# Research report: sustainable vacuum cleaner adopting circular design principles

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This report aims to discover and evaluate methodologies for minimising the environmental impact of mixed material electronic products, namely by exploring the potential of upcycling to create a circular economy. The report culminates in a Product Design Specification (PDS) to aid a forthcoming exemplar design of a vacuum cleaner.

The circular economy is a closed-loop system that aims to design out waste and pollution in order to reduce unsustainable resource consumption, create new business opportunities, and minimise environmental impact. We are already creating a circular economy through recycling, as well as lesser utilised methodologies such as reuse, repair and refurbishment of products and materials (Ellen MacArthur Foundation, 2023). As the ultimate goal of the circular economy is to keep products, components, and materials at their highest utility and value, it is important to consider prioritising these processes and for this we can look to methodologies such as Life Cycle Analysis (LCA).

LCA's can be a highly contentious issue as the varying scope/depth to which impact is measured mean that they cannot always be compared like for like (due to a number of proprietary datasets e.g. Granta Edupak, GaBi, Thinkstep), and their complexity can make them difficult to interpret such as that without careful inspection the headline figures can sometimes be manipulated in order to fit an agenda. The ISO standards 14040 and 14044 (British Standards Institute, 2006) set some guidelines for LCA's but it is worth considering that we do not always know exactly which impact to measure and also that adverse consequences can arise where design intent does not align with infrastructure and consumer behaviour. One such example is the current move to replace plastic bags with paper bags (The Times, 2020) . This is actually a reversal of prior thinking as the plastic bag was invented in the 1960's in order to replace paper bags which were linked to deforestation (The Independent, 2019). Plastic bags are no doubt a more durable than paper, yet most consumers do not reuse them enough times or properly dispose of them at End of Life (EOL) to offset the pollution associated with a petroleum derived product. As sustainability has become a more prominent talking point in society and begins to weigh more significantly in consumer purchasing decisions (Muhammad Amad Saeed *et al.,* 2019) we are seeing the shunning of plastic and an increase in the number of bioderived polymers, we should think back to plastic bags as an example that changing the material is not a silver bullet solution and that instead sustainable materials requires consideration and weighting of factors such as manufacturing emissions, how durable the product is, and how the product is treated at EOL (BBC, 2019). As we scale up these material evaluations to products we can also see the impact and complexity of other designed factors such as business objectives, infrastructure, consumer behaviour and legislation.

Sustainability is often seen as anti-business- if a consumer keeps their product for longer then business revenues will decline, and also anti-growth as declining business revenues lead to declines in employment, tax revenues, and traditional measures of economic health such as GDP. However

many studies have found that sustainable business models will be good for the economy- creating many opportunities for new businesses, as well as expanding revenue streams for existing companies. There are a huge number of business models that will increase revenue for businesses (Lüdeke-Freund, 2022).

Under capitalism, businesses thrive by selling more products as their main method for generating revenue, and this has incentivised practises such as the drive for iterative annual product cycles and limited repairability that has seen designers taking actions which reduce the recyclability of these devices, e.g. the use of adhesives & proprietary screws (Campbell-Dolloghan, 2019). This is fitting with the theory of 'planned obsolescence': 'the production of goods with uneconomically short useful lives so that customers will have to make repeat purchases' (Bulow, 1986). Designing products to have a purposefully short life-span or which cannot be easily recycled is unethical but the implications of this often go unseen because of waste distancing.

Waste distancing – a descriptor for the adage 'out of sight, out of mind' – refers to the 'growing distance, geographically as well as mentally, between consumers and their waste' (Clapp, 2002, p.1). This is statistically exemplified in figure 1 which shows estimates of the amount of plastic waste generated. Distancing creates problems for overconsumption because it prevents over-consumers from acknowledging the extent of their behaviour. Clapp argues that 'when decision-makers have little knowledge of the ecological and social impacts of the wastes associated with goods they produce or purchase, they have little incentive or ability…to change their habits based on waste considerations' (Clapp, 2002, p.1).

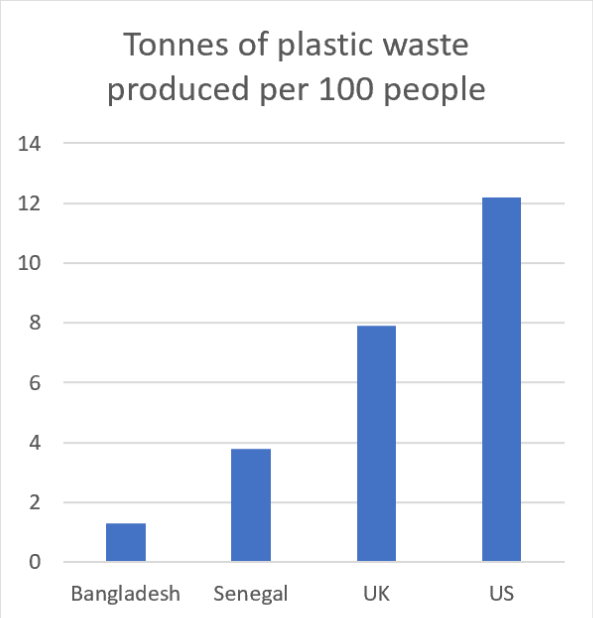



*Figure 1: Comparative quantity of plastic waste produced per 100 people (Ritchie and Roser, 2018)*


*Figure 2: Quantity of plastic waste exports compared to the quantity internally managed (BBC, 2019)*

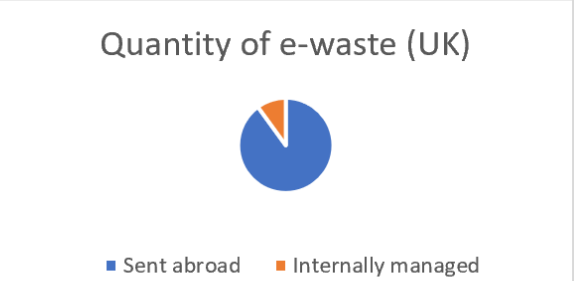



*Figure 3: Quantity of e-waste exports compared to the quantity internally managed (Pellow, 2008, p.237)*

Figures 2 and 3 show that the majority of UK plastic waste is exported. Many of the countries our waste is sent to resort to open air burning of the waste which is a clear sign that they cannot cope with the quantity of our international exports. Distribution of waste to the global poor has three main consequences: economic, environmental & human health. We typically justify our international waste exports based upon the economic benefits they provide, creating jobs in a developing nation,

but waste exportation is a matter of worker exploitation at the lowest socio-economic levels in poorer nations (Mignolo, 2011) because of the unequal relationship between centre and periphery nations based on exploitation (Ghosh, 2001). Dependency theory argues that developing countries become dependent on developed countries for their economic growth, so can only grow in the shadow of developed countries (Ghosh, 2001).

This research shows that reuse and recovery of materials is significantly undervalued, and we can observe this not just on a commercial scale but as a cultural attitude amongst a large subsection of western consumers. Wastefulness can be viewed as a aspirational sign of wealth- whether that be driving inefficient SUV's in urban areas, adhering to the annual upgrade cycle of consumer electronics, and getting drinks in disposable coffee cups.

This cultural phenomena explains why at 37% it is only the minority of people who say that they would buy second hand appliances (TNS, 2014), and according to market data the actual rates are significantly lower- alluding to a significant psychological barrier to frugal consumption.

Vacuum cleaners represent the ideal product to begin testing new methodologies as in the category of electrical products they have one of the highest quantities of embodied greenhouse gas emissions (Product Sustainability Forum, 2012) and are ubiquitous in households (MINTEL, 2010).

The EU ecodesign directive targets 31 product groups that make up the fastest-growing waste streams and vacuum cleaners are one such product singled out for specific enforcement legislation in the EU. This legislation set performance targets across energy consumption, power, dust pick-up, motor life and hose durability (European Parliament, 2013)

Although this directive only lowered annual energy consumption by 10% this led to a saving of approximately EUR 120bn on energy costs for consumers (EU Commission, 2022). With new products able to advertise energy savings it can lead to consumers replacing their product rather than repairing them and it is important to consider how much more efficient a product must be to warrant replacement rather than repair.

One such example of research into making this decision is the PRO-ENDURANCE equation- which gives an output to quantify the durability and environmental impact of trading up to a new product including the improvement in energy efficiency.

$$D'_n = \frac{\frac{P_n}{T} \cdot X + \frac{E_n}{T} \cdot X - (1-\delta) \cdot U_n \cdot X - R_n}{P_n + U_n \cdot T + E_n} \cdot 100$$

Equations such as this can help consumers overcome misleading marketing claims, although interpreting this equation is not be an accessible task for most people, it could be converted into a simple online toolkit to could help consumers feel confident and justify decisions. Research has shown that confidence and trust is a significant barrier across stages in repair and reuse – extending to whether or not repair shops will do an adequate job and charge a fair price (Darby and Karni, cit. in McCollough, 2009). This highlights the need for a source of unambiguous information such as the quality of repair and refurbishing services (BIO by Deloitte, 2013). Through local repairshops there is also an opportunity for expanded community and social connections which are intrinsically linked to confidence and trust - as tends be to the case with local independent stores such as Greengrocers and Butchers shops who are on a first name basis with customers and are trusted to make recommendations about purchasing decisions.

Reflecting on the earlier statistics highlighting the low percentage of consumers that are prepared to purchase second hand appliances we can see that there may also be a lack of trust that these devices will function properly- perhaps a valid concern given that proper product maintenance plays a significant role in preventing product breakdown. There is no guarantee that a previous owner will have kept up with the required preventive maintenance and there is data to suggest most consumers do not - avoiding it as they find it irritating (Electrolux). Data from Which? Identifies common causes of product breakdown – blocked filters and broken brushes. Further empirical research should be undertaken to evaluate which parts of vacuum cleaners the most significant product innovation and efficiency improvements are likely to occur- collating this data can highlight where simple and compelling maintenance and replacement components should be prioritised in the design of a long life vacuum cleaner.

The use of prompts and visual indicators for maintenance is well established, particularly in relation to 'consumable' components: toothbrush brands Oral-B and Phillips Sonicare take two different approaches to this with Oral-B using a visual indicator in the form of colour changing bristles advising replacement whilst Phillips Sonicare uses an accompanying product app to tell users it is time for replacement of brush heads. It would be well advised to seek data on the accuracy of these replacement suggestions and the mechanisms behind them to better understand their accuracy compared to used judgement and weigh up whether they result in improved adherence to maintenance schedules or the deliberate curtailment of a component life span (planned obsolescence).

Effluence and affluence (the economist, 2012) are intrinsically linked and we can see that as a driving factor in wastefulness and our throwaway society. Capitalism puts affluence on a pedestal and people are keen to show that they have achieved this success through effluence and the act of being able to afford to be wasteful. This behaviour can be observed across products both large and small including the prevalence of fuel efficient SUV's in dense cities, replacing rather than repairing a high value appliance, and the semantic allure of disposable coffee cups- projecting a sense of being too busy to sit down and enjoy the beverage in a ceramic cup at the providing establishment.

Fashion trends and accountability should be a much larger focus in making the circular economy an alluring proposition to status focused consumers. We can achieve this perhaps through greater product transparency from brands and consumers about the provenance of products- as suggested by the idea of product passports (European Commission, 2023). A system that could benefit from the increased transparency of the blockchain.

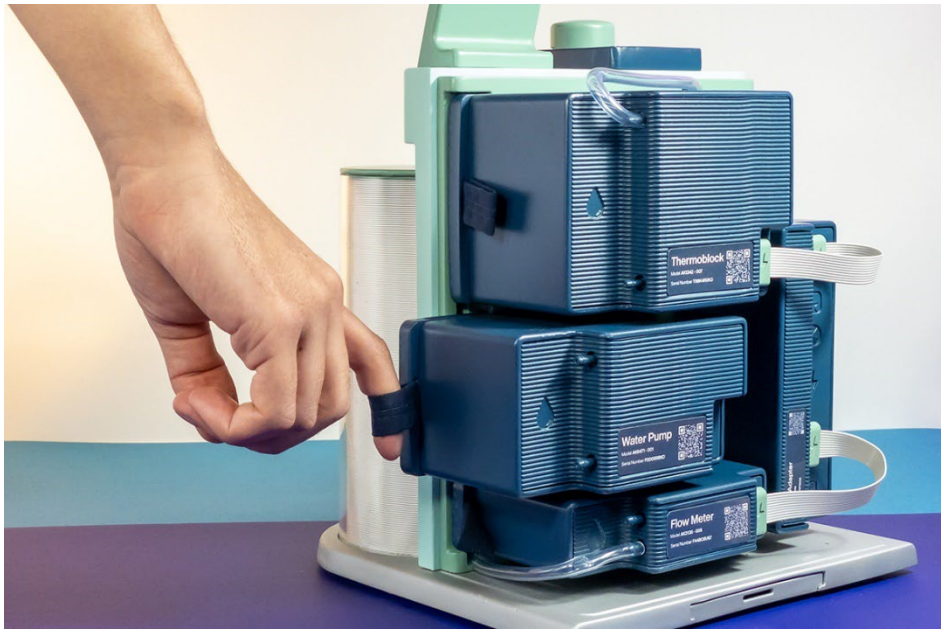
Reuse is currently not fashionable or popular with consumers and there could be several reasons for this including product novelty and concerns about hygiene that arise from seeing a familiar scratched product vs a shiny new one. As such we should consider semantic transformation and reconditioning presents an opportunity to make these concerns less relevant through a hierarchy of transformation for example retiring a handled product to become a static fixture. Medical (Packaging) > consumer discretionary (vacuum cleaner dust bin) > household static (lamp shade).

## Case study: repairable toaster's

The flatpack toaster by Kasey Hou (Kasey Hou, N.D) aims to help consumers to feel confident repairing the device by making them assemble it at the start of ownership. This is affirmed through the principles of emotional durability suggesting that the consumer builds a relationship with the product (Jonathan Chapman, 2012). It is also a widely identified phenomena referred to as Ikea Effect (Michael I.Norton, Daniel Mochon and Dan Ariely, 2011).

Additionally it furthers continued product novelty (Jonathan Chapman, 2012) by allowing users to easily customise the colour and structure.

## Case study: modular coffee machine



Kara is a repairable coffee machine designed by Thomas Mair  (DesignBoom, 2022) .

It improves repairability by foregoing proprietary connections between components such as the bottom load nipple, meaning that any container can be used as the water is pumped from the top with a straw.

Where it attempts to simplify the assembly by using a single type of screw, two lengths must still be used whoever these are colour coded for easy identification.

The process of repair is improved through clear interaction points- such as loops help users to remove modules correctly and alignment magnets but in learning lessons for the vacuum cleaner it should be considered that it may be necessary to use more secure fixtures for any modular components as vacuum cleaners move around so much more.

## Case study: empirical reverse engineering

The product for this case study is the Roidmi S2 - a cordless and bagless model that aligns with current market sales.

# Packaging


*Figure 1: Product packaging (WYLAM, 2023)*

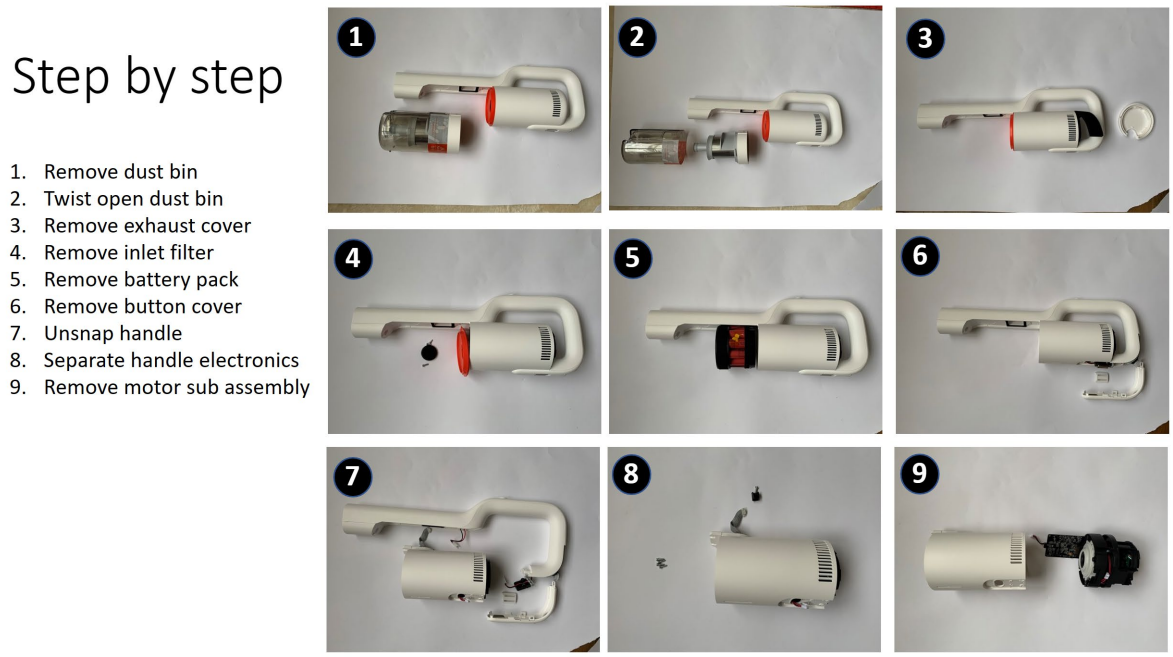



*Figure 2: Reverse engineering process (WYLAM, 2023)*

Bill of materials (identified through reverse engineering)

Whilst the assembly is generally excellent with its use of a single screw type (albeit in different lengths) there is some risk that consumers permanent damage the product mouldings- especially as there are several instances that require fairly unintuitive gestures to safely undo snap hooks.

The circuit board has a coating designed to prevent reverse engineering of the electronics, however it also negatively impacts safe specification of replacement components during repair. This may be acceptable where companies can assure the availability of spare parts such as Nokia, but Roidmi provides no opportunities to purchase spare parts.

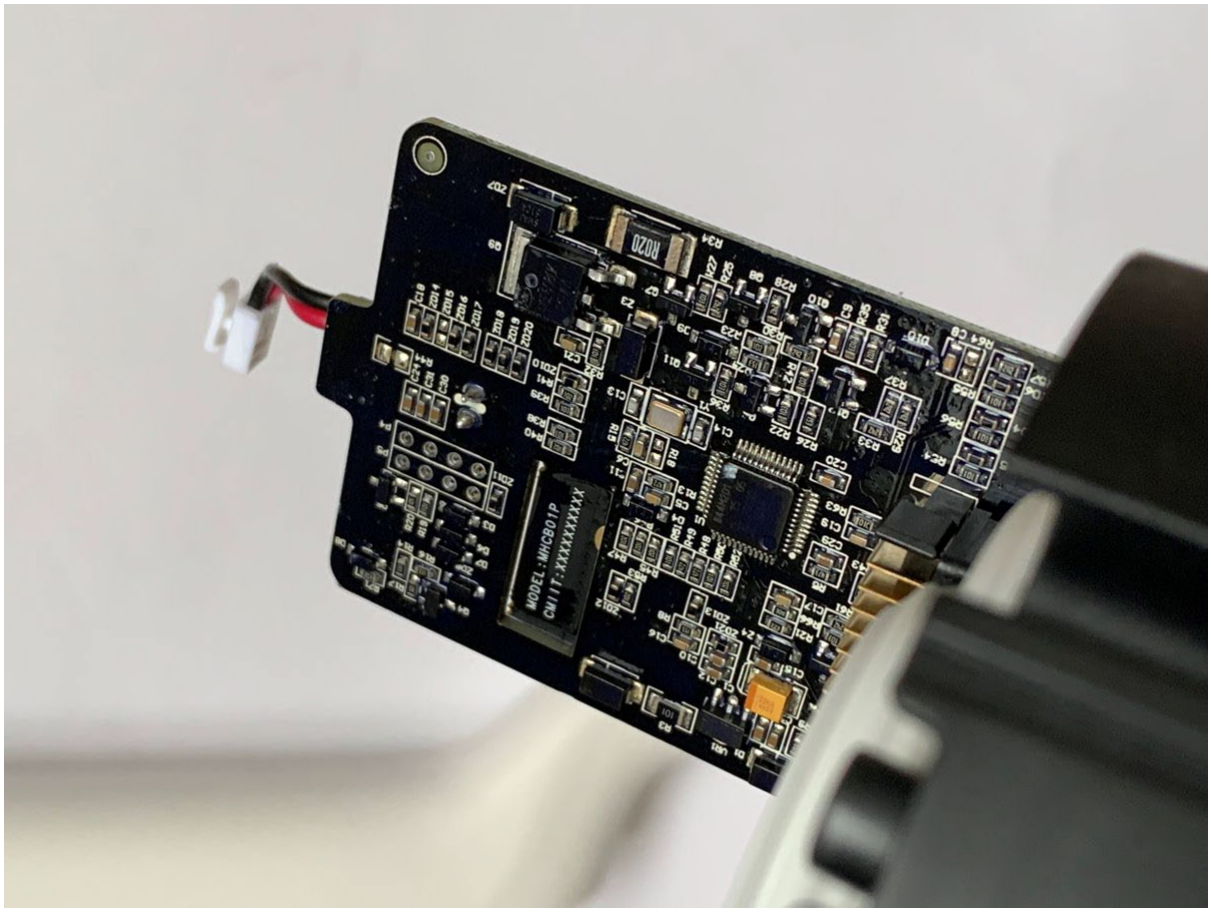


*Figure 3: Anti-competitive circuit board (WYLAM, 2023)*

Another insight is that the repair times are slightly excessive as the product must be fully disassembled in order to access the motor and circuit board for potential replacement in the future. This repair flow could be sped up by changing the position of the handle.

In contradiction to that it may be a sensible idea to implement mechanical locks that increase the time to open when it comes to accessing some of the more dangerous components such as high voltage capacitors.

## Product Design Specification

| ***Intended outcome*** | ***Feature*** |
|---|---|
| Preventing product breakdown | Automated brush bar cleaning |
| Preventing product breakdown | Improved prompts for maintenance tasks |
| Lifecycle extension | Automated filter cleaning |
| | Avoid the use of adhesives and proprietary fixtures: aim to use a single tool to open up the entire device |
| | Easy access to components for which upgrades lead to the largest efficiency extensions |
| | Faster repair process flows to lower repair costs through reduced labour time |
| Emotional durability | Imbue personality |
| Emotional durability | Connected products as living objects |
| Emotional durability | Adaptability and continued novelty |

| | |
|---|---|
| Awareness of EOL options | Product system app for decentralised product passport |
| Awareness of EOL options | Improved labelling quantifying product disposal outcomes |
| Expanded EOL options | Design components with versatile fixtures so that they can be upcycled at EOL |

## Conclusion

To summarise, this research has discovered several opportunities for design innovation that may help to extend the lifecycle and repairability of vacuum cleaners including designing **machines that maintain themselves** (in order to preserve product performance and extend lifecycle) and designing to allow **faster repair workflows** (to lower the labour costs of repair). It has also been found that in order to design a sustainable vacuum cleaner we must avoid tackling the issue in a silo of creativity and instead use a **multidisciplinary network of practitioners to cover all touch points** of the product journey: publicity campaigns (to improve the perception of second hand appliances), new legislation (part availability and credible information to support purchasing decisions), adoption of digital tracking technologies (to enable better labelling and disposal instructions) as well as engineering improved EOL processing (for material and part recovery).

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