CONNECTING THE LOOP: TEACHING END-OF-LIFE DESIGN ISSUES THROUGH PRACTICAL WEEE DISASSEMBLY

Claire POTTER[1] **and David GREENFIELD**[2]
[1]University of Sussex, United Kingdom
[2]SOENECS / Tech Takeback, United Kingdom

ABSTRACT
It is often cited that '80% of a product's environmental impact is decided at the design stage' [1] and yet it can be very difficult to ensure that undergraduate students truly appreciate the impact of their decisions in the early stages of the traditional double diamond design process. Whilst lectures, statistics and information can give the students an academic outlook on end-of-life issues, there is much to be gained from a hands-on engagement in the delivery of education around these pressing problems.

This paper examines two case studies from two sessions where design for disassembly was taught in a practical way, with each student physically taking apart a waste laptop through a guided session completed in collaboration with a local community interest project focussed on WEEE. By examining feedback from each session, these case studies discuss the impact of physical sessions on the understanding of disassembly by undergraduates, and also its context and importance in the role of design in the circular economy (CE).

The circular economy – a system that aims to keep materials and resources in constant flow, whilst also creating a regenerative future is arguably a critical system to be understood by all undergraduates, equipping them with the broadest sets of skills and contextual, experience-based understanding. This work is relevant to anyone teaching product design - particularly those teaching circular economy elements and the impact of design on end-of-life processes.

Keywords: Circular economy, disassembly, WEEE, product design, pedagogy, HE, education

1 INTRODUCTION
Despite initiatives such as the 'Reduce, Reuse, Recycle' [2] mantra from the 1970's, our lifestyles and demands on Earth's resources has only increased, and unfortunately quite dramatically. Over the five years from 2018 – 2023, our material consumption reached around 500 gigatonnes, which equates to around 28% of all the materials that humans have ever consumed since 1900 [3]. Instead of 'reducing' our global consumption we are accelerating, and at speed. In 2023, Earth Overshoot Day – the day where humanity's demands exceed the natural resources that can be annually replenished – fell on 2nd August, 151 days before the end of the calendar year [4]. Therefore, it is becoming increasingly important that we not only address global consumption, but ensure that we are using, and reusing resources and materials as efficiently as possible. The circular economy, a series of cross sectoral closed-loop systems can be part of this transition – encouraging practices such as refurbishment, repair, reuse, regeneration and at the last resort, recycling. However, for too long, recycling has been the main focus of industry, which is problematic as by its very nature, recycling is a destructive process. Recycling does not always translate to usable materials at the start of the supply chain either, as between 2017 - 2023 there was a decrease in secondary (life) material use of 21% [3].

For some products, recycling poses a complex range of issues, from social, to material, to environmental. Once such growing waste stream is WEEE – Waste Electronic and Electrical Equipment – which encompasses a wide range of products, from fridges and washing machines, to computers and mobile phones, and constitutes the largest, fastest-growing source of waste globally [5]. In 2019, around 52.6 Mt of WEEE was produced globally, equating to around 7.3kg per capita – a growth of 9.2 Mt from 2014 [6]. According to the United Nations Global E-Waste Monitor, this figure is estimated to rise to 74.7 Mt by 2030 – almost doubling in just 16 years, fuelled by growing consumption rates, short lifespans of products and lack of repair options. Most concerningly, only around 17.4% of WEEE was reported as being collected and recycled properly [6].

However, when combined with a well-constructed circular economy, WEEE has significant economic opportunities, with the raw material value locked up in waste products equating to ca. 55 billion Euros [7]. Higher up the waste hierarchy, reduction, sharing, repair and leasing also are huge opportunities for WEEE. For example, the European Union WEEE Directive lists the reduction of WEEE as a primary objective, along with efficiency of material use and reuse of items, including also Extended Producer Responsibilities and targets for the collection of WEEE [8].

Another barrier to a functioning circular economy is the issue of WEEE exporting (both legal and illegal) – particularly when recipient countries are poorly prepared for the correct handling of these items. 23% of WEEE generated in developed countries is sent to approximately seven developing countries, and 75-80% of all WEEE produced globally is exported solely to developing regions in Africa and Asia [9]. This translates to both deep social and safety impacts of WEEE, which contains a large variety of substances that are hazardous to both human and environmental health, from mercury, to brominated fire retardants, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). The uncontrolled and unsound disposal of products are directly linked to the health of exposed workers and widespread environmental damage to land, waterways and air [6, 10].

So how does this relate to higher education (HE), and especially, Product Design education? Fortunately, there are multiple avenues that can be explored. According to the Ecodesign study by the European Commission in 2012, up to 80% of a product's environmental impact is decided at the design stage [1], therefore embedding core aspects of product circularity, such as disassembly, repair and material recovery in HE could translate to WEEE that is simpler to handle at the end-of-life stages, once a student designs transition to industry. Indeed, De Ios Rios and Charnley have also shown how a working CE can only be created through a change to design skills [11] so it is the responsibility of HE institutions to manifest this change. It has been observed however that there is a distinct gap in the education of circularity to design students, which is concerning as they will be the creators of 'things' in the future – without a clear understanding of an entire products lifecycle, design decisions can be made with unintended consequences that could lead to poor options at end-of-life [12]. This is despite educators advocating for the use of disassembly sessions to better teach assembly and simplify manufacturing systems for many years [13, 14]. As attentions have turned away from just 'manufacturing efficiency' to the advancement of circularity, these core product design skills become even more critical.

These observations led to the two pilot case studies discussed in this paper; examining the possibilities of cross sectoral value-creation for WEEE if disassembled in the UK through a practical design sprint and WEEE disassembly session, and how undergraduate product design students rank the importance of disassembly, repair, second-life materials, upgradability etc both before and after a practical WEEE disassembly session. Would their perception of the importance of disassembly ease in products change? How can we reimagine opportunities for WEEE (and specifically waste laptops) in the UK, and how can we prevent problematic WEEE in the design stages through educational interventions?

2 REIMAGINING WEEE IN THE UK THROUGH DESIGN INTERVENTIONS

2.1 CASE STUDY ONE: The Design Sprint and Business Model Creation

The first case study examines a Higher Education Innovation Fund (HEIF) project completed in summer 2023 entitled '*mining a WEEE stream for greater economic, social and environmental value'*, led by Claire Potter (course convenor BSc/BA Product Design, University of Sussex) in collaboration with local partner Tech Takeback and University of Sussex Business School. The purpose of the project was to evaluate the potential of reusing scrap WEEE materials into new products through higher value circular economy solutions. This project helped to build on the Multi-Criteria Assessment Tool (previously created by the US Business School) and was structured to find possible income generation opportunities for disassembled laptops, their materials and component parts through three stages:

- **Secondary research** – identifying the main materials found in scrap laptops, opportunity for recovery (and current values), current recycling by Tech Takeback (and values), global issues and impact of WEEE, case studies of design-led products made from global waste WEEE.
- **Design Sprint** (one day in May 23) – which brought together professional designers, artists, Tech Takeback employees / volunteers and students from cross-disciplines together to initially disassemble a variety of scrap laptops (See Figure 1) and create concepts for the materials and components using design briefs related to 'Fashion', 'Packaging' and 'Toys and Games'.

- **Assessment of briefs -** Each selected final group idea was Design Assessed by Project Lead, Claire Potter, for possible localised commercial viability. These were further analysed using the Business Model Canvas and Value Proposition Canvas from US Business School to identify three key elements, enabling an understanding of where the desirability of value proposition, feasibility of value creation and delivery and viability of value capture could be balanced.
    1. Value proposition - What value is provided to the customers?
    2. Value Creation and Delivery: How the value is provided?
    3. Value Capture: How does the firm make financial gains?

Figure 1. disassembled laptops and component examination

In this paper however, we will be focusing on the second stage - the Design Sprint. This started with a brief introduction to the global impact of WEEE from Tech Takeback, (background, statistics and future impact), along with their current local activities of recovering, decommissioning and dismantling waste laptops. After a health and safety briefing and equipment introduction, The Disassembly began.

It is worth noting that the participants of the Design Sprint came from a wide variety of backgrounds and experience – some had never taken apart any form of WEEE and some were very well versed in dismantling a waste laptop. Whilst it may seem that this was problematic, it actually enhanced the learning experience for all – those who were experienced offered help to the novices and became reacquainted with the shock of how complex and resource heavy a laptop can be. One participant remarked how they *'had forgotten how badly a laptop is designed and how complicated the disassembly is'* until they were helping a novice. The mixture of experiences also fostered deep conversations and reflections about resource uses, material values and consumption, along with responsibility – with participants reflecting on how they *'would have designed this in a much simpler way!'*

Another key discussion point was time. Whilst participants disassembled the laptops, the project partner Tech Takeback gave a running commentary on where they would expect disassemblers to be, which of course, was much further on than most of the participants. Understanding the speed of disassembly required to create economic value from the current usable elements of waste laptops was a key seed to sew for the later stages of the Design Sprint. Participants also reflected together on why WEEE is so commonly exported to developing countries to enable economic viability of resource collection, despite the evident exploitation to both humans and environment. Seeing, experiencing and understanding the consequences of design decisions first hand was described by one participant as *'deeply sobering'*.

Material identification was also a very important part of the disassembly session. Whilst many participants could list some materials that went into making a laptop, actually removing them, holding them, list them and weigh them created a deeper understanding of real resource use in a product. Discussions around material values followed, both from a design and economic perspective, with participants being given the current market value per gram / kg of different components. This also fostered a deeper understanding of what are the most 'important' parts to remove and why.

Establishing new 'values'

The second part of the Design Sprint purposefully didn't focus on these 'valuable' parts, but on the other elements that were deemed to have no/low economic value once removed from the waste laptop. Thus began the creative element of the day – what can we design that utilises materials / components with low/no current value? How can we make a waste laptop have higher returns to allow UK disassembly to be more economically viable, reducing impacts of exports on developing, underprepared countries?

Each group was asked to create concepts for a new, unrelated sector (Toy and Game, Fashion, Packaging) and was taken through a series of idea generating exercises, allowing them to create a series of experimental designs utilising the waste materials identified in the disassembly section. These took the form of sketches, low-fi models using parts of the disassembled laptops and plans for social media campaigns to target specific users, communicating the origins of the new 'product'. All exercises were completed in a few hours, so the ideas were very loose and conceptual, however they were able to be discussed for economic and local manufacture / making viability in the session and assessed in more detail by project lead Claire Potter in the final report, along with new business model possibilities.

Enabling WEEE to be disassembled and monetised in a local circular economy rather than relying on exporting helps to reduce the impacts on human and environmental health in overseas locations, where recycling is often an exploitative business. The results of this project will be taken forward by Tech Takeback to create new business models for scrap laptops that are donated, as well as the possibility of new jobs and/or income streams from the design and production of new products by local makers. Plus, the participants left the session with a deeper understanding of both WEEE issues and the importance of designing for disassembly (why products need redesigning) and also how materials and could be incorporated in new designs (using WEEE as 'second life' materials). The Design Sprint was a huge success and highly enjoyable for participants, therefore it was decided that the session would be run again, with new participants, and a twist to allow for further, more quantitative investigation.

2.2 CASE STUDY TWO: The Module Disassembly Session

During the autumn '23 semester in the US final year Product Design module 'The Role of Design in the Circular Economy', a similar practical disassembly session was arranged with a completely new cohort. However, before the students (who were all product designers) were given the introduction talk by the partner Tech Takeback, they were asked to rank the importance of the following statements in their own design practice on an anonymous statement sheet (1 being the highest importance, 10 being the lowest):

- Waste as Food (using second-life materials).
- Making Items Repairable.
- Using the minimum amount of materials (reduction).
- Designing items for disassembly.
- Creating items with the lowest embodied carbon footprint.
- Designing items that can be upgraded.
- Creating items that have a transparent (trackable) supply and manufacturing chain.
- Designing and creating items that can be manufactured locally.
- Creating items that are fit for sharing (collaborative consumption).
- Assessing whether a product really needs to exist (reduction / refusal).

The introduction talk and Q+A was then given – outlining the global issues with WEEE, stats, videos and material discussions, and then as with the Design Sprint, each student was given a waste laptop, health and safety instruction, tools and basic advice to start the disassembly. Again, some experienced dismantlers were on hand to assist if needed, but in this session, students were encouraged to try and figure out the laptop construction and order of disassembly themselves. Using this more 'hands-off' approach resulted in the dismantling of the laptops taking a longer amount of time, however this fostered a more animated discussion from students who were frustrated at the poor design decisions that had led to the difficulty of the task. After dismantling was complete, as with the Design Sprint, students categorised, identified and weighed components and materials, to allow for a tangible understanding of economic value and quantities in each waste laptop.

Each student was then asked to complete the same ranking exercise on their retained sheet, with the aim to see if the practical disassembly session had affected the priority of disassembly / repair in their own practice. We can see from Figure 2 below, that over the entire cohort, 'making items repairable' was the most important both before and after the session, (ranking of 1) however 'designing items for disassembly', 'lowest carbon footprint' and 'local manufacture' all increased in ranking by one place of importance. Interestingly, 'waste as food (using second-life materials)' and 'creating a transparent supply chain' fell in importance (post disassembly ranks of 7 and 10 respectively). 'Does it need to exist' also fell in importance when scored across the whole cohort, although it was still high in importance overall (in top 3 both before and after the disassembly).

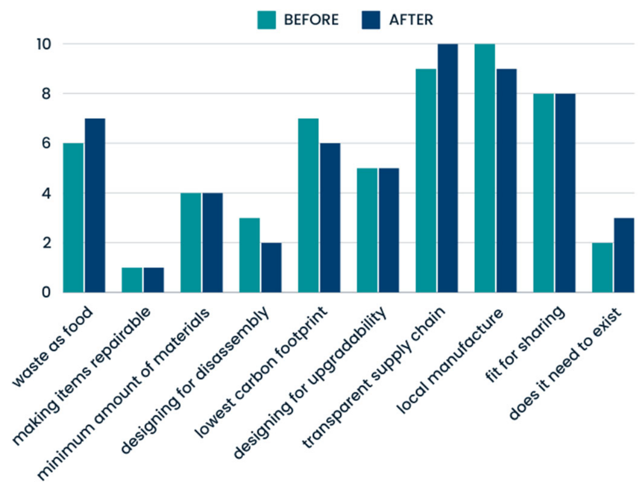

Figure 2. Before and after scoring of rankings (lower number = higher importance)

However, this was combined score data from the whole cohort – if we look at individual student product designers, there were some very interesting, detailed observations. After the disassembly, one student raised the importance of using the 'minimum amount of materials' from a rank of 5, to the highest of 1, whilst another student raised the importance of 'designing for disassembly' by three places, and another student by two. 'Making items repairable' also saw an increase in rank by one place in two different students. So, whilst there were not huge movements in ranking scores across the whole cohort after the session, in some students the disassembly experience had a very marked affect in their design priorities. It is planned for data such as this to be collected again in future module presentations to further investigate the immediate impact of disassembly sessions and student attitude changes over time.

3 CONCLUSIONS

Whilst both case studies had differences in session focus and length, cohort type and research methods, there were a number of takeaways and observations from participants and organisers that were the same. Firstly, disassembly is hard, complex and takes time. Participants understood and could better reflect on why WEEE is currently exported to developing countries after experiencing the disassembly first hand. This allowed more participant reflection and empathy for exploitation issues with WEEE and reflect on how re-design could allow for end-of-life products to be re-used or re-processed easier, safer and quicker. Secondly, materials can be held by participants, weighed and quantified, and separation (essential to create high-value second-life materials) can also be discussed with physical context. Participants can also learn to visually identify materials, which is a very useful skill when working with second life (and sometimes unlabelled) components. Thirdly, participants can start to consider how to use second-life materials in new designs – even those in completely unrelated sectors, which previously they may not have thought were possible (e.g. WEEE to Fashion).

There was also a deepened sense of responsibility from the designers – understanding that the difficulties they experienced in the disassembly were the result of decisions at the design stage was very impactful (and as shown above, was reflected in their ranking changes). Ensuring that items are able to be easily disassembled and repaired is critical to a functioning circular economy, and exposing undergraduate students to the current landscape of WEEE helps to galvanise this importance first hand. It is only through practical sessions that these lessons can truly be learnt, understood – and be embedded in the circular practices of our future designers who have the power to create real change.

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