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Opportunities For 3D-printable Spare Parts: Estimations From Historical Data.

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Abstract: The Sharepair project aims to decrease the waste of electronic and electric consumer products and increase their useful life, by supporting repair communities and scaling up citizen repairs through digital tools. One of the focus areas of this project is to support the discovery or manufacturing of spare parts. With a 3D CAD model of a part and a 3D printer, repair communities could manufacture spare parts. This paper discusses the possibilities of identifying repairs, within repair communities, that can be met through 3D printed spare parts. To understand and identify these possibilities, the repair entries expressed in the Open Repair Database (ORD) from the Open Repair Alliance were examined. The analysis aimed to identify documented examples of repairs that have broken or missing parts, and estimate how many may be suitable for replacement by 3D printed versions. The ORD includes 41,874 repair data entries from 229 repair communities (Repair Café, Restart Project, Fixit Clinic, and Anstiftung) in eighteen countries. Repair entries include information such as product category, brand, model, repair status and notes regarding the repair process and result, all in different languages.
The analysis identified a list of the most commonly repaired product categories, brands, and models, as well as an estimate that between 7.5% and 29% of products in repair cafes that are not repaired today could be repaired with 3D printed spare parts. The analysis also showed that the data and information about the repairs is inconsistent, open to interpretation and often too limited to precisely pinpoint opportunities for 3D printed spare parts. Specifying the product parts that need repair or replacement and their functional requirements would be key to a successful identification. Thus, the study proposes recommendations to improve the process of capturing repair information that specifies the repair needs that can be met by the use of 3D printing.

Introduction

The Sharepair project aims to decrease the waste of electronic and electric equipment (WEEE) and to increase their useful life, by supporting repair communities and scaling up citizen repairs through digital tools. WEEE is a rapidly growing waste stream, partly because advances in technology have contributed to shorter product lifetimes (Cole, Cooper & Gnanapragasam, 2017). The most logical approach to closing the loop on product use and extending the product's life is simply to repair the product. However, while the concept of repair seems simple, it is seldom practiced (King et al., 2006). Consumer interest in repair is increasing (Scott & Weaver, 2014), but there are still barriers that discourage consumers from repairing broken products (Pérez-Belis et al., 2017). In a survey among self-repairers, Sabbaghi et al. (2016) found the main reasons for an unsuccessful product repair were the complicated repair process (26%), expensive spare parts (17%) and spare parts unavailability (16%). Lack of spare parts is the most mentioned reason for unsuccessful repairs in repair cafes across the world (Repair Café International Foundation, 2020).

Producing spare parts on demand would be expensive using traditional manufacturing, which makes additive manufacturing (AM) more attractive. 3D CAD files of spare parts can easily be shared, today, however, access to such files is limited (Ford, Despeisse & Viljakainen, 2015). Sharepair wants to provide digital resources so repairers can produce spare parts with AM. To provide such resources, the necessary parts and the products they belong to should first be identified. The focus of this paper is to identify the repairs within repair communities that can be met through 3D printing spare parts.

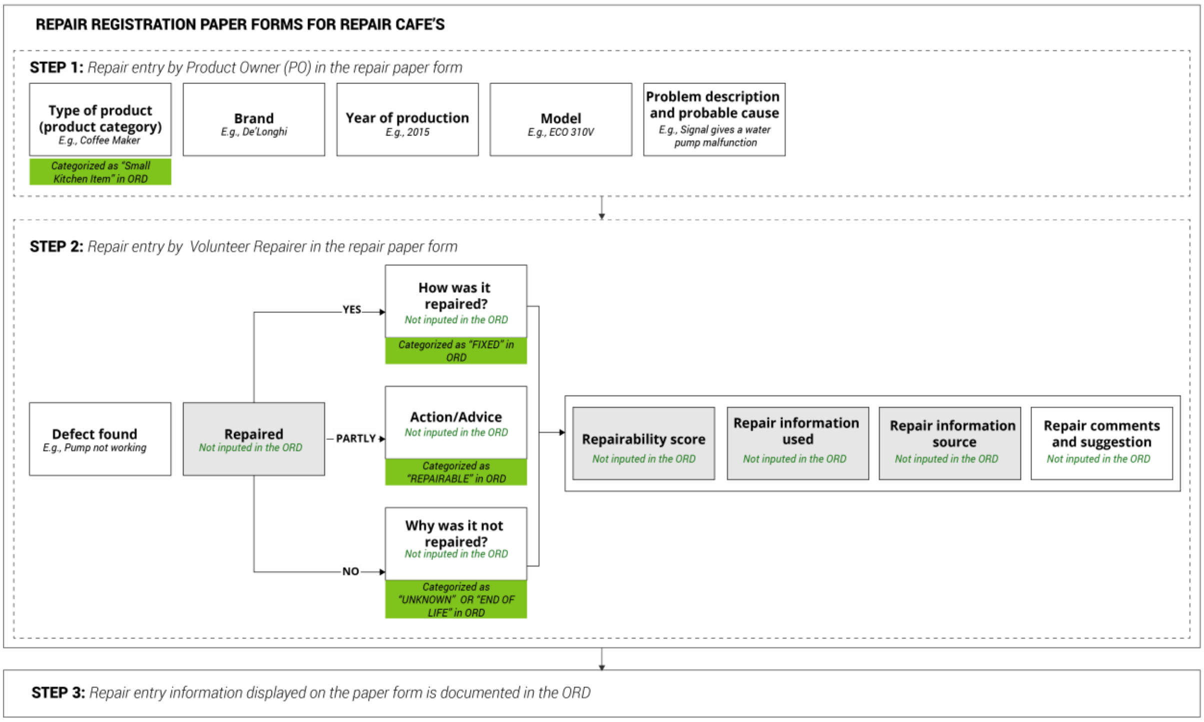

Figure 1. Current repair data entry process.

Method

Estimating the demand for 3D printed spare parts, and what products would be the best candidates for such parts, was determined by combining quantitative and qualitative analysis. The best candidates for 3D printable parts were determined by counting the most common products brought in for repair, and whether the repairs would be solvable with 3D printed spare parts.

All data was gathered from the Open Repair Database (ORD) of March 2020 (v0.1). The database contained the following fields: Data “ID” (e.g., repaircafe_2163), “Data provider” (e.g., Fixit Clinic), “Country”, “Product category” (e.g., Mobile), “Product brand” (e.g., Apple), “Product model” (e.g., iPhone 6S), “Year of manufacture”, “Repair status” (fixed / repairable / end of life / unknown), “Repair date”, “Group Identifier” (e.g., 5073) and “Problem” (any other notes on the repair process and result). Figure 1 illustrates the data entry process for Repair Café’s in the Netherlands, however other communities may have different processes. The ORD included 41,873 repair entries in six languages (English, French, Dutch, German, Spanish and Italian) from Open Repair Alliance communities in 18 different countries, documented from June 2012 to March 2020. Countries represented were Netherlands (43.4%), Great Britain (26.8%), Germany (11.2%), Canada (3.2%), Italy (3.1%), Belgium (3%), USA (2.2%), Norway (1.9%), Argentina (1.5%), Sweden (0.9%), France (0.5%), Spain (0.5%), Australia (0.4%), Hong-Kong (0.4%), Ireland (0.4%), Israel (0.2%), Tunisia (0.2%) and Switzerland (0%). All database entries were translated into English using Google Translate.

The “Repair status” field was a key entry, because 3D printed spare parts are only needed for products which are either “Repairable”, “End of life” (see Table 1). “Unknown” entries could either be fixed, repairable, or end of life, and thus was not used for analysis.

The most common product categories, brands and models were determined by counting the “Product category”, “Product brand” and “Product model” fields. Both “Product category” and “Product model” needed refinement before further analysis. The “Product category” field needed recategorization to align with the newest ORDS (v0.2) updated in January 2021, which is closely aligned with the EU directive on WEEE product categorization (Open Repair Data Standard, 2021; EU Directive, 2012).

Repair Status	Description
"Fixed"	*If the repairer and owner were satisfied that the item can continue to be used.*
"Repairable"	*If the repairer and owner didn't complete a repair, but identified what reasonable additional steps or professional help is needed doe successful repair.*
"Unknown"	*An empty or zero value recorded.*
"End of life"	*If the repairer and the owner decided that it is not cost-effective or realistic to repair the device.*

Table 1. Repair Status definition (Retrieved from Open Repair Data Standard, 2021).

For example, the "Small kitchen item" product category included both coffee makers and food processors, which have their own categories, causing redundancy. The "Product model" field contained mostly incorrect entries (most users entered the product category in this field instead of the model), so its data was refined before analysis by separating mislabeled entries from correctly labelled entries. The "Product brand" field did not require further analysis steps as it was generally filled out correctly or left blank.

There was no data available on spare parts. The closest data available could be found in the "Problem" field, which included open comments about the repair and why it was (not) successful. Therefore, the 3D-printable spare-parts potential was estimated by qualitative analysis of the "Problem" field entries. Because of the extensiveness of data in this field for the complete database, we used a representative subset of 1,463 repair entries constructed by selecting 5 entries per product category per year between 2012-2020. For product categories with less than 5 entries, all entries were selected. The data was not filtered by repair community, country, product model or product brand, as these varied too widely in the number of entries. The sub-selection does not perfectly mirror repair event demographics, but it was a close enough approximation.

Within the qualitative analysis the 1,463 entries were categorized in 5 repair types: (i) mechanical, (ii) electromechanical, (iii) electrical, (iv) software, and (v) unknown. Electrical, software and unknown entries were per definition unsuitable for the purpose of this research. Mechanical and electromechanical entries were further coded on their estimated 3D printability using the following categorical division: high certainty, plausible, unlikely and unknown. The categories were counted to provide quantitative estimates of repairs that might be fixed using 3D printed spare parts.

The minimum and maximum of the repair type estimates were determined by taking the outer ends of the error bars. The 3D-printability error bars overlap, so to prevent double counting, the minimum was determined by taking the low end of the high-certainty error-bars, and the maximum by taking the absolute number of high certainty and the high end of the error bar for plausible. The estimate for the whole database (represented by the qualitative subset) was made by multiplying the repair type and 3D printability percentages.

Results

Figure 2 shows the number of repair entries and their status from 2012 to March 2020 (OpenRepairData V0.1, 2020). In this period, 41,873 repair entries were documented in the ORD from 229 repair communities (Repair Cafe, Restart Project, Fixit Clinic and Anstiftung). Of all 41,873 repair entries, 53% were "Fixed", 21% "Repairable", 18% "Unknown" and 8% "End of life". The yearly rate of "Fixed" and "Repairable" repairs largely remained stable over time, "Unknown" percentages increased slightly, and "End of life" percentages decreased slightly.

Product Category

Recategorization of the ORD gave 40 product categories (see Figure 3). The category "Small kitchen items" was by far the most often recorded entry, with 13.8% of the database total, while the average product category was 2.5% of the total. Within the "Small kitchen item" category, 51.4% of the entries were "Fixed", 15.4% "Repairable", 27.2% "Unknown", and 5.9% "End of life". Other common product categories were "Laptop", "Lamp", "Hi-Fi separates", and "Vacuum" with relatively substantial "Fixed" and "Repairable" entries. The product categories with the highest percentage "Fixed" entries were "Sewing machine", "Lamp", "Paper shredder", "Hair dryer", and "Toy".

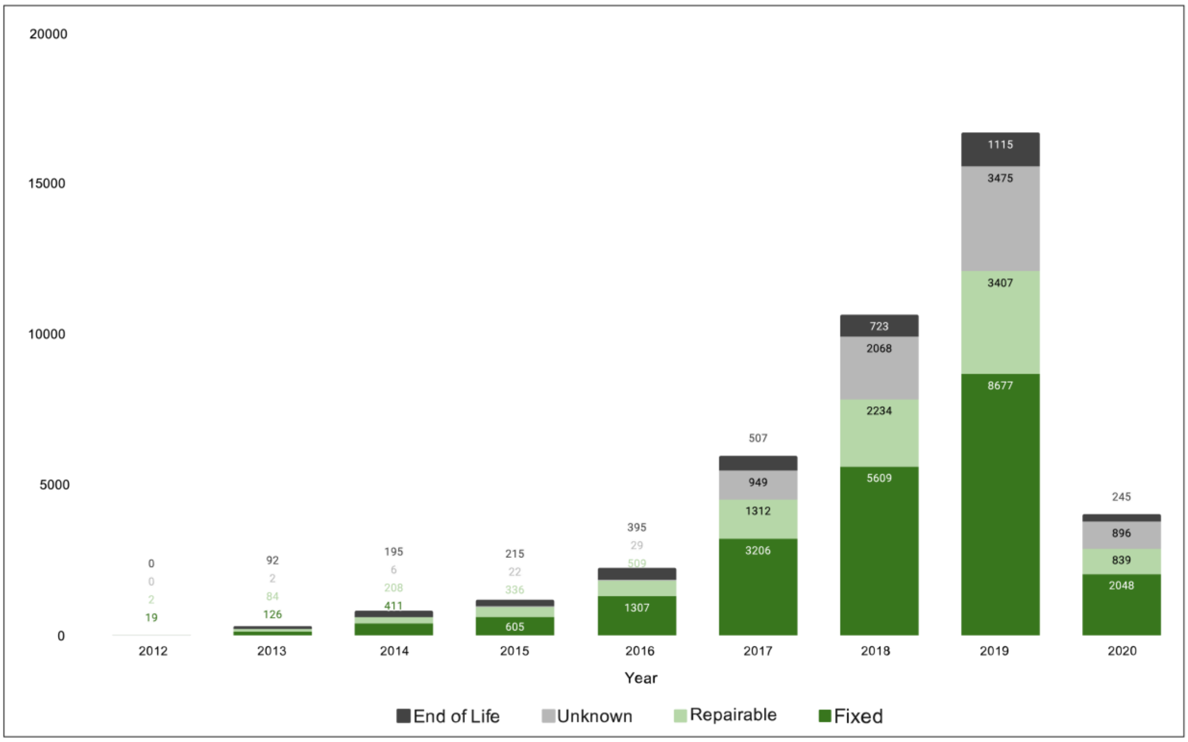

Figure 2. Number of repair entries brought in between 2012 - 2020 and their respective repair status.

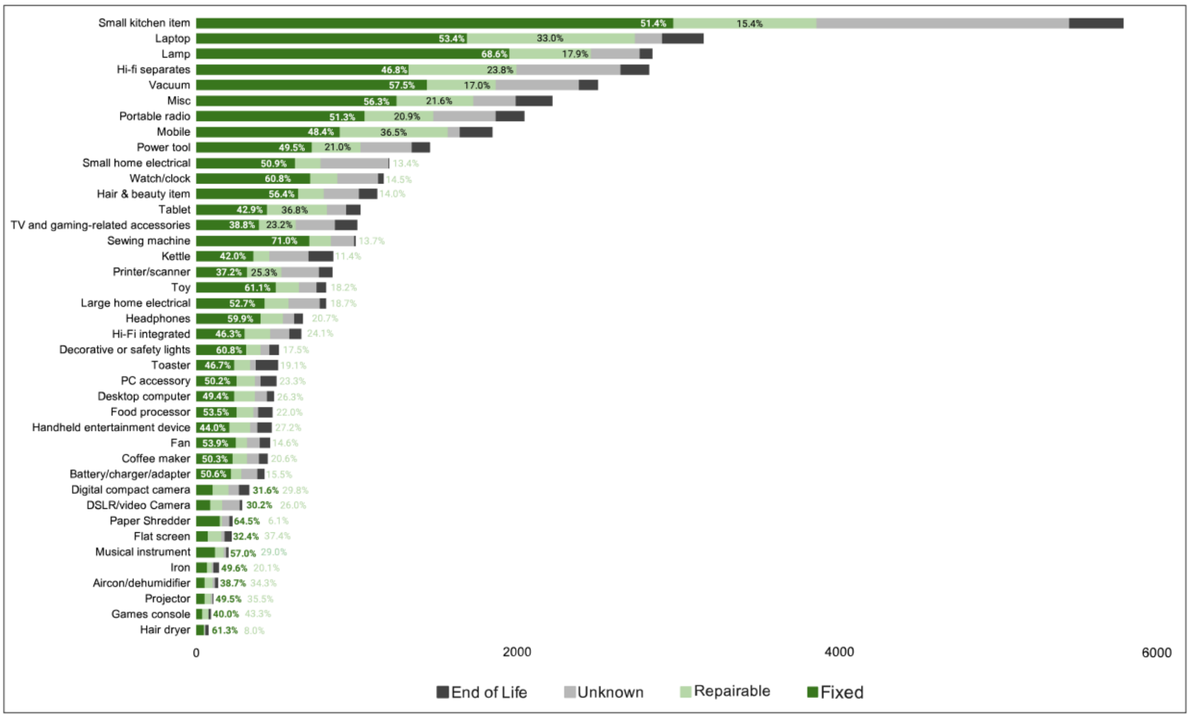

Figure 3. Number of entries in each product category, and their repair status (listed as percentages), sorted by total entry numbers.

The product categories with the lowest percentage "Fixed" entries were "Flat screen", "Digital compact camera", and "DSLR/video camera". Product categories with the highest "Repairable" percentage were "Games console", "Flat screen", "Tablet", and "Mobile", and the lowest were "Kettle", "Hair dryer" and "Paper shredder.

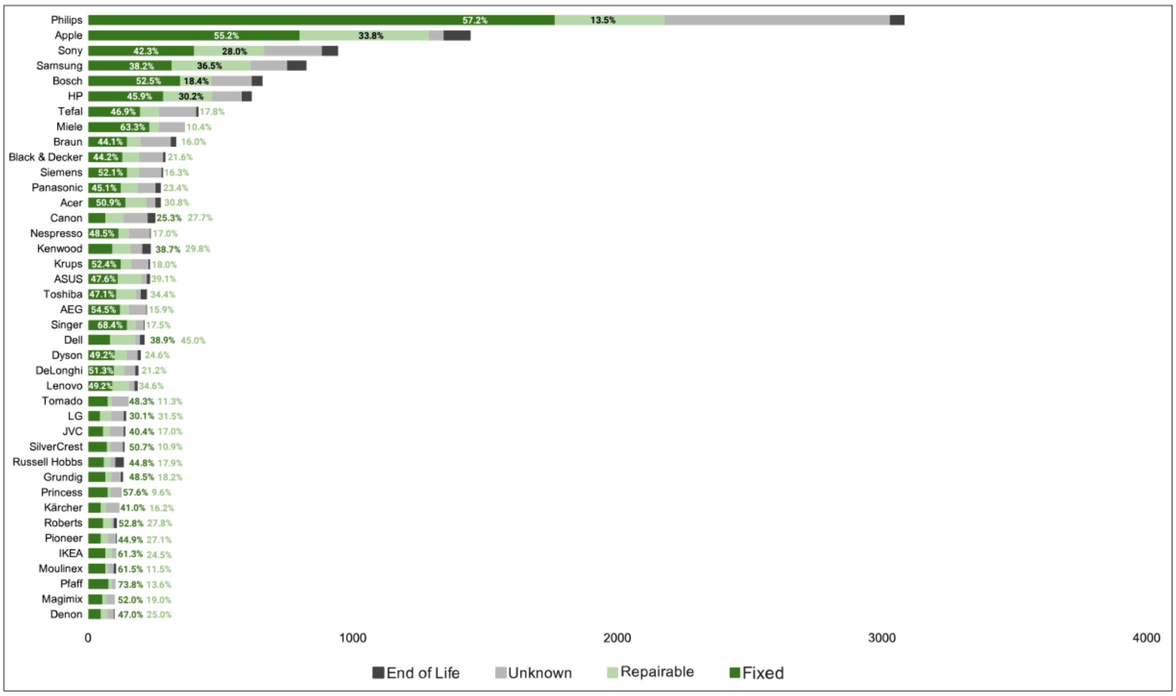

Figure 4. Number of entries for each product brand with over 100 repair entries, and their repair status, sorted by total entry numbers.

Product Brands

39% of database repair entries had unlabeled product brand names, of which 55% were "Fixed", 20% “Repairable”, 12% “Unknown”, and 13% “End of Life”. Within the correctly labelled product brands, 3,234 unique brands were identified. “Philips" was most often recorded, and other common brands recorded were “Apple” “Sony”, “Samsung”, and “Bosch” (see Figure 4). Brands with the highest “Fixed” percentages were “Pfaff”, “Singer”, “Miele”, and “Moulinex”, and the lowest were “Samsung”, “LG”, and “Cannon”. Brands with the highest “Repairable” percentages were “Dell”, “Asus”, and “Samsung” and the lowest were “Tornado”, “Silver Crest”, “Miele” and “Princess”.

Product Models

72% of the total repair entries in the ORD had unlabeled product models; 28% were either correctly labelled or mislabeled. Of the entries with product model labels, 90% were mislabeled as product types (e.g., laptop), serial numbers, or only product model numbers. Only 10% with labels were correctly labelled (3% of total entries). Figure 5 shows the most often listed (top 10) correctly labelled product models; nine of the ten were models of iPhones. Not shown in the figure, the correctly labelled product models with the highest “Repairable” percentages were “iPad 2”, “iPhone 7 Plus”, “MacBook Air 13-inch 2015” and “iPhone 8”. The lowest percentage “Repairable” were “iPhone 5C”, Senseo HD 7840”, “Senseo HD7825”, and “Galaxy 2”.

Similarly, Figure 6 shows the most often listed (top 10) mislabeled product models, starting with "Laptop", “Sewing machine”, “Vacuum cleaner”, “CD player”, and “Coffee machine”. Mislabeled product models with the highest "Fixed" percentages were “MacBook Pro 2012” and “Bike light”, and the lowest were “iPod” and “Amplifier”. Mislabeled product models with the highest “Repairable” percentages were “Kindle”, “Galaxy” and “iPhone”, and the lowest were “Coffee machine”, “CD Player”, “Radio” and "Lamp".

Repairs addressable by 3D printing

To estimate to what extent repairs could be met by 3D printed spare parts (plastic desktop 3D printing), a qualitative analysis of 1,463 “Repairable” entries was used. Figure *7* shows that of the 1,463 entries, 30% were electrical, 21% were mechanical, 14% were electromechanical and 5% were software related repair types. Thus, a total of 35% of the repair types categorically could be addressed by plastic desktop 3D printing. That is, mechanical or (possible) electro-mechanical repair types.

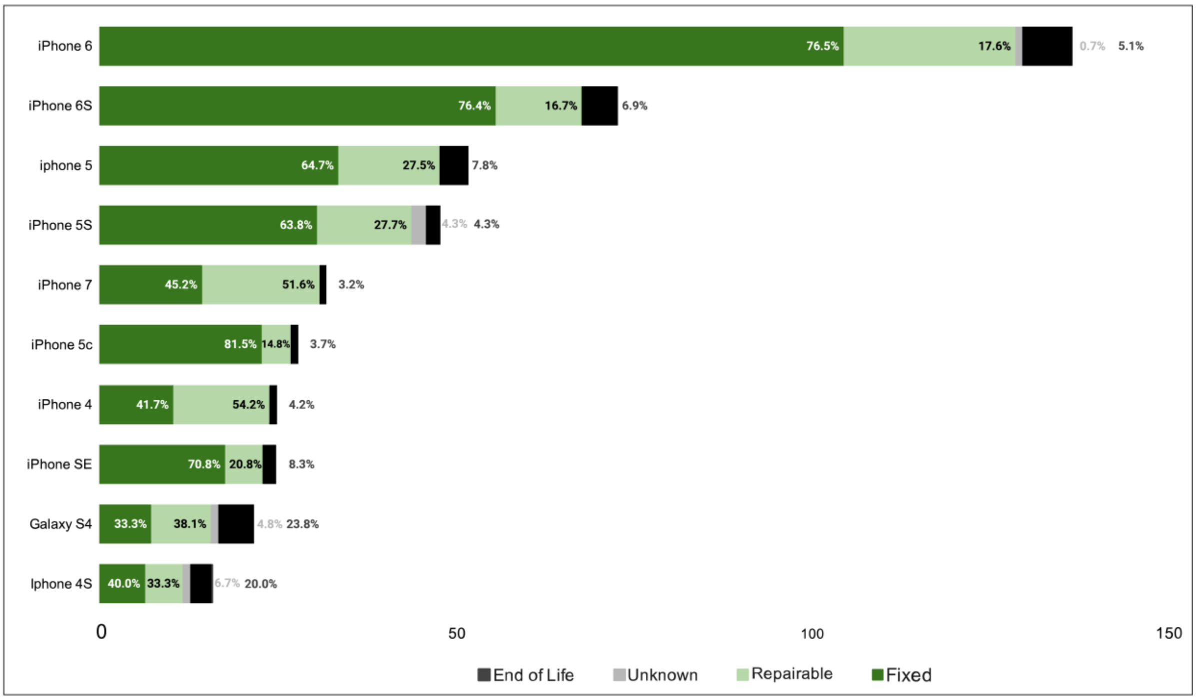

Figure 5. Number of entries for the most often listed correctly labelled product models, and their repair status, sorted by total entry numbers.

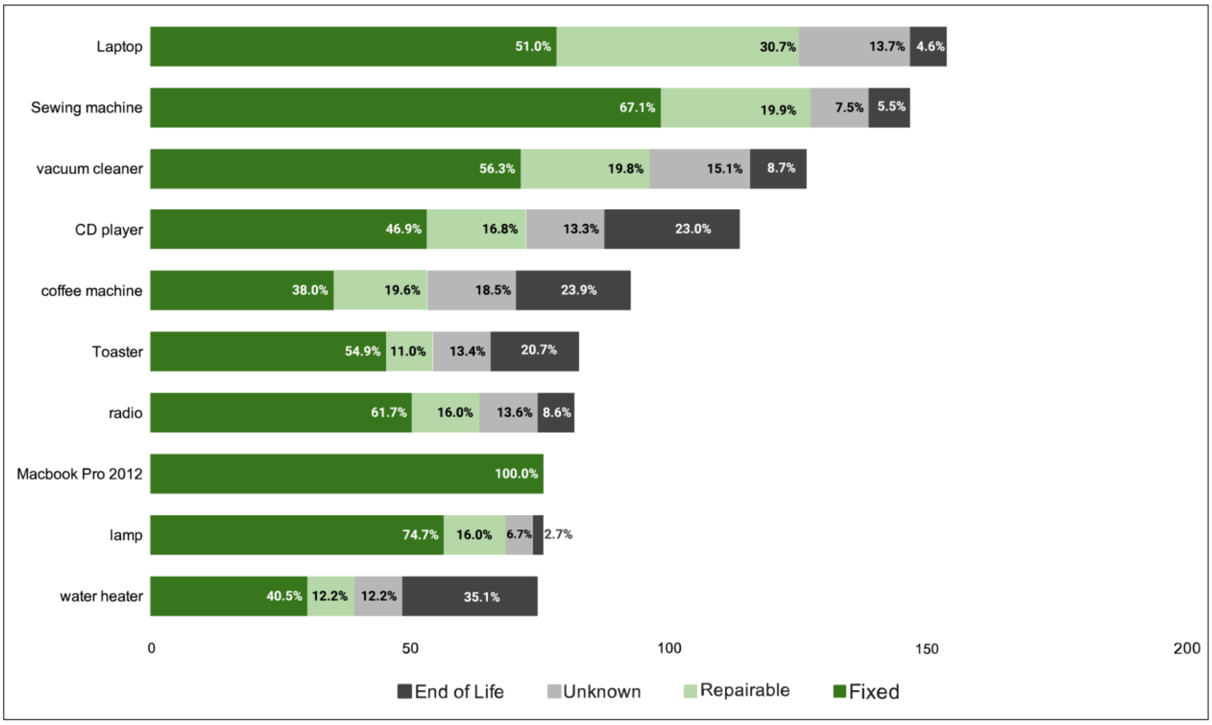

Figure 6. Number of entries for the most often listed mislabeled product models, and their repair status, sorted by total entry numbers.

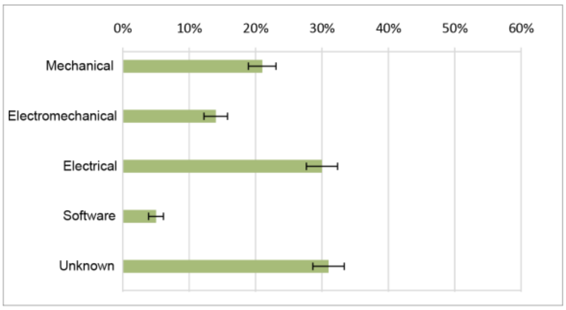

Figure 7. Different repair types within the selected data. Error bars are 95% binomial confidence intervals.

Likewise, Figure *8* shows the 3D printability for the mechanical and electromechanical repairs, of which 34% to 80% of mechanical repairs and 9% to 66% of electromechanical repairs might be able to be repaired with 3D printed spare parts. For the whole qualitative dataset, this would be between 7.5% - 29 %.

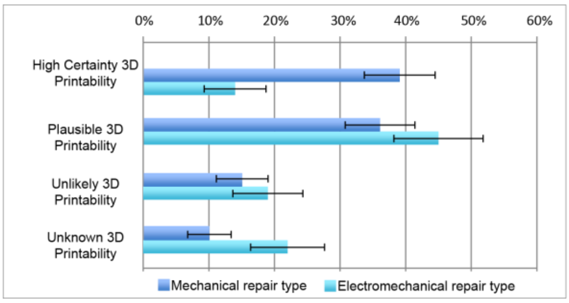

Figure 8. D Different levels of assessed 3D printability within the selected data. Error bars are 95% binomial confidence intervals.

Discussion

Product category/ model/ brand

The best product category for 3D printed spare parts is likely “Small kitchen item”, since it was by far the largest, and contained a large percentage of mechanical repairs that could arguably be repaired with 3D printed spare parts. However, this category contained a great diversity of products, and thus a great diversity of parts that would need to be 3D modeled and tested.

Several brands, including Philips, Apple, Sony, and Samsung, had high numbers of repair entries. Notably, Apple, Sony, and Samsung also had high percentages of entries labelled as “Repairable”, but with many of their products being primarily electronic and the possibilities of being fixed by 3D printed spare parts are limited. Similarly, the product models which were correctly labelled were almost all smartphones, so this did not help find targets for 3D printed parts.

The most-mentioned product categories and information on product models and brands are currently insufficient to plan the generation of 3D printed spare part libraries. The current categorization lacks distinctness or allows for a large number of mislabeled entries (e.g., the ambiguity of the “Miscellaneous” category, “Small kitchen item” being a separate category from “Toaster” and “Kettle”). To improve this, we recommend using the European Directive WEEE categorization (Directive 2012/19/EU), as a guide to reframe the “Product category” entry, since it provides more granularity. In addition, we recommend providing examples of product models, to avoid the currently rampant mislabeling.

Repair Status

“Fixed” products are unlikely to need 3D printed spare parts, so most opportunities for repair with 3D printing were estimated to be in entries labelled as “Repairable”. There are potential opportunities in the "Unknown" and "End of life" categories, but these have insufficient data to conclude. This “Repair Status” data could be clarified by asking what would be needed to finish a repair marked as “Repairable”. We recommend request further information to justify the selected label, specifically when it is labelled as “Repairable” (E.g., spare part is necessary; Figure 9).

3D Printability

Between 7.5% to 29% of all recorded repairs from these repair communities might be helped by 3D printed spare parts, when counting “highly likely” and “plausible” entries within those labelled as “repairable” with “mechanical”, and “electromechanical” repairs. These percentages are an initial estimate of 3D printability, but this also depends on the functional and performance requirements of each part. Further analysis is required to consider the specifics of each component. This information is not currently available in the ORD.

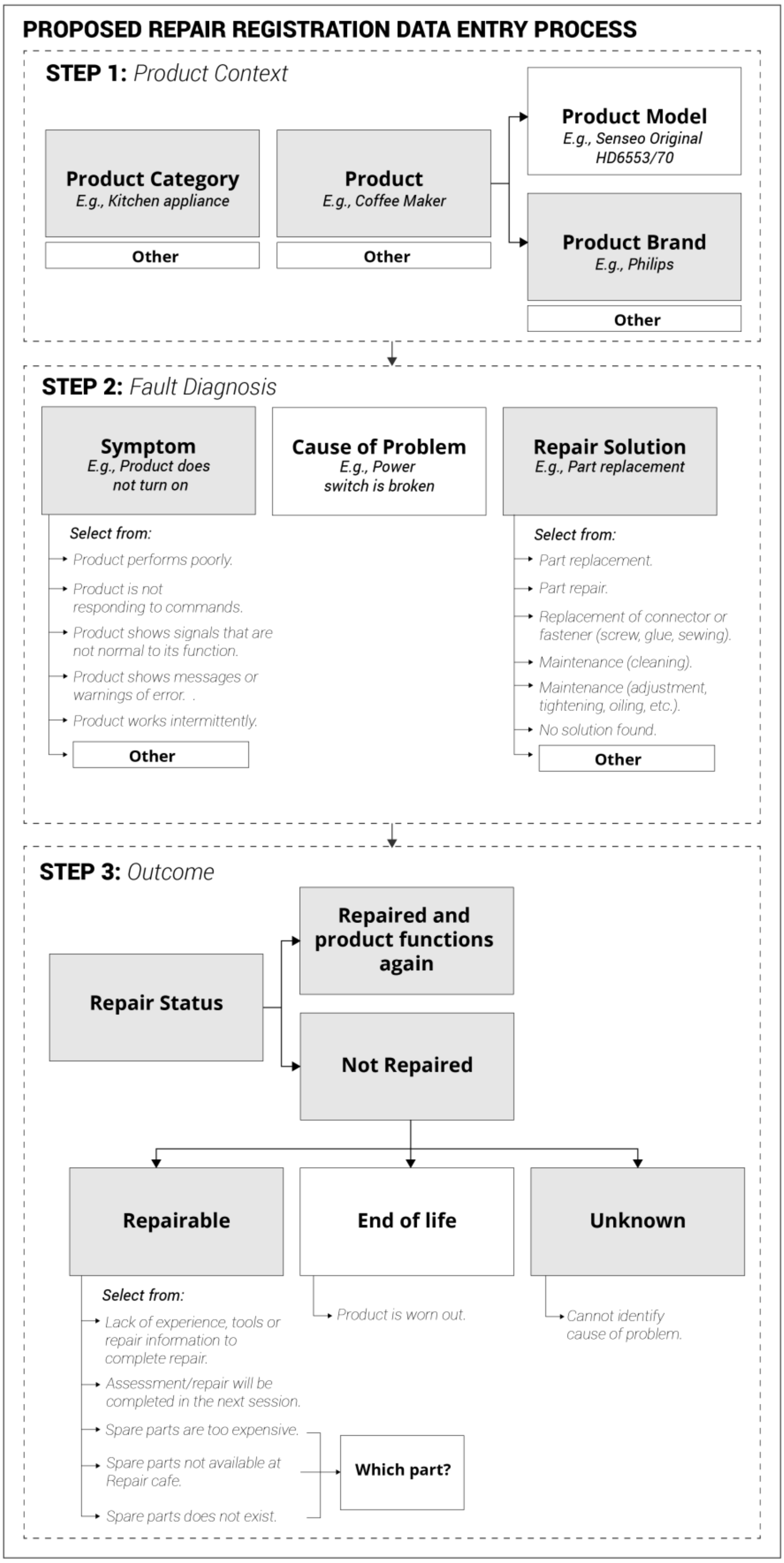

Figure 9. Proposed repair registration data entry process. Categorization of symptoms based on Pozo et al., 2020.

ORD Limitations

Entries within the ORD were often mislabeled or incomplete, in many cases due to vagueness of the entry fields, as mentioned above. In addition, a large part of the repair data was entered in multiple languages in open comments, without pre-categorization. In consequence, considerable data processing and interpretation are required to analyze it, leading to information getting lost in translation and inconsistent data sets. Table 2 shows examples of "Problem" field comments which lacked detail or included information that should have been entered in other fields.

Fixed	**Repairable**
"Bolt does not work"	"Failure"
"cut"	"Clogged element"
"HVAC 1.1kg"	"Yes ~ Does not"
"Changed capacitor"	"Valve is broken"
"Broken riser pipe break"	"PCB Board faulty ~ Not charging the fence"
Unknown	**End of Life**
"Unknown ~ Do nothing"	"Coffee machine leaks"
"Makes too much noise"	"Engine broken"
"Stops halfway"	"Heating defective"
"Broken water filter- does not filter"	"Fell out ON-OFF button"
"Clutch/drive connection failed"	"Blenders - power broken button"

Table 2. Example of comments in the "Problem" field in the ORD.

We estimate these limitations arise mainly from the repair registration form and data entry process; which asks an extensive number of open questions that do not correspond to the database, is filled in by more than one individual per entry, and is recorded using a paper form which is later manually digitized (Figure 1).

We recommend the following for the streamlining of the entry process and to facilitate the identification for the need of 3D printed spare parts: switching the entry process into a directly digital format, limiting the number of people entering information to only the volunteer repairer, requesting only relevant information in the form of closed questions with pre categorized fields, and allowing the specification of spare part requirements within the "Repair Status" field. (See Figure *9*) We also recommend testing and validating the recommended process with users in repair communities. Such revisions of ORD data entry would not only help expose opportunities for 3D printing in repair, but would also help expose opportunities to improve the repairability of products in many other ways.

Conclusion

The goal of this paper was to find opportunities for 3D printing of spare parts for repair communities by analyzing repair needs in the Open Repair Database from the Open Repair Alliance. The objectives were to estimate how many repairs 3D printing could address, and what kinds of products should be targeted for creating libraries of 3D printable parts.

To answer the first question, qualitative coding of repair problems showed 7.5% - 29% of non-repaired items in repair cafés might benefit from 3D printed spare parts. Suitable repairs were mainly estimated to be mechanical, so mechanical parts of kitchen appliances would be the priority when constructing a library of downloadable 3D CAD files of spare parts.

To answer the second question, quantitative analysis showed "Small kitchen item", "Laptop", and "Lamp" were the most common product categories. "Small kitchen item" had many "Repairable" and many mechanical repair entries, which made it a promising target for 3D printed spare parts. Product model data was too often mislabeled to be trustworthy, and the most common correctly labeled product models were electronic, thus unlikely candidates for 3D printed spare parts. Common brands included Philips, Apple, and Sony, but their products were also mainly electronic. Therefore, specific product models or brands were not useful to target.

This study's effectiveness was limited by significant amounts of incomplete or incorrect data. Many entries had unidentifiable product models and/or brands, and most product models were incorrectly labelled as either a product sub-category, serial number, or just product model number. Information on product fault and spare part use was also limited, which made it difficult to conclude if parts could be printable. To better estimate possibilities for 3D-printing for repair in the future, and provide other insights into product repairability, we recommend improving the data entry process. This can be done by streamlining the data entry process and minimizing the number of open questions.

Repair is one of many ways to create a more sustainable world with longer-lasting products. Although 3D-printing cannot solve all repair problems, by further testing and developing 3D-printing for Repair, we can make a positive impact by saving product lives.

Acknowledgements

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References

Cole, C., Cooper, T., & Gnanapragasam, A. (2017). Extending product lifetimes through WEEE reuse and repair: Opportunities and challenges in the UK. 2016 Electronics Goes Green 2016+, EGG 2016, 1–9. https://doi.org/10.1109/EGG.2016.7829857

Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) Text with EEA relevance.

Ford, S., Despeisse, M., & Viljakainen, A. (2015). Extending product life through additive manufacturing: The sustainability implications. Global Cleaner Production and Consumption Conference, December, 1–4. Retrieved from https://www.researchgate.net/publication/282075975_Extending_product_life_through_additive_manufacturing_The_sustainability_implications

King, A. M., Burgess, S. C., Ijomah, W., & McMahon, C. A. (2006). Reducing waste: Repair, recondition, remanufacture or recycle? Sustainable Development, 14(4), 257–267. https://doi.org/10.1002/sd.271

Pérez-Belis, V., Braulio-Gonzalo, M., Juan, P., & Bovea, M. D. (2017). Consumer attitude towards the repair and the second-hand purchase of small household electrical and electronic equipment. A Spanish case study. Journal of Cleaner Production, 158, 261–275. https://doi.org/10.1016/j.jclepro.2017.04.143

Pozo Arcos, B., Bakker, C., Flipsen, B., & Balkenende, R. (2020). Practices of fault diagnosis in household appliances: Insights for design. Journal of Cleaner Production, 265, 121812. https://doi.org/10.1016/j.jclepro.2020.121812

Repair Cafe International Foundation. (2020). Repair Monitor - Analysis Results 2019. Retrieved from https://repaircafe.org/en/wp-content/uploads/sites/2/2020/05/RepairMonitor_analysis_2019_05052020_ENGLISH.pdf

Sabbaghi, M., Esmaeilian, B., Cade, W., Wiens, K., & Behdad, S. (2016). Business outcomes of product repairability: A survey-based study of consumer repair experiences. Resources, Conservation and Recycling, 109, 114–122. https://doi.org/10.1016/j.resconrec.2016.02.014

Scott, K. A., & Weaver, S. T. (2014). To Repair or Not to Repair: What is the Motivation? Journal of Research for Consumers, January 2014, 1–31.

Open Repair Data_V0.1. Aggregate dataset 2020-3-31. Retrieved from https://github.com/openrepair/data/tree/master/aggregated/202003

Open Repair Data Standard. 1st January 2021. Retrieved from https://standard.openrepair.org/document.html.