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Design for Cyclability: Pro-active approaches for maximising material recovery

Abstract

The holy grail of sustainable design is to develop products whose materials can be eternally re-used. When they reach end of life, they could be taken back to their base materials and transformed into a completely different form or function. In short, a product lifecycle that behaves just like a natural one, repeatedly transforming materials for new cycles of growth.

Whilst certainly attractive, this vision of a never-ending supply of materials that doesn't further deplete our global resources presents a number of challenges. At present, many design approaches to recycling are re-active as they attempt to work with existing waste streams. However, on the journey from raw material to product, previously recyclable resources are often inextricably fused together to create material mixes or 'monstrous hybrids', as coined by McDonough and Braungart (2002), and this ensures a one-way route to landfill.

Designers need to adopt a more pro-active, systems-based approach that truly 'closes the loop'. In order to design fully recyclable textile products, potential barriers to recycling should be identified and 'designed out' at the production stage. This means designers must start to understand the processes that occur at a product's end-of-life in order to ensure it can be fully incorporated back into the materials pool. The author calls this 'Design for Cyclability', a pro-active approach to material preservation which respects materials as borrowed resources, ours to use for a limited time and return for future use.

Here this approach is reflected on through a series of case studies of designer-maker and industry projects and also through the author's own studio practice, developing new production techniques for recyclable textiles, towards a more connected materials economy.

Although pro-active strategies are a key area for designers to develop, re-active approaches will continue to be needed to address the waste already in the system. Both of these options are vital areas for innovation and will be discussed in the context of design strategy.

This paper will introduce lifecycle thinking as a visual framework for design ideation that allows for a deeper understanding of the key issues and barriers to closing the loop on textiles. By mapping the varied routes around and through the lifecycle, we can define new briefs for the designer working towards a more connected material economy.

Introduction

'Design for Cyclability' is the conceptual framework developed for the author's PhD project and on-going research relating to designing closed-loop material systems. Her research interest led her to expand the limited concept of 'recycling practices' into a much broader range of activity 'cyclability' which incorporates now, near and far scenarios enabled by design. This is a long view of material recovery which acknowledges the long life-cycle of many materials and products as compared with a human-centric timeframe, with the average polyester product likely to survive in landfill for over 200 years. The term 'cyclability' expresses this long view and is explored in the following paper.

The idea of a contained and never-ending supply loop of material resources that don't require further materials extraction, from an already depleted global supply, promises a more sustainable future. But the reality of designing in this context presents the designer with many challenges. In order to consider a product's eventual incorporation back into the materials pool, the designer must understand the processes at end-of-life and create products which are truly recyclable. Often, on the journey from raw material to product, previously recyclable resources are transformed and inextricably fused together to create material mixes or 'monstrous hybrids', as coined by McDonough and Braungart (2002), that are guaranteed a one-way route to landfill. How can designers begin to approach working with materials differently, designing them with a recycling system in mind at the outset?

Design for cyclability has been explored through case studies from industry and design and also tested through Goldsworthy's own practice projects (Mono Finishing, Laser Line and Twice Upcycled). There is much evidence of designers working effectively with 'upcycling' strategies, but this only postpones the arrival of the discarded material at landfill if followed without consideration of future cycles. The problem of biodegradability and harmful substances introduced into the environment could still be present. As part of a design brief for cyclability, materials are made to be recycled indefinitely without losing value, and ultimately to consider the 'material ecologies' to which they return. In this interconnected process, unlimited materials can have unlimited life cycles, and the material exchange would be open, dynamic and include all material resources.

Through visual mapping it became clear that there are two ways to approach material recycling for designers: they can either work with existing material waste streams – a 're-active' approach, or they can design from the outset for the product to be closed loop – a 'pro-active' systems approach. Many design approaches to recycling are re-active and could be described as 'extended life techniques' rather than true 'design for recycling'. In order to design fully recyclable textile products, potential barriers to recycling needed to be identified and 'designed out' at the production stages.

In the following text case studies are discussed in the context of these re-active and pro-active approaches.

A re-active approach (end-of-life interventions)

A 're-active approach' begins at the 'point of disposal' with a waste stream as the raw material, and this is by far the predominant approach today. The selected waste stream can be redesigned and reprocessed in many different ways in order to return materials back into use. It is the point on the lifecycle map at which they 'return' that is key in determining the impacts of each particular process. The 'hierarchy of recycling options' (Gertsakis and Lewis 2003) states that the further back in a product's lifecycle journey the recycling process extends, the more energy is used in that transformation. However, as the energy required increases, the value of the resulting material can also be seen to increase.

The diagram in Figure 1 illustrates these 're-active' journeys which start at the point of disposal. Where the cycle fades along its path represents a decreasing material value during subsequent cycles. This will always be the case unless the material goes through a process of 'recovery' which returns it to virgin quality raw materials which can be repeated endlessly.
As shown in the figure, this is the only path which ensures retained material value.

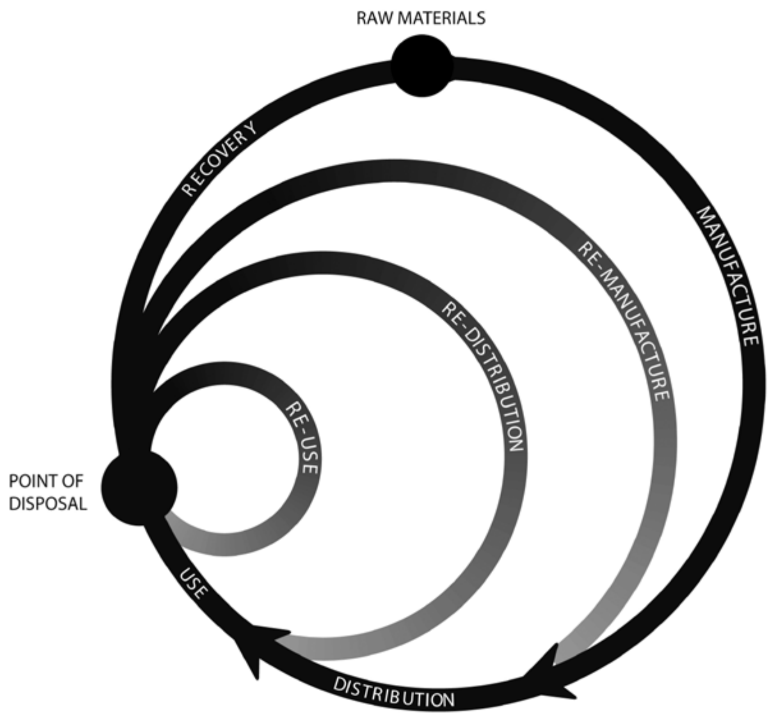

Figure 1. Re-active approaches to recycling, with point of disposal as starting point. Graphics by Louise O'Brien (2013)

Re-use [at product level]

Extend life through prolonged ownership

The least impactful approach is re-use, or in other words extending product lifespan. Here I use the term re-use to refer to prolonged ownership rather than passing on to another user (which I discuss in the following section – 're-distribution'). Although this has obvious environmental benefits it is arguably the strategy which has the least potential for design input. Tactics for prolonging use could include repair and care processes that preserve the value in the product for as long as possible. Environmental impacts avoided with this approach include impacts at every stage of the product lifecycle (materials, energy, emissions and wastes), but changes in consumer habits are very difficult to achieve and potential losses in sales for manufacturers through a reduction in economic transactions often make it a difficult sell to the commercial world.

Re-distribution [at product level]

Re-sale/re-distribution of garments through second-hand markets

Re-use through re-distribution involves the redirection of products which have been discarded in a useful state of repair, to new owners, again without the need for design intervention. Charities and commercial enterprises both play a role here, along with the rising popularity of community-based swapping events such as the Ethical Fashion Forum's 'swishing' or online auction sites such as Ebay or ASOS's Marketplace. A second or subsequent life for these products can be achieved with virtually all the environmental impacts associated with the production of new products cut, bar transportation costs (use of fuels, air emissions) and perhaps laundry between customers (water and detergents). Avoided environmental impacts with this approach include impacts of materials processing and product manufacture (materials, energy, emissions, wastes) plus avoided landfill impacts (air emissions, leachate, visual impact). Again, changes in consumer habits are needed here and economic considerations also include new business opportunities to establish collection and refurbishment services. Ultimately the garments will become too worn to allow further distribution and become waste.

Re-manufacture [at material and product level]

Upcycling or downcycling of materials and products

By far the predominant design approach we see is what I would call 're-manufacture', which is an end-of-life approach to material recycling with design as the agent for transformation. As with the other re-active approaches, it begins with a waste stream at the point of disposal and returns it 'transformed' to another stage in the lifecycle through some process of redesign. The lifecycle stage it returns to can broadly be described as 'manufacture', but this can relate to processes which occur during a broad range of production stages, including fibre, yarn, fabric, finishing and construction processes.

At product level, re-manufacture is used to convert a waste product into a new product of value. This relates to a wide range of activities from updating or refurbishing a product right through to a more complete deconstruction and reassembly, but always starting and finishing with a finished product. It is usually hoped that the process will add value to the re-manufactured product resulting in 'upcycling'. Many of these processes are downcycling the original materials, although value can be elevated through design and aesthetic qualities.

Example: Earley and Goldsworthy (Twice Upcycled)

Rebecca Earley and the author collaborated in the development of a series of *Twice Upcycled* garments (2008). Here the original shirt was bought and worn by a consumer, and then handed on to a second-hand or charity shop, from where Earley purchased it for her Top 100 project. This first upcycling occurred through simple reshaping and overprinting with Earley's heat photogram print technique using re-active dyes, to create an overprint that hides any staining or soiling from the garment's first life. A second life is thus given quickly and stylishly to a polyester shirt that would otherwise take more than 200 years to decompose in landfill. Following a period of wear by the same or next consumer, the shirt can be returned and its third life can be created. For the second upcycling stage, the shirt becomes a quilted waistcoat, where it has been re-cut and lined in recycled polyester fleece, and then laser-welded and refinished, by Goldsworthy. The materials are fused together according to a preset digital pattern, which creates a permanent bond between the layers with surface decoration achieved as part of the same process. It might be possible for this process to be repeated several times as part of a service system.

Figure 2. Twice Upcycled (2008), Earley and Goldsworthy, www.upcyclingtextiles.net

Example: Natalie Chanin (Alabama Chanin)

Natalie Chanin initiated Project Alabama in 2000, a community revitalisation project that combined traditional local craft with re-manufacturing. In 2006, the project was re-formed as Alabama Chanin to maintain the uncompromising, community-based vision for the project. Based in Florence, Alabama, where the designer herself grew up, the company employs local women aged twenty to seventy, to help sew one-of-a-kind, handmade garments, preserving the region's dwindling tradition of quilting. Chanin initially used only vintage fabrics found at local thrift shops, but now relies on bulk shipments from the Salvation Army to fill all the orders. From low-value waste garments the new products created here have value imbued through the skills of the workers and the story told through the label.

Figure 3. Alabama Chanin (2014), www.alabamachanin.com

At material level, re-manufacture design relates to any activity that attempts to take a waste material back to a fibre product either through mechanical or chemical means. This can include everything from shoddy fibre production to certain polymer recycling technologies. But processes that fit this category still relate to downcycling. An example of this would be recycling plastic bottles into fibres through mechanical recycling. The initial recycling produces a quality product; however eventually, over subsequent recyclings, quality is lost to such a degree that eventually further recycling is not possible. For this reason, these approaches can usually only be applied for a limited number of cycles. Avoided environmental impacts with both re-manufacture approaches include impacts of materials processing and product manufacture (materials, energy, emissions and wastes) and landfill impacts (air emissions, leachate, visual impact). However, potential for negative environmental impacts to occur in any reprocessing include transport (use of fuels, air emissions), manufacture of replacement parts (materials, energy, emissions, wastes), re-manufacturing process (materials, energy, emissions, wastes). One of the main challenges is the need to engage the consumer and change their waste disposal patterns, but there are also new business opportunities in re-manufacturing that make this economically attractive.

Example: Michelle Baggerman (Precious Waste)

Michelle Baggerman succeeded in processing used plastic carrier bags without heating or added chemicals and turned them into durable but fine threads with which she created a new fabric, for her graduation project, *Precious Waste*. The plastic was transformed by pure hand-work into a beautiful new material, much stronger than the original. Poor-quality waste materials are transformed into a sophisticated and high-value product.

Figure 4. Precious Waste (2010), Michelle Baggerman, www.bureaubaggerman.com

Example: Luisa Cevese (Riedizioni)

The original 'upcycler' Luisa Cevese has been innovating with waste materials since 1999. As Head of Research for a major Italian textile company, she became aware of the amount and consistency of textile waste. This led her to consider the possibility of a design and production project using these scraps as a resource: large blocks of unusable end pieces, damaged fabric, yarns and threads, salvages, small pieces of uneven cloth and cuts from garments. Having gained some understanding of the plastics industry and technology, she started to combine textile waste with plastic of different kinds, seeing in this new material an opportunity for development which neither a textile- nor plastic-producing company could fully exploit. Different kinds of textile waste, plastic with different properties and different production facilities resulted in different finishes. Although beautiful and enduring, these materials would be problematic to recycle further due to their mixed-material construction.

Figure 5. Riedizioni (2014), Luisa Cevese, www.riedizioni.com

Recovery [at chemical level]

True recycling [cradle-to-cradle] with infinite recovery loops of raw materials or 'nutrients' according to material metabolisms

The only way to retain material value in all future recycling journeys is to create 'closed loops' of material recovery where the inherent value of materials is retained for unlimited future lifetimes. Recovery [at chemical level] follows the principles of 'cradle-to-cradle', as promoted by McDonough and Braungart in their 2002 book of the same name. Cradle-to-cradle processes return materials to their raw chemical components which can then be rebuilt (or grown) into new materials without ever losing quality.

The best example of this is nature's own process, biodegradation, whereby biological nutrients are returned to a form which can support new growth, thus completing the cycle. In our man-made material world the closest we have to this is chemical re-polymerisation, where technical nutrients are returned to manufacturing systems for the production of brand new materials. Avoided environmental impacts with this approach are the most impressive: impacts of manufacturing virgin materials (materials, energy, emissions, wastes), landfill impacts (air emissions, leachate, visual impact), impacts of fertiliser and pesticide manufacture (materials, energy, emissions, wastes, water conservation), carbon sequestered in land or reprocessed into new polymers. There are environmental impacts to be considered in the transport (use of fuels, air emissions) and chemical processes used (materials, energy, emissions, wastes) and again consumers are required to change their waste disposal patterns. But new business opportunities lie in composting services or the re-polymerisation industry, where there is currently a large amount of activity around innovations in chemically recycling mixed-fibre materials for closed-loop systems.

Example: Teijin (Eco Circle)

One example of where it is possible is in the re-polymerisation of thermoplastic polymers, in particular polyester, which represents as much as 70 per cent of global fibre use (Engelhardt 2010) and therefore is significant. The Eco Circle process was developed by Teijin Ltd, a Japanese chemicals company, in 2000. The process uses a reverse chemical engineering process to return polyester fibres back into the building blocks needed to produce virgin polyester. This means that in comparison to the usual mechanical recycling processes, it can work as biodegradation does in perpetual cycles, ad infinitum. The process first breaks down polyester products and granulates them into small pellets. These pellets are decomposed using chemicals and returned into the raw material DMT (dimethyl terephthalate) which can then be polymerised again and finally spun into new polyester fibres (DEFRA 2009: 21).

These two processes are usually mutually exclusive and the natural and technical cycles are, at this point in time, to be kept separate in order for either to be achieved effectively. However, recent developments are challenging this polarity by using biological agents to deconstruct synthetic polymers, and one designer has even managed to demonstrate this potential through a critical design project which seems to achieve the impossible – to reclaim synthetic materials as natural nutrients.

Figure 6. Eco Circle (2006), Teijin, www.teijin.com

Example: Maurizio Montalti (Bodies of Change)

Maurizio Montalti worked with a group of scientists on his graduate project *Bodies of Change* to explore the possibilities of using fungi to literally 'eat' synthetic polymers and return them as nutrients to the soil. Considering the length of time it usually takes plastic to decompose, and the harm it causes when it does, these experiments could have enormous benefit. Maurizio focused the project on an iconic object: the plastic monobloc chair. The 'bio cover', intended as a decomposition tool, literally feeds on the plastic – the fungus gradually chews and substitutes the material, until the new organic material, once plastic, can be used as a natural fertiliser, providing extra nutrients to the soil for the growing of new life.

Figure 7. Bodies of Change (2010), Maurizio Montalti, www.mauriziomontalti.com

But, 'recycling by itself, only postpones the arrival of the discarded material to landfill, where it may never biodegrade, may degrade very slowly, or may add harmful materials to the environment as it breaks down'. A genuinely sustainable future depends on creating closed-loops, 'where materials would never lose their value and would recycle indefinitely' (Livingstone 2003).

The thing that links all but this final example of re-active approaches to recycling design is that none of them can be repeated endlessly to create new materials. Even in the cases of 'upcycling by design' the materials themselves would be 'downcycled' with each reincarnation until eventually they end up on landfill, albeit much later than perhaps they might have done. It is for this reason that re-active approaches alone cannot provide a lasting solution for our finite materials, unless they take materials back to the original chemical building blocks as they do in recovery processes (which on the whole are technology rather than design innovations). In re-active design approaches, the best we can hope for is a series of upcycling stories which will extend the lives of the materials involved through multiple (though not endless) reincarnations. Eventually the materials will be lost to landfill or incineration where their value can never be reclaimed.

A pro-active approach (Design for Recovery)

So, what if we flip the problem on its head? What if we identify the best possible routes for materials value retention (recovery) and *begin* our design process from that point forward? Rather than using waste as a starting point, what if we start from the best possible virgin quality materials and design them to be recovered and retained over and over again? This needs a complete rethink of the design brief to include these aspects at the outset. Design for Recovery is a closed-loop approach which embeds future recycling into the very DNA of the products we design.

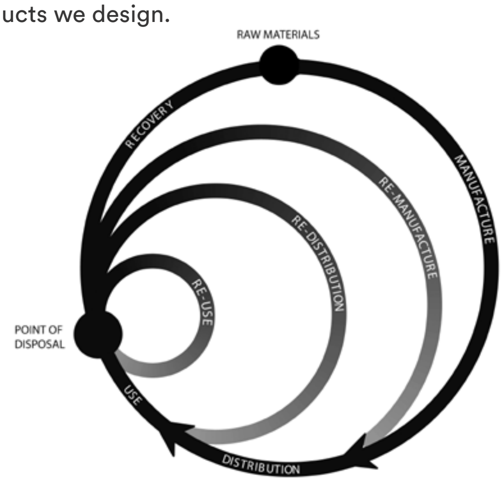

Figure 8. Pro-active approaches to recycling, with raw materials as starting point. Graphics by Louise O'Brien (2013)

In order to do this and to build in true C2C recyclability as part of the design process, a designer needs to understand the systems or metabolisms of the materials they are using and the barriers to recovery for the process they are designing for. The C2C framework described creates systems of consumption and production in which materials move cyclically into appropriate biological or technological nutrient cycles, consistently replenishing themselves. These are closed cycles in which materials are broken down and used as the 'nutrients' for new products. Thus, in this process, 'waste equals food'. Suddenly the brief for design changes completely and becomes design for recovery at the chemical level.

This promotes a methodology which, rather than focusing on logistics and technology to solve our resource problems, places the designer at the centre of the solution (Goldsworthy and Lang 2010). Designers working to this end can adopt many different routes to get there, but there are two main strategies which need to be integrated into the very start of the design process, setting a brief which ensures all materials involved in a product's construction can be recovered through either technical or biological means.

Natural fibres and biopolymers belong to a biological metabolism (the cycles of nature). The source material is usually supplied through agricultural methods such as cotton growing; therefore products should be able to biodegrade and become food for biological cycles. This is not to say that biological textiles cannot be recycled, but due to the processes required they tend to be downcycled into lower quality products. The ideal recycling scenario for these fibres is to be returned to the earth where they harmlessly decompose and become food for plants and animals while rebuilding nutrients in the soil.

Technical fibres or synthetic polymers belong to a technical metabolism (the cycles of industry). These products are predominantly made from non-renewable resources such as petroleum and should stay in closed-loop technical cycles and become valuable nutrients for industry to recycle. It is possible for these materials to be taken back to their original elements through re-polymerisation in order for the material to be of equal quality to the virgin material. These fibres should be returned to industrial cycles when no longer useful, thereby supplying high-quality raw materials for new products.

These two subsets relate to intrinsically different materials with varied properties and recycling needs. For the cycles to function one must not become contaminated with the other. If materials from both cycles are present in one product, such as in blended fibres, separation becomes problematic. If we continue to design blended fibre products without finding a solution to the problem of their disposal, then this problem will endure. Textile production has been moving steadily towards blended fibres in order to produce new functionality, and this has been a serious barrier to recycling levels. Design needs to find solutions which are 100 per cent mono-material without sacrificing functionality.

Design for Recovery: The biological cycle [biodegredation]

There are some inspiring examples of this 'designed in' approach for biological materials. Designing with materials that harmlessly biodegrade back into the environment is the most fundamental example of C2C thinking. However, this is not straightforward; all materials derived from living sources (animal and vegetable) are 'biodegradable', but few decompose in an ecologically safe manner if dyed and finished with chemicals. For example, an organic cotton printed with biologically safe dyes is C2C compliant; the same textile overlaid with even the smallest spot of gloss or metallic finish is not. Therefore, designers working with this idea need to find new ways to achieve the desired design effects that are also environmentally considerate.

Example: Hyun Jin Jeong (Earth dyeing)

Ancient and mostly forgotten, the art of earth dyeing uses soil from different geographic regions to create a varied if subtle colour palette. Chemicals in the textile-dyeing industry have a troubling legacy, but natural dyes are often seen as niche or impractical and in many cases need heavy-metals to fix for usability. For her master's project at Central Saint Martin's, Jeong collected forty-five different soils across South Korea and the United Kingdom. She was able to categorise them into seven different colour families, creating a range of vivid dyes. The benefit of this technique is that no additional mordent is needed to fix the colour, thus removing harmful chemicals from an otherwise natural process. The resulting materials are also completely compatible with natural systems when the time comes to return them to the soil for biodegrading – from soil to soil without harm.

Figure 9. Earth dyeing (2011), Hyun Jin Jeong, www.textilefutures.com

Example: Suzanne Lee (BioCouture)

The BioCouture research project investigated the use of bacterial-cellulose, grown in a laboratory, to produce clothing. The ultimate goal was to literally grow a dress in a vat of liquid. Designer and researcher Suzanne Lee collaborated with material scientist Dr David Hepworth to develop a process whereby fibre is formed in a vat of liquid consisting of a mixture of yeast and sweet tea. When dried, this forms a compact leathery papyrus-like substance. Colour is then achieved with simple food substances such as turmeric, port, curry powder and cherries. The experiment began in 2006 and is still undergoing tests. Eco Kimono, shown at the *Warp Factor 09* exhibition at Central Saint Martins, explored an ancient Japanese technique for waterproofing paper in order to bring the material one step closer to a wearable solution. The material is water and bug resistant whilst being completely organic and biodegradable.

Figure 10. BioCouture (2009), Suzanne Lee, www.biocouture.co.uk

Example: Trigema (Edible fabrics)

A more commercial example is Trigema's edible T-shirt. Trigema partnered with Dr Michael Braungart of the Environmental Research Institute in Hamburg and suppliers, including dye-stuff manufacturer Ciba, to develop a T-shirt which can end its life on the compost heap. They only used components which can be fully biodegraded to substances which are part of the known biological cycle. To achieve this, Trigema used 100 per cent cotton, from the USA and Pakistan, which was free of pesticides and fertiliser residues, and the yarn was spun with natural paraffin. They also used dyes which were specially developed to be biodegradable and also reported to be longer-lasting and truer than standard dyes in addition to their eco- and human-friendly properties.

Design for Recovery: The technical cycle [re-polymerisation]

The above examples represent materials compatible with the biological cycle. However, there are far fewer examples when we are tackling technical materials, primarily because of the complexity of the material systems we have created (as compared to natural materials which are all governed by one system – biology). The key with recovering material for re-use in a technical system is whether or not the recovery can be repeated ad infinitum as it can in nature. In most cases it can't.

Example: Patagonia (Common Threads Programme)

In 2005, Patagonia launched a line of recyclable polyester base-layer garments, and announced a five-year goal to make all Patagonia products recyclable through the Common Threads Garment recycling programme (Patagonia 2009). This program invites customers to return used clothing and delivers the retired garments to Teijin, a fibre manufacturer that uses them to make new products through their Eco Circle chemical recycling process. By 2005, Patagonia had been using recycled polyester for several years. However, this was the first product that – at the end of its useful life – could be collected, chopped up, chemically recycled and spun into new polyester yarn to then sew into a new first-quality garment. Moving to Eco Circle recycled polyester reduces CO2-emissions by 77 per cent and energy consumption by 84 per cent (this relates to fibre and textile production in comparison to using virgin polyester).

Several brands have since joined Patagonia with this approach, including Houdini, a Swedish performance wear brand who became Teijin's first European partner in the closed-loop polyester recycling system Eco Circle in 2006, followed by Finisterre, a UK-based sportswear brand, and more recently Puma, who launched their 'Incycle' range to include products designed for full C2C recycling.

Example: Kate Goldsworthy (Mono Finishing)

The author's own practice project *Mono Finishing* (2008–2011) was a series of monomaterial experiments designed for the technical cycles and in particular for polyester re-polymerisation. The major barriers to this cycle are impurities, chemicals, adhesives or mixed fibre composition. The aim was to explore the potential for new finishing processes to be developed which could improve environmental performance and recyclability. The original work consisted of a series of fully finished textile samples, each demonstrating a different technique developed through access to a new laser-finishing technology at TWI (The Welding Institute) in Cambridge between 2008 and 2009.

Lasers have been used in the apparel industry for some time for cutting, scouring and etching textile materials. Here the laser was used to create surface finishes and new textile composites replacing traditional methods. The environmental advantages of this are clear – no glues, no mechanical stitching, no print pastes or finishing chemicals – making it cleaner than traditional production. Additional benefits include the programmable nature of the technology. These materials are not only recyclable into virgin-quality fibres but each piece can be a design original.

This project also provided the basis for ongoing development of these monomaterial techniques in the Laser Line project (2010–2013) that proposes monomateriality could be extended from the finishing of a fabric through the entire production supply chain of a garment (or other textile product). The first prototype garment demonstrated how the Mono Finishing technique could allow the designer to add surface patterning and seaming to a synthetic textile product in a single process. The end products are constructed from a monomaterial fibre (100 per cent recycled polyester), making them completely recyclable at 'end of life'. It could also help textile manufacturers to reduce their use of materials, water, energy and chemicals whilst permitting shorter production runs, thus reducing cost and risk of wastage. Effects including quilting, flocking, gloss coating and transparency can all be created without added chemicals or adhesives. The technique possesses the advantages associated with digitally-driven manufacture by allowing customised production, finishing and construction to occur close to market and in small production runs.

Figure 11. Mono Finishing (2008), Kate Goldsworthy, www.kategoldsworthy.co.uk

Conclusion

As this paper sets out, there are multiple and complex approaches to recycling design both re-active and pro-active. As a designer it is essential to shift the act of design from a 'product' focused activity to a more systems-based approach. By adopting 'lifecycle thinking' as a visual framework and mapping the varied routes around and through the lifecycle we can define new briefs for the design of materials which can be eternally reclaimed in industrial and biological cycles.

As the paper illuminates, there are currently few truly C2C solutions which can convert waste materials into the highest quality raw materials, but technologies are constantly being developed to address this shortfall in industry, so technology-driven re-active approaches are essential in order to supply new solutions to waste. This technology landscape is changing rapidly and a designer needs to be fully aware of new developments as they occur so they can adapt their practices accordingly.

There are four key pro-active approaches to 'designing for recovery', outlined in this paper, which correspond to current possible recovery options for textile materials, without losing the value inherent in them.

Design for Recovery in the Biological Cycle: design with materials that biodegrade back into the environment safely without leaching harmful dyes and chemicals.

Design for Recovery in the Technical Cycle: design with materials that can be infinitely recycled without compromising original quality.
Use Monomaterials: the simple use of one material makes for a clearer path to recycling for both cycles.
Design for Disassembly: if monomateriality is not possible, use construction methods that use reversible fixings to ensure easier re-use and recycling of monomaterial components.

In conclusion, as long as a C2C framework is followed then all other extended life techniques also become essential and important activities in order to celebrate a diversity of approaches and the slowing down of material cycles. In this way design holds the key to a future of abundance and true cyclability for all valuable material resources.

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