TABLET PCs THROUGH THE LENS OF ENVIRONMENT – DESIGN TRENDS AND IMPACTS ON THE ENVIRONMENTAL PERFORMANCE

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Abstract: The mobile IT market is seeing a significant growth in the tablet PC shipments. The high sales numbers combined with potential short use and complex design lead to concerns about tablets' environmental relevance. In this respect, it is of specific interest to assess the environmental performance of tablets, comprising the evaluation of the design solutions with regard to repair and recycling as well as the identification of the environmentally relevant life cycle phases. 21 tablet models have been disassembled and compared in terms of non-destructive opening for repair purposes and partly destructive dismantling for end-of-life scenarios. Furthermore, an assessment of the environmental impacts associated with tablets in comparison with netbooks has been carried out. The modelling is performed using the LCA to go tool. In addition, using X-Ray Fluorescence spectrometry, the paper examines the content of critical raw materials in selected components. Quantified results from the assessments are presented.

1. INTRODUCTION

Tablet PCs are relatively new electronic product; nevertheless they are contributing to a tremendous increase in the sales figures of the mobile IT market.
In spite of this, little is known of their environmental properties along their entire life cycle.
Many studies on the environmental impacts of mobile IT electronics claim that the manufacturing phase contributes mostly to the overall environmental footprint of the product. Therefore, it is important that the design features enable rather longer lifetime as well as material recovery at end-of-life.
This paper builds on a previous study [1] and provides an integrated overview of the design options from repair and recycling perspective.
Furthermore, to gain more knowledge about the environmental impacts associated with the manufacturing of tablets some additional investigations have been added.

Table 1: Devices under test

Product Name	Display Size in Inch
Odys Neo X7	7,0
Asus Google Nexus 7	7,0
Lenovo IdeaTab A2107A	7,0
Kindle Fire HD	7,0
Huawei Media Pad 7	7,0
Intenso TAB714	7,0
Samsung Galaxy Tab 2	7,0
Toshiba AT270	7,7
Apple iPad mini	7,9
Sony Xperia Tablet S SGPT121DE/S	9,4
Blaupunkt Discovery	9,7
Apple iPad 4	9,7
Odys Noon	9,7
Samsung Galaxy Note 10.1	10,1
Acer Iconia A510	10,1
Asus Transformer TF300TG	10,1
Asus MeMo Pad Smart ME301T	10,1
Dell Latitude 10	10,1
Samsung Google Nexus 10 GT-P8110	10,1
Dell Latitude 10 ST2	10,1
Acer Iconia W700	11,6

To illustrate the current design variations, an investigation of the material composition has been performed, on a system as well as on component level.

2. DEVICES UNDER TEST

The devices under test (DUT) have been selected based on their market representation at the end of 2012 and beginning of 2013. A total of 21 tablets representing the screen size segment between 7 and 11,6 inch have been investigated (see table 1).

Table 2: Scoring algorithm of the disassembly process

DUT	Number of used tools	Number of special Tools	Different screws	Number of connectors	Number of screws	Number of clips	Adhesive (one-sided) in cm²	Adhesive (two-sided) in cm²	Adhesive (two-sided, heat) in cm²	Number of steps
DUT_01	2	0	1	0	3	33	0	16	0	3
DUT_02	2	0	1	0	10	22	0	24	0	5
DUT_03	2	0	1	1	4	30	16	0	0	4
DUT_04	1	0	0	0	0	18	0	0	0	1
DUT_05	1	0	0	0	0	20	0	0	0	1
DUT_06	1	0	0	0	1	3	0	0	0	3
DUT_07	5	1	4	2	23	0	0	1	17	9
DUT_08	1	0	0	0	0	21	0	0	0	2
DUT_09	3	0	1	0	6	4	4	0	0	7
DUT_10	1	0	0	0	0	20	0	0	0	1
DUT_11	2	0	1	1	2	19	1	9	0	3
DUT_12	1	1	0	0	0	0	0	0	35	2
DUT_13	1	0	0	0	0	22	0	0	0	1
DUT_14	1	0	0	0	0	36	0	0	0	1
DUT_15	2	0	0	0	4	34	0	0	0	4
DUT_16	2	0	0	0	2	14	9	0	0	2
DUT_17	2	0	0	0	2	13	0	0	0	2
DUT_18	2	0	1	0	5	46	0	0	0	3
DUT_19	1	0	0	0	0	23	0	0	0	1
DUT_20	1	0	0	0	0	23	0	0	0	1
DUT_21	2	0	1	0	2	31	0	0	0	2
mean value	2	0	1	0	3	21	1	2	2	3
min value	1	0	0	0	0	0	0	0	0	1
max value	5	1	4	2	23	46	16	24	35	9

3. DISASSEMBLY ANALYSIS - FINDINGS

The main goal of the disassembly analysis was to investigate the DUT design solutions in terms of repair and recycling. Therefore, during the opening of the devices and the disassembly of the main parts (battery, mainboard and display) two scenarios have been kept in mind.

In the first one – the repair scenario, the main focus was put on the non-destructive disassembly. In addition, interviews with German and American repairmen were conducted to investigate the current practices in tablet repair.

In the second scenario, the design features from a recycling perspective have been analysed. To reveal the impact of certain design features on depollution and material recovery at end-of-life interviews with recycling experts have been conducted as well. In contrast to the non-damaging factor in the first scenario, the recycling scenario emphasises a time efficient and safe disassembly. It needs to be stressed that the repair experts have not kept any failure statistics at the time of the interviews. Nevertheless, the repairmen indicated that tablets are mostly brought to repair due to breakage of the display unit or front glass after accidental damage. Failures of the battery and the mainboard are possible as well, but happen rather rarely.

The documentation of the individual steps for the opening and the removal of the main parts provides quantitative data and allows the comparison between the individual design solutions within the tested samples.

3.1. Opening of the device

The opening of the DUT is associated with substantial differences in terms of number of process steps required for disassembly and types of connection used [1]. Mostly, the opening of the DUT has to start from the back side and rarely from the front side.

Three main opening mechanisms have been identified – clips, screws and adhesives [1]. Some of the DUT applied a combination of these three in order to avoid unintended opening. Furthermore, the individual design solutions might be based on design and robustness reasons, which may not be obvious from the initial look (see table 3). In general, with respect to the repair scenario, screws are preferred over clips and adhesives. The use of adhesive is in principal least desired. Adhesives differ in their melting temperature; therefore an overheating during opening may damage the heat sensitive components, such as the battery.

In respect to the recycling scenario, the time efficient and safe opening, depollution and removal of valuable parts has the highest priority, which typically means a destructive process, applying mechanical force. The recycler indicated that clips are the preferred opening mechanism, as they can be disengaged with rough tools in nearly no time.

3.2. Battery and mainboard removal

The removal of the battery revealed two main attachment approaches. In the first, the battery was placed in a metal or plastic tray, which in turn was screwed to the housing. In the second approach, the battery was directly glued.

The interviews with the refurbisher indicate that for the repair scenario the first approach is preferred. The glued option is not desired due to safety reasons.

The safe removal of the battery has as well for the recycling scenario the highest priority; moreover, the separate treatment of batteries is mandatory under the WEEE directive. All interviewed recyclers emphasized the importance of information availability regarding the localization of the battery in order to avoid damage of the battery and thus the explosion risk for workers and pre-processing facilities [1].

The mainboard is the component with highest material value for the recycling. However, taking into account the effort for its removal, it is most likely that after the depollution, the device will be shredded as a whole.

In general, screws seem to be the better option for repair. However, for recycling they don't present the favourable option as they might reduce the time efficiency of the disassembly, if being used in excessive amounts and variants.

3.4. Display removal

The dismantling of the display unit is particularly relevant for the repair scenario. According to the interviewed repair shops most often, tablets are being brought to repair because of accidental breakage of the display unit. Moreover, the interviews revealed that in some cases only the front glass was broken.

Therefore, the fusion of the front glass to the LCD display and multi-adhering of LCD components such as backlighting, digitizer, front glass to the panel frame will require the replacement of the entire display assembly.

With respect to the recycling scenario, the interviews indicate that the display might be separated, under the condition that an easy access and removal are ensured. In general, the front glass would be separated from the LCD unit, if it is not glued to it. However, according to the current practice, most probably they will be processed in the shredder.

The display contains rare earth metals from the LEDs and indium from the ITO layer in very small quantities. Current recycling practices do not involve the recovery of these metals, however in a long term they might be of interest for the recycler.

4. MATERIAL CONTENT

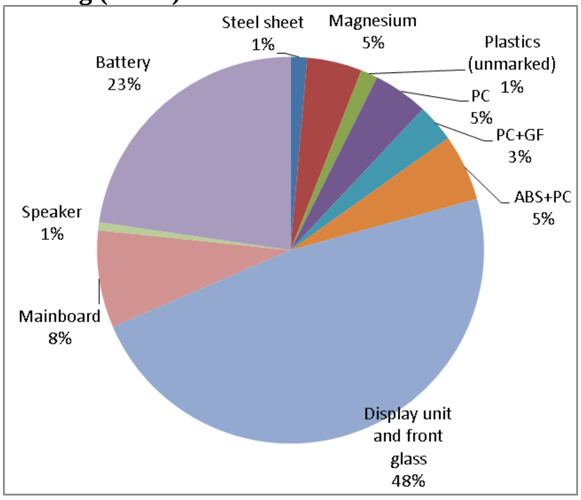
In [2], the material content of the DUT was analysed, through determination and weight measurement of all removed parts. As no chemical analysis was carried out, the study differentiates between mono-materials (e.g. Aluminium, Steel, and plastics) and complex parts (e.g. display unit, battery, mainboard)

Furthermore, [1] differentiated the material content of the DUT according to the screen size (7-8" and 9-11"). In this study, we expand the material analysis and classify the DUT according to the housing material – Aluminium or plastic (see figure 1 and 2).

4.1. Material content on system level

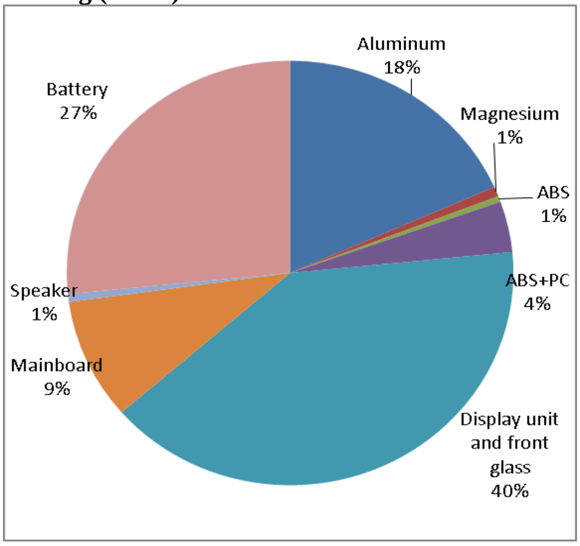
The analysis indicates that in both cases, the display unit together with the front glass and the battery are the parts with highest weight contribution. However, an interesting finding for the recycling is the absence of Aluminium in the tablets with plastics housing as well as the relative low percentage of plastics in tablets with Aluminium housing.

Figure 1: Material content of DUT with plastic housing (wt-%)



The mainboard is the component, which has the highest material value. Nevertheless, taking into account the small weight percentage and the effort for disassembly, it is not very likely that the mainboard will be removed for separate processing.

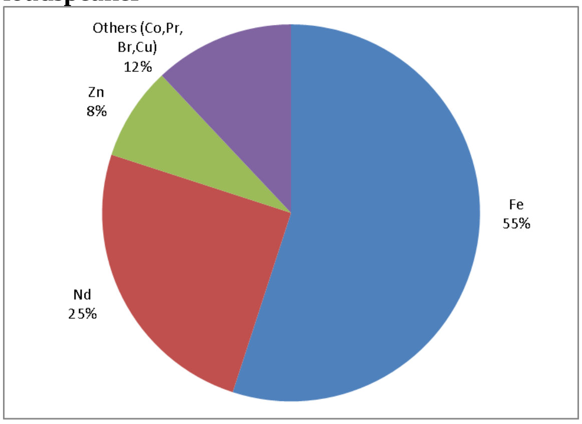
Figure 2: Material content of DUT with Al-housing (wt-%)



4.2. Material content on component level

Rare earth metals are still identified as critical in the second report on critical raw materials as well [3]. Rare earth metals find application in components required for numerous key technologies. Magnets are one of the main end uses for rare earth metals. Therefore, we analysed the material content of three magnets from different DUT loudspeakers (see figure 3). For the characterization fluorescence spectrometry (XRF), energy dispersive X-Ray diffraction (Polytax) and integrated scanning electron microscope/energy dispersive X-ray spectroscopy (SEM/EDX) were used.

Figure 3: Material content of magnets in DUT loudspeaker



The biggest weight contribution comes from the content of Iron followed by Neodymium with approximately 25wt%. The analysed magnets contain on average 8 wt% Zinc. Praseodymium, Copper, Cobalt and Bromine were also detected. The content of Iron, Zinc, Neodymium and Cobalt was identified through the XRF. Furthermore, their content was confirmed by the Polytax. Using the integrated SEM/EDX, Iron and Neodymium were identified. The measured percentage of the metals differs depending on the used analytical technique; however the ratio between the contained metals remains stable.

4. ENVIRONMENTAL ASSESSMENT

The environmental performance of tablets was further analysed using the LCA to go tool, which enables a simplified life cycle assessment. A typical netbook was selected for the benchmark modelling. The decision to compare a tablet with a netbook is based on the performance similarities of the two products. Moreover, both devices are representing the mobile IT market.

The selected devices, both from Acer, have the same screen size (11.6 inch), however they differ substantially in respect to storage capacity and housing materials to illustrate the effect of these material and specification choices. There are slight differences in the capacity of battery and memory and the mainboard dimension as well (see table 2). For both devices is assumed that the use lifetime amounts to 4 years and the failure rate is 10% per year. For the data entry, data from the disassembly was used as well as publically available information for the two products.

The specifications of the two products were entered into the LCA to go webtool (http://tool.lca2go.eu). At this point it should be stressed that the use phase of the DUT differs gradually in terms of power management and consumption, therefore a comparison of the use phase is limited and would not deliver truthful results. For this reason, the emphasis is on the manufacturing phase of the two devices.

Specifications of the two Acer products are listed in Table 3.

Table 3: Specifications of the tablet and netbook

	Tablet	Netbook
Lifetime	4 years	4 years
Annual Device Failure Rate	10%	10%
Display	LCD	LCD
Display Size	11.6 Inches	11.6 Inches
Display Ratio	16:9	16:9
Processor	1.8 GHz Intel Core	1.4 GHz Intel Celeron
Processor Count	Dual-core	Dual-core
Memory	4 GB SDRAM	2 GB DDR3L SDRAM
Flash Memory Size	16 GB	16 GB
Hard Drive	128 GB SSD	16 GB SSD
Graphics Coprocessor	Intel HD Graphics 4000	Intel HD Graphics
Wireless Type	802.11 a/b/g/n	802.11 a/b/g
No. of USB 2.0 Ports	1	1
No. of USB 3.0 Ports	1	1
HDMI port	1	1
Audio-out Ports	1	1
Battery	Li-ion	Li-ion
Battery Capacity	54 Wh	45 Wh
Housing material	Estimated 230 g Aluminium	Estimated 400 g PC/ABS
Estimated Mainboard dimensions	10 cm x 8 cm	19cm x 8cm
External power supply	Max output rating 65 W	Max output rating 65 W
Tantalum capacitors	2 units (3.5x2.8mm)	2 units (3.5x2.8mm)

The Carbon Footprint associated with the manufacturing of the netbook and tablet was modelled and compared (see table 4 and 5). As the assessment model of LCA to go builds on generic parameterised background data, same data entries yield same results.

With 95 kg CO_2-eq. per lifecycle the Carbon Footprint of the manufacturing of the tablet exceeds significantly the Carbon Footprint of the netbook (55 kg CO_2-eq.).
As table 4 shows, the memory of the tablet has the highest contribution to the Carbon Footprint, followed by the battery. In particular a large storage capacity, if realised as an SSD module, excessively contributes to a much higher Carbon Footprint. For an environmentally conscious consumer this means, storage should not be dramatically oversized. On the other hand a storage capacity too small might result in a short product lifetime. This correlation between Carbon Footprint, storage capacity and lifetime is also a strong argument for upgradeability, i.e. storage extension later on, if really needed. Upgradeability however is not featured by tablets yet at all. In alternative to hardware upgrades are cloud based storage, which is a huge trend for mobile IT anyway. It remains to be assessed, what might be better in terms of a low Carbon Footprint: Less device storage capacity and more energy consuming cloud services or vice versa. In the course of this screening assessment this complex issue could not be tackled, but should not be ignored.

Table 4: Tablet Manufacturing Carbon Footprint

	CF
	kg CO_2-eq
TOTAL per product lifecycle	219.89
MANUFACTURING	95.41
Housing & internal structural elements	2.38
Display	6.49
Printed Circuit Board Assemblies	2.66
Tantalum capacitors	-
Memory	26.37
Processor	8.00
Storage	16.56
Optical Disc Drive	-
Connectivity	0.67
Power supply	4.52
Cables	0.19
Battery	18.90
Overhead miscellaneous parts	8.67

Another major difference between the two Acer products is the bulk housing material: Aluminium versus plastics. Although the amount of both contributes significantly to the overall weight of each of the devices, the differences in the products' Carbon Footprint are minor.
Slightly more important is the difference in the mainboard size: The nearly twice as large board in the netbook yields a 2.4 kg higher Carbon Footprint.

Table 5: Netbook Manufacturing Carbon Footprint

	CF kg CO_2-eq
TOTAL per product lifecycle	119.44
MANUFACTURING	54.74
Housing & internal structural elements	1.74
Display	6.49
Printed Circuit Board Assemblies	5.02
Tantalum capacitors	-
Memory	5.25
Processor	8.00
Storage	2.07
Optical Disc Drive	-
Connectivity	0.67
Power supply	4.52
Cables	0.25
Battery	15.75
Overhead miscellaneous parts	4.98

The high impact of the battery should not mistakenly be taken as an indication, that a battery with less capacity is better. It actually is with respect to production Carbon Footprint per unit, but low capacity means more frequent charging, which also means reaching the maximum number of charging cycles more rapidly, thus end-of-life of the device, if the battery cannot be replaced.

The batteries from the disassembled tablets are actually subject to charging cycle tests at TU Berlin labs and results will be published later in 2015 [4]. Findings are expected to contribute to the discussion, whether glued-in batteries in tablets are a factor for device obsolescence.

6. OUTLOOK

The findings indicate that there is no optimal design solution, which satisfies both the repair and recycling scenarios. Features, which make repair easy, might not only be controversial to robustness but also hamper the recycling. However, the statement is valid vice versa – design features, which seem to favour recycling are rather complicating the access and exchange of broken parts. A general observation is that the most product designs do not consider repair and the requirements of the end-of-life actors.

At the present moment the amount of devices reaching the final phase of the life cycle is negligible. At this point, the analysis of the material content is especially important for the recycling, because it points out to the potential resource losses of improper processing. Nevertheless, the analysis allows the upscaling of the material flows and can serve therefore as basis for consideration how to adapt the pre-processing practices to the changing mobile IT technologies and material streams.

In addition, the results of the LCA screening stress the relevance of the manufacturing phase. It should be mentioned that the mobile IT market in general aims to drive up to tablets with high storage capacities up to 500GB.

Furthermore, the results point once again to the importance of integrating the repair scenario in the tablets design. Making tablets repairable and the exchange of components with high breakage tendency possible will extend the lifetime and therefore reduce substantially the total Carbon Footprint per year of tablet use.

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