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E-waste and Obsolescence: Designing out toxicity

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Abstract
Electronic and electrical products have become indispensable and ubiquitous in many facets of our daily lives. The quantity with which electronic and electrical products are produced, consumed and discarded is growing rapidly. In addition, the lifespans of these products are getting shorter with many products still functioning when disposed of. Consequently, the combined result of shortened product lifespans with growing demand and consumption of electronic and electrical products, in both developed and developing countries is the escalating growth in end-of-life electrical and electronic products. Electronic waste (e-waste) is highly toxic and is the fastest growing waste stream. Unlike many other categories of waste, e-waste has particularly unique qualities. It not only contains many highly toxic substances it also contains valuable materials and precious metals.

This study highlights particular aspects of obsolescence and e-waste processing which have implications for the design of electronic and electrical products in our throwaway society. It investigates growing concerns about the flows of e-waste from industrialised countries to the developing world where hazardous recycling takes place by a burgeoning informal sector. Many of whom are marginalized social groups who resort to e-waste recycling for income and survival. Furthermore, this paper outlines the opportunities for efficient and economical resource recovery and how the design of electronic and electrical products can contribute to improve the integrity and value of recyclates and facilitate safe and efficient end-of-life resource recovery.

Keywords: e-waste, informal e-waste sector, obsolescence

Introduction

This research seeks to understand how design and consumption of consumer electronic and electrical products impacts upon e-waste. It asks the question, how can design contribute to the mitigation of negative environmental and social impacts associated with e-waste recycling? The methodology of this study is to explore the links between upstream' design and consumption activities, and end-of-life e-waste impacts. It does so, by drawing upon primary research on consumption practices of consumer electronic and electrical products and informal e-waste collection in China. Secondary research material is drawn from a body of literature on design, consumption and e-waste.

Electronic and electrical products have become indispensable and ubiquitous in many facets of our daily lives. Without them, the many services they provide in areas including medicine, mobility, education, food supply, communication, security, and popular culture would be inconceivable. They represent the essence of our contemporary technological society and a significant focus for Industrial Design activity.

Obsolete and discarded electrical and electronic products (e-waste) are the fastest growing waste stream (Hester and Harrison 2009) growing at 3 to 5% per year (UNEP 2006). In Australia, 234 million items of e-waste were destined for landfill during 2009 and without intervention[1] this quantity is projected to treble by 2020 (TEC 2009). E-waste comprises of a large range of commercial office and domestic products, such as, personal computers, printers, mobile phones, handheld electronic device, televisions and refrigerators. A significant proportion of e-waste, mostly obsolete televisions, computers and computer peripheral products still function when discarded. Up to 90% of discarded PC's are claimed to be still functional when disposed of (van Nes 2003). In addition, large volumes of these obsolete products exist 'out of use' stored throughout households and in dedicated storage sites.

Contributing to the growth in e-waste is the diminishing lifespan of these products. Technological change as well as the proliferation of electronic devices into new product sectors, expanding communications networks and dramatic reductions in purchasing prices, all contribute to a massive escalation in the consumption of electronic devices. Resultant from this, consumer perceptions have shifted so that many of these products are no longer seen as 'durables' but as 'consumables' (Cooper and Mayers 2000) replacing the old with the new in ever quickening cycles.

Unlike many other categories of waste, e-waste has particularly unique qualities. It not only contains many highly toxic substances (Grossman 2006), it also contains valuable materials and precious metals (Hagelüken 2010). E-waste constitutes a complex inventory of components, sub-assemblies and material combinations that can result in environmental impacts throughout their lifecycle. When discarded these products present considerable environmental and health challengers - far greater than for many other categories of consumer waste (Grossman 2006). They contain toxic or scarce substances such as mercury, cadmium, chromium, lead, copper, silver and bromated flame-retardants. For example, a standard sized cathode ray tube (CRT) monitor is estimated to contain two kilos of lead. Meanwhile, a tonne of discarded mobile phones (without batteries) can yield 300 grams of Gold – a far greater yield than the most efficient gold mine (Hagelüken 2010). While safe and economical processing solutions do exist for e-waste, most products are still condemned to landfill or illegally processed in developing

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[1] Australia has legislated a national television and computer product stewardship scheme commencing in 2012. http://www.environment.gov.au/settlements/waste/ewaste/index.html

countries. In these countries, such as China, India and Ghana a burgeoning informal sector collects, sorts and dismantles e-waste in often appalling conditions that compromise human health and the local environment (Xing et al. 2009).

For design teams of electrical and electronic products, there is first a need to be aware of the magnitude and scope of problems associated with e-waste and, furthermore, to become familiar with how design can contribute to mitigating negative consequences of e-waste recycling whilst maximising the opportunity for efficient, safe and valuable e-waste material recovery.

Consumption and Lifespan

The growth in household consumption of electrical and electronic products (EuPs) during the past three decades has been extraordinary. In the 1970s a typical household would contain around seventeen products, notably a Television, Vacuum cleaner, Hi-fi music system, Washing machine, Radio, Cassette player, Fridge and a Toaster. Today, typical households would own in excess of forty-five EuPs (Owen 2006). There are many notable reasons for this growth including, rising material affluence, availability of new and novel devices driven by technological change and greater affordability.

Affordability

Greater affordability, aided by deflationary price trends over many years, has ‘democratised consumption’ (Linstead et al. 2003 of EuPs) enabling new material benefits to those who could not previously afford such ‘luxuries’. As well, this has enabled ownership multiple of devices in households, such as additional televisions in bedrooms and the kitchen. Table 1 illustrates affordability since 1975 as a percentage of average Australian weekly earnings (ABS 2011). More recently, the deflationary trend for certain EuPs products has been even more dramatic. During the past 12 months television purchase prices have dropped by 25% and are expected to decline by a further 25% over the next year (O'Rourke & Black 21011).

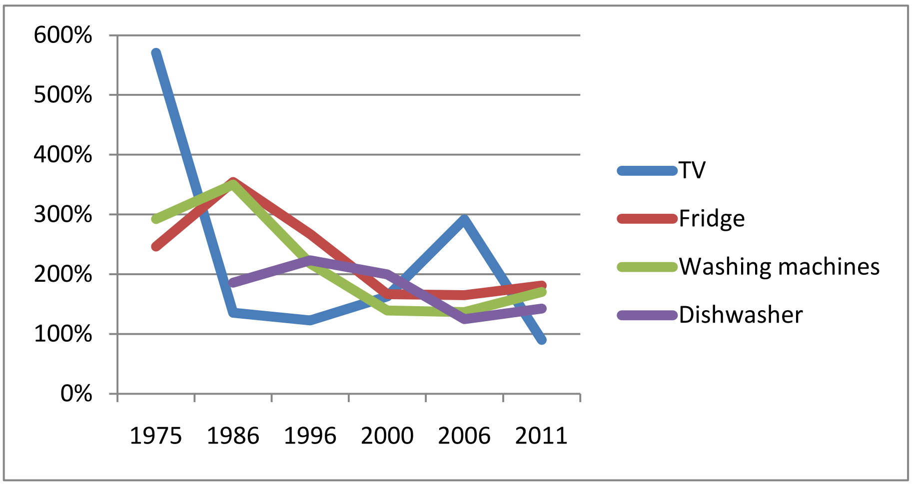

Table 1

Purchasing cost as a percentage based upon average Australian weekly earnings

However, initial purchasing cost price is only one part of picture. The ratio between cost of repair and cost of replacement has dramatically reversed in recent years. A Scandinavian study found that over a ten-year period the cost of repair work for a television and a washing machine increased by 150% and 165% respectively (Consumers International, cited in Cooper 2005). Labour is a significant component of this cost, but even repairs or upgrades undertaken by the owner may not be feasible due to the cost or unavailability of spare parts.

Technological novelty

During the last 20 years or so, electronics have migrated into many new product areas that traditionally have been populated by manual or mechanical devices. This includes kitchen appliances (such as bread makers and electronic pepper mills), personal hygiene devices (electric toothbrushes and feminine razors) and children's toys (electronic games and illuminated balls). Novelty, fashion and affordability are features of these increasingly ephemeral products. Australians, in particular, are ranked amongst the top 10 as consumers of electronics goods in world (TEC cited in Ongondo et al. 2011).

Profound technological change is particular feature for most EuPs, not least for Televisions and computers. Over the last decade the Australian market has experienced the transition to digital broadcasting services along with many households replacing older CRT televisions for the larger LCD or Plasma flat screen models. According to the consumer electronics research group GfK, large flat screen televisions recorded 75% growth during 2010 alone (GfK cited in Singer, 2010). This massive changeover to flat screen and digital technology has produced a large spike in product obsolesce and e-waste televisions.

> *"In 2007/08 31.7 million televisions, computers and computer products were imported into Australia, and by 2009 the number of these products imported had increased to 40.3 million. The surge in television and computer ownership will increase the number reaching their end of life over the coming years"* (DSEWPC 2011).

There exists a strong correlation between product lifespan and technological change. Products normally described as 'consumer durables' are ending up in waste streams. This is particularly evident with the larger bulkier technology items such as televisions and computers. While data on product lifespans is patchy and variable a reoccurring claim, in the literature for developed countries, is that the average lifespan of computers has dropped from six years in 1997 to just two years in 2005 (Babu et al. 2007).

While televisions and computer e-waste are often the most conspicuous example of the e-waste problem, many other smaller obsolete technology products, such as mobile phones and MP3 players, languish in drawers, cupboards and boxes across many households as a dispersed depository of 'hidden' waste. In addition to e-waste that also exists stockpiled in various storage facilities presenting a delayed e-waste burden.

Eco-obsolescence

Another emerging factor contributing to the decline in product lifespans is the push to replace old inefficient products with new energy efficient products. As consumers become increasingly aware of environmental impacts and increasing costs of excessive household energy use they are encouraged through various government programs and product eco-labelling schemes (E3 2011), to upgrade to more energy efficient appliances. This new observation of obsolescence, 'eco-obsolescence', is based on the logic that it is better to retire old inefficient products for more efficient ones. One UK study concluded that the optimum lifespan of a dishwasher is 8.1 years, after which it is environmentally beneficial to replace it with a more technologically advanced eco-efficient model (Chalkley et al. 2003). However, when other important variables are accounted for, including behavioural factors (actual frequency and duration of product use) and total life-cycle impacts (embodied energy associated with manufacture and distribution, etc), assumptions used for lifetime optimisation calculations may present an incomplete and misleading picture of energy related environmental impacts.

Problem or Opportunity?

Toxicity

While the growing amount of e-waste generated may seem in itself to present a big enough problem, the most significant problem with e-waste is its toxicity. Many toxic substances bound up within e-waste and are released or new toxins produced when processed for recycling. They presents dangers to human health, eco-systems and water resources and is manifested in appalling labour work practices and unregulated international trade.

The effects of e-waste toxicity on health and the environment are well documented (Puckett et al., 2003; Wong et al., 2007; Luo et al., 2009; Sepúlveda et al., 2010; Ye et al., 2009 cited in Ongondo et al. 2011). These health and environmental problems are far greater than for many other categories of consumer waste (Grossman 2006). E-waste contains varying quantities of toxic or scarce substances such as mercury, cadmium, chromium, beryllium, lead, copper, silver and bromated flame-retardants. Cadmium can cause cancer in humans, beryllium is a known carcinogen and can cause lung disorders if inhaled, and chromium can cause liver and kidney damage. Brominated flame retardants (BFRs) are used in the plastic housing in numerous electronic products. This class of compounds are classified as Persistent Organic Pollutants. When disposed they are difficult to break down and bio-accumulate having been found to impact on thyroid and hormone systems in humans. When dumped either illegally or in poorly managed landfill sites, over time e-waste can leach (leachate) into groundwater, contaminating soil, waterways and ultimately the food chain.

Meanwhile the deplorable conditions and crude processes with which e-waste is handled in many developing countries has a considerable negative impact on human health and the local environment (Ongondo et al. 2011). In order to liberate valuable materials dismantled products are subjected to various toxic treatments and processes including open burning and acid bath stripping (Ongondo et al. 2011). These processes either directly expose workers to released toxic substances (such as those listed above), or as toxic by-product substances resultant from extraction processing, such as dioxin which has been found in soil samples where e-waste has been processed (Kuper & Hojssk 2008, Terazono 2010). The magnitude of this activity undertaken in many developing nations across Africa, Lain America and Asia has only recently become widely reported. It highlights the exposure to workers and the surrounding populations to a cocktail of toxic substances, vapours and smoke. Non Government Organisations (NGOs) as well as various media organisations have dramatically illustrated through their reportage the situation for the many informal e-waste workers in the developing world who process large volumes of e-waste often originating from countries such as Australia, UK and USA.

Regulation

During the last decade the level of toxicity within EuPs is improving. The EU Waste Electrical and Electronic Equipment (WEEE) Directive has signalled to many manufactures and distributors around the world obligations involving design, ‘take-back’ or product stewardship and recycling. Closely linked with the WEEE directive, launched in 2006, is the Restriction of Hazardous Substances Directive (RoHS). It requires marketed electrical and electronic equipment to not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE). RoHS and equivalent regulatory initiatives in other countries have a compatible objective of reducing toxic materials in EuPs. By default, those manufacturers who export into those regulated markets need to comply. Despite the short lifespan for many EuPs, the lag and overlap between the RoHS compliant and older non-RoHS compliant legacy products (that contain a greeter range of toxics) will remain a problem for e-waste processing for some considerable time.

Valuable resource

Inversely, unlike most other categories of waste e-waste presents an opportunity to recover high value and scarce materials. Most notably, e-waste contains valuable metal fractions such as aluminium, copper, silver, tin and gold. These are used within printed circuit boards, subassemblies and wiring. A tonne of discarded mobile phones (without batteries) can yield 300 grams of Gold - a far greater yields than the most efficient mine (Hagelüken 2010). In addition, metals recovery offers other significant benefits, CO^2 savings by recapturing embodied energy and no loss of quality in primary recovered metals. However recovering gold and other precious materials can be difficult to quantify in inconsistent supplies of ‘raw’ e-waste and complex to extract without contamination as it is often bound up in complex compounds or subassemblies with many other ‘worthless’ compound.

Material combinations within subassemblies, connections between components (mechanical, adhesives, fasteners and finishers) also play a critical role in the efficiency of material liberation and recovery rates (van Schaik & Reuter 2010). Large scale recovery of valuable materials is a costly process that, at best, can only recover a closed loop of 34% original material input (Hagelüken 2010). An industrial ecology of a highly efficient closed loop material flow may be unrealistic, but with improved product design and sophisticated e-waste recycling systems the quality and value of recyclates could be greatly improved (van Schaik & Reuter 2010). Unfortunately, while such safe and economical processing solutions are possible, e-waste is progressively being condemned to landfill or dumped in developing countries and manually processed in unsafe and environmentally damaging ways.

The informal recycling sector

E-waste recycling is labour intensive and a hazardous activity that in developed countries can be costly and laden with regulatory compliance. However, as with consumer manufacturing sectors, e-waste recycling is shifting to the developing world where labour costs are low and regulatory compliance poor. Much of this work in the developing world is undertaken by a burgeoning informal sector often comprised of poor and marginalized social groups who resort to scavenging and waste picking for income and survival (Wilson et al. 2006 cited in Chi et al. 2011). In Asian and Latin American cities it is reported that up to 2% of the population depend on waste picking to earn a living (Medina 2000 cited in Chi et al. 2011).

Of the 4000 tonnes of e-waste generated globally per hour 80% is exported to Asia and 90% of this share ends up in China (Ketai et al. 2008 cited in Ongondo et al. 2011). As well as being the largest exporter of electronic goods in the world, China is also the world’s largest importer. China imports estimated of 35 million tonnes of e-waste from developed countries each year (Jinglei et al. 2009) much of which is processed by a large informal sector. A thriving black economy deals in the movement of e-waste across cities, regions and national boarders (Terazono 2010). In addition, Chinese consumers will often withhold obsolete products in storage (Li et al. 2006) and when they do discard their e-waste they overwhelmingly prefer informal collection methods (Xian et al. 2011). A study of 428 consumers in Beijing found that nearly 94% of respondents chose informal collectors when disposing their obsolete EuPs (Liu et al. 2006). China’s formal recycling sector is disadvantaged by higher running costs and struggles to get enough e-waste to maintain operations (Jinglei et al. 2009). Lax regulation on occupational safety and environmental management, along with low labour costs and a strong demand for low-priced secondary materials drive employment for approximately 700 thousand people. Chinas widely distributed and often-secretive informal e-waste recycling sector undertakes, collection, backyard dismantling, wayside dumping, and open burning.

Illegal trade

China's international trade in e-waste highlights the illegal dumping of e-waste from the developed to the developing world, despite international regulatory agreements on the movement of hazardous substances. Notably agreements include the Stockholm Convention on Persistent Organic Pollutants and the Basel convention on transboundary movement of hazardous waste and their disposal. What is apparent in regard to these international agreements is that e-waste finds a path of least resistance bypassing regulatory and well-intentioned agreements. For instance, e-waste destined for developing countries can be exported as functional second-hand electrical and electronic equipment for resale or social welfare projects. In some instances this is a well-intentioned program to 'bridge the digital divide', and in other cases it is fraudulent and illegal export. While there exists a high rate of repair and reuse in the developing world a large proportion of imported electrical and electronic equipment is discarded as e-waste into poorly managed landfill (Ongondo et al. 2011) and scavenged by recyclers. The e-waste trade is as much a social problem as it is an environmental problem, with the burden of unsafe and low value work placed on a burgeoning informal e-waste sector.

Discussion

Increasingly, the significance of the growing problem of e-waste is being addressed through policy and regulatory compliance targeting e-waste collection, the reduction or elimination of hazardous substances, and transparency and enforcement in international trade. However, as with many seemingly intractable problems prevention is often better than cure. This suggests that the e-waste story should start at the beginning - the design stage.

This drive for regulatory compliance (such as WEEE, RoHS and Australia's product stewardship legislation) also has implications for the design of electrical and electronic devices. Most notably the push to design out certain toxics substances (such as a shift to lead-free solder or the elimination of bromated flame-retardant additives in plastic housings) and quotas for e-waste recovery. However, these first steps are likely to have little initial impact in regions of the world where e-waste is imported, regulations are difficult to enforce, and due to the time lag between the moment of design change and when 'compliant' products become dominant in waste streams. In addition, the problem of toxicity for the informal sector in the developing world goes beyond the primary constituent materials (toxic or otherwise) within e-waste. In order to liberate valuable materials in e-waste many new secondary and tertiary toxic substances are unleashed during processing. For example, the open burning of PVC coated copper cable or the use of reactive or leaching agents to extract gold and other valuable metals result in the release of hazardous substances.

Toxic e-waste emissions	*Description*
Primary	Hazardous substances that are contained in e-waste (lead, cadmium, chromium and bromated flame-retardants
Secondary	Hazardous reaction products of e-waste substances as a result of improper treatment (open burning of plastics)
Tertiary	Hazardous substances or reagents that are used during recycling (e.g. cyanide or mercury for gold extraction)

Table 2

Classification of toxic e-waste emissions (UNEP 2009)

The constituent base metals within e-waste drive the value chain in end-of-life e-waste processing. As e-waste promises to become progressively less toxic (due to regulation and technological development), the yield per product of valuable metals (such as gold and silver) is also diminishing (Babu et al. 2007). This requires an intensity of secondary and tertiary toxic separation processes to extract valuable materials. In the developing world this can lead to disastrous consequences (Ongondo et al. 2011).

Design

While design-for-disassembly is a well-documented strategy for end-of-life product management it is still not widely practiced or understood. Design-for-disassembly can offer efficient, safe and material integrity during recovery. However, efforts need to be redoubled to not only facilitate more efficient access to the internal components and sub-assemblies within products, but also ways to facilitate efficient and non-toxic means to extract valuable materials that are ‘locked-up’ inside these same components and sub-assemblies.

Additional to the elimination of primary toxic substances within products, designers should also focus upon how valuable materials in components and subassemblies can be liberated to reduce the intensity for toxic secondary and tertiary separation processes. Reducing toxic processing and emissions can offer significant environmental and health improvements for informal sector workers while still offering them a means to earn vital income. This entails the elimination of contaminating substances, paints, adhesives and non-reversible bonded materials that can render recyclates worthless.

Other design initiatives can also support and facilitate efficient end-of-life processing. Materials identification, at its simplest, could be labelling or laser marking of products during manufacture to display materials fractions - as similarly done with food labelling on processed food packaging. A more sophisticated approach may include use of RFID chips containing the ‘DNA of a product or linking to a CAD or inventory database inventory for a recycler to access. As digital communication networks become prolific, even in some of the poorest regions of the world, product data could be obtained though database networks to assist e-waste processing.

Aim	*Design objective*
Reduce intensity for toxic secondary and tertiary separation processing	Focus upon how valuable embedded materials in components and subassemblies can be liberated
	Elimination of contaminating substances, paints, adhesives and non-reversible bonded materials
Improve yield of valuable materials	Materials and Parts identification
	Product 'metadata' inventory database

Table 3

Design objectives to facilitate efficient and non-toxic recovery of valuable materials

Conclusion

Recycling e-waste is a labour intensive and costly activity requiring complex and toxic processes to yield recyclates of value. In industrialised countries, this requires substantial investment in equipment, labour and transport that needs government and industry subsidy and regulatory support, or costly large-scale automated facilities to achieve economic viability. By contrast, the developing world offers lower labour costs but inconsistent regulatory enforcement. As with many manufacturing sectors, e-waste recycling is relocating from the industrialised to the low cost base of the developing world where e-waste recycling if often undertaken in hazardous conditions by a growing informal sector. The growth in the disposal of electrical and electronic goods is driven by complex interacting technological and sociological factors that result in obsolescence and diminishing product lifespans. In this fast moving sector prolonging product lifespans will not be enough to mitigate the growth in e-waste. Designers need to understand the how their products end up in waste flows to the developing world, and design accordingly for end-of-life. This not only entails the elimination of primary toxic substances within products (as mandated through emerging e-waste regulatory initiatives), but also design-for-disassembly strategies so to eliminate the need for toxic processing and emissions to liberate the valuable recyclates.

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