufacturers). Over half a million pairs of jeans have been placed on the market from this project, based on DfD 'made to be made again' principles.

We can already see many practical examples of the application of this way of thinking. In West Africa, wrapper cloths (iro, pagne) are used for multiple purposes, including as a dress or wrap accessory. Indian saris are embellished to increase their value so that they can be handed down from generation to generation. Their design includes the possibility to be wrapped and temporarily pinned to fit different body shapes and sizes (UNEP 2023).

A Japanese-born designer, Yuima Nakazato, may be an example of design for disassembly thinking in this field. His circular TYPE-1 collection consists of dresses, t-shirts and skirts, which are building blocks. Styles can then be created by adding hems, collars and sleeves, which are detachable and fastened by hand using dot press studs. Each of the building blocks features these removable and customisable additions (Mahlich 2021).

The work of British designer, Stella McCartney, is also worth highlighting. Her collection of Loop trainers uses an innovative production method to overcome recycling barriers prevalent in the industry. Instead of attaching the sole to the upper section with glue as is done traditionally, the Loop collection uses interlocking clips and eco-friendly threads (Houghton 2018). With this solution, the product can be disassembled, replaced, or recycled. It also extends the life of a given shoe by enabling the replacement of the soles.

The real driving force behind the change in the textiles market and the introduction of the widespread use of DfD may be technical innovations and disassembly infrastructure investment. Solutions to reduce the lack of competitiveness in this field can contribute to a significant spread of the practice.

Challenges and opportunities

Repair cafes, second-hand shops or sharing economy practices form a part of this growing trend of design for disassembly, accompanied by social movements and regulations, supporting a less wasteful approach or the right to repair. The latter, in particular, focuses on the need to provide easily accessible instructions and repair toolkits. Such changes leads to growing interest in legislative changes, such as promoting repairability stores in France (Stone 2021).

Repairability goes deeper into the issue of easily removing parts of the product (i.e. through modularity) or being able to quickly re-use (i.e. building materials). While at first glance this may seem obvious, producers often point out that in some cases there is a conflict of consumer priorities.

Such is the case with electric and electronic appliances. Due to progress in technologies and design, different appliances such as washing machines became lighter and more visually attractive. That often came at a cost - technological complexity was often connected with unifying built elements, which in turn, made the moving and exchanging of singular parts more cumbersome (UNEP/GRID-Warsaw 2017).

Overcoming such a challenge will - on the one hand - require applying more eco-design principles at the project stage so that possible solutions to this tension can be found. On the other it also requires coherent messaging to consumers about possible trade-offs between, for example, repairability, aesthetics and/or weight of the product to gain more acceptance of such shifts.

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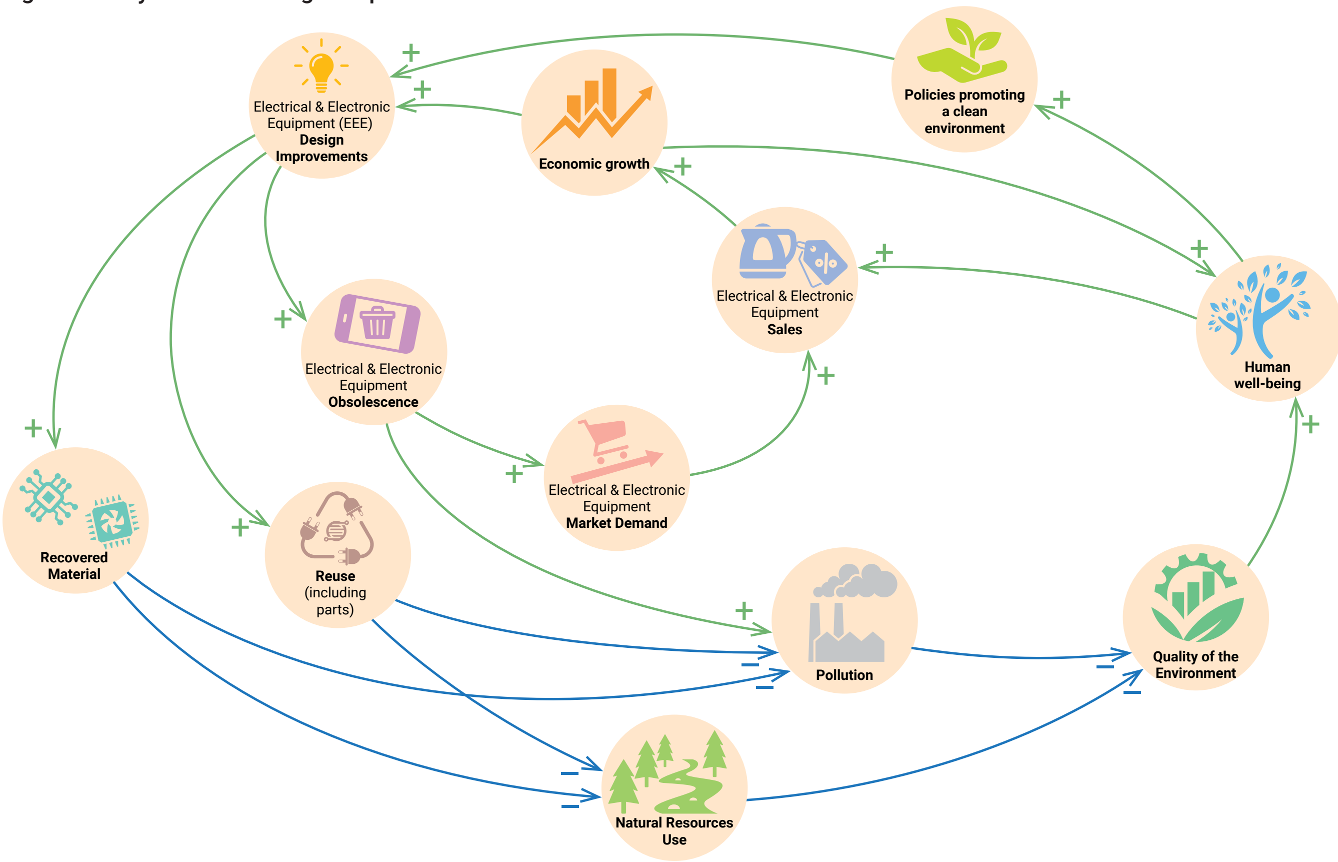
For example – the possibility to easily swap a smartphone battery on the one hand makes a do-it-yourself change easy, while at the same time it may lead to a lower ingress protect (IP) rating for dust and water resistance, that in turn leads to potential higher durability. While such challenges may be overcome (not all non-modular smartphones have high IP ratings, and modular ones can achieve them as well) they need to be clearly communicated – in the same way as discussions (and design decisions) on phone thickness and battery capacity are connected.

It should not be overlooked that consumer priorities are not taking shape in a vacuum. Looking at textiles, many high-profile celebrities today are the ones promoting cheap and disposable fashion, with powerful fast fashion players backing such messaging with big media spending and heavy discounting to encourage purchases. UNEP's Sustainable Fashion Communication Strategy therefore proposes to "build demand and inspire action for a positive fashion future, by changing the dominant narrative of the sector from one of extraction, exploitation and disposable consumption, towards regeneration, equity and care" (UNEP 2021).

Reputational issues are also something that should not be discarded. Ideally, building codes should include design elements conducive to circularity, however, the majority of countries do not even have mandatory building energy codes in place. Therefore, re-thinking codes holds considerable opportunity as it impacts on the entire buildings value chain (UNEP 2022). Prefabricated buildings in some contexts can be seen as less prestigious – and also less environmentally efficient, such as the case of parts of modernist residential high-rises in countries of Central and Eastern Europe (but not limited to such geographies). When buildings are seen as spaces of contemporary social exclusion – and the technology used as obsolete and inefficient – promoting of ideas such as modular education facilities (City of Warsaw 2019) will require additional effort to reframe it as people- and planet-centered.

Figure 4: A Systems Thinking Perspective



A simplified systems thinking view of a design for disassembly approach for Electrical and Electronic Equipment (EEE) manufacturing through a wider web of processes that can improve human well-being as well as promote more sustainable economic growth. A key reinforcing loop is economic growth that improves human well-being which also boosts the sales of EEE leading to further economic growth. Another key reinforcing loop is the manufacturing cycle. Economic growth leads to more EEE technical innovations which results in further design improvements. These improvements in turn cause obsolescence of existing EEE and this also drives the demand for new EEE resulting in increased sales. EEE obsolescence also contributes to pollution. Design for Disassembly policies that encourage the reuse of parts and recovered materials, can reduce the traditional linear use of natural resources. Through reducing pollution this circular economy approach helps improves the quality of the environment which benefits human well-being and promotes further economic growth. Key for reading feedback loops: (+) means influence is in the Same direction, a reinforcing loop, and (-) means influence is in the Opposite direction, a balancing loop.

Source: Adapted from Laurenti *et al.* (2014)

What are the policy implications?

Several challenges to talking in detail about specific circularity practices occur, depending on the levels of knowledge of key stakeholders. Design for disassembly - as other circular practices - intertwine with policies, technological solutions, social awareness particularly through women engagement and its influence on behavior of economic actors, as well as the wider environmental context (OECD 2021). As in other cases these aspects may either support or hinder DfD development.

In the context of local authorities, interest in circular economy practices in many cases is limited to waste management - either due to lack of knowledge or regulatory limitations that hinder creating coherent local circularity policies. It is a challenge not limited to regions in which waste management itself is a challenge. While regulations promoting more responsible resource use are pushed forward the global economy still struggles to reach levels of circularity above 10%, as Circle Economy (2022) yearly research shows.

The nature of the global economy leads to increasing material footprints of humanity due to rising levels of virgin material production and use (UN 2020). The mix of narrowing climate policies to energy issues, along with an above mentioned view of circularity as limited to waste management shifts the focus away from material resource use and efficiency – a trend visible when there is a need to address disruptions such as the war in Ukraine and its influence on energy markets, shifting the focus away from systemic change.

Some trends seem to help to broaden the scope of imagination. Connecting circular economy with the potential of job creation, innovation and - especially - greenhouse gas reductions allows it to be seen as a relevant idea and practice for sustainability policies. A good example is the European Green Deal (EGD) which includes circular economy strategies and policies,

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e.g. with its Renovation Wave Plans (European Commission 2020b). The EU, even before the birth of this vision, had already started work on its circular economy strategies - later on put in the EGD framework (European Commission 2020a) that in turn inspired similar documents in different member states (European Circular Economy Stakeholder Platform 2022). Examples of policy practices include a rising interest in the idea of material passports - a document that would summarize the information about all the materials used, for example in the building sector, that later on allows the re-use of materials embedded in the construction in the spirit of urban mining (Block, Schouten and Dasnois 2020). Another enabling policy includes creating circularity strategies and material flow analysis documents, showcasing both obstacles and opportunities related to local circularity, as well as policy interventions that may have the most profound impacts on local production and consumption patterns, as well as local lifestyles (Circle Economy and Institut Cirkularni Ekonomiky 2019).

The response from parts of the consumer and business community also allows for more space for profitable circular business models. Their growth stems, for example from financial incentives from resource efficiency and a quest for answers to contemporary problems, such as growing costs or supply chain disruptions as mentioned above.

In the case of the electronic sector the insufficient amount of semiconductors, aggravated during the coronavirus pandemic and the demand for equipment necessary for remote working was a moment that showcased the friction in the current, largely linear economic model. A similar reckoning may occur in the building industry as growing labour and material costs may lead to rising interest in circularity practices – in the same way as energy price shocks lead to interest in energy efficient home appliances, thermal insulation or installing renewable energy sources.

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It is worth mentioning that aligning gender responsive approaches in climate and resource policies - besides challenges – offers opportunities as well (United Nations 2022). The Global Alliance on Circular Economy and Resource Efficiency is one of the bodies showcasing this, linking resource efficiency and circular economy to the just transition concept in its global form, as it would allow for a more equitable use of (non-renewable) resources. Issues, such as industrial symbiosis, decoupling economic growth from resources used, or the need to disseminate best practices are also raised by the Alliance (GACERE 2021).

Conclusion

Design for disassembly practices are becoming more prevalent due to a rising awareness of environmental challenges ahead. A more far-reaching view of solutions to the climate crisis, not limited to changes in energy systems, helps in showcasing connections between energy and resource efficiency, as well as wider climate and circularity policies.

Extending the life of products and materials used for its creation – be it in construction, electronics or textiles – is one obvious example of a practice limiting our negative influence on the environment. Design for disassembly allows for easier access to positive outcomes, such as the ones presented in "Re-defining Value. The Manufacturing Revolution" report (IRP 2018). DfD was presented as one of the design principles allowing for the recovery of value and a part of a set of actions limiting material and energy use (as well as the associated greenhouse gas emissions) in comparison to the production of new goods.

Several types of limitations can occur, related to choices of priorities and consumer awareness. Different stakeholders including women and men need to ask themselves how to create an enabling environment (by using tools such as policy, regulation or standards) to encourage and provide guidance on design for disassembly (United Nations Industrial Development Organization [UNIDO] 2023). The role of producers, who design their products, is also important, as they have more liberty to make changes - and a lot to lose if they are perceived as engaging in planned obsolescence of the products they create.

An answer to such challenges requires raising awareness through labelling, giving choices, such as easy availability of spare parts for swift repair, as well as 'choice editing' by e.g. nudging consumers into choosing more sustainable products or reducing overconsumption. It also requires market signals, be they regulatory or financial. If producers and consumers can more clearly see the benefits of choosing options like designing for disassembly – including financial ones (i.e. thanks to more robust implementation of life cycle approaches or reaching recycling goals) - then such practices may become more widespread.

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