Repairing and recycling electronic components while learning from them: Some guides for fablabs

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Abstract

We live surrounded by electronic devices of increasing complexity, usually having short lifetime and high environmental impact. How can we, from fablabs, contribute to reduce this waste of resources? What role should we play in such a "resource-consuming" environment?

We describe how within a collaborative environment and with few technological resources, many electronic devices (or furniture, or clothing, or vehicles) can be repaired, improved, and reused. We describe what we consider good uses of material resources inside a fablab, from design to manufacturing, including sources of waste materials. We also describe briefly some repairs and maintenance we must carry out on our machines, common to many fablabs.

The knowledge to repair an electronic device is valuable since it allows studying real problems analyzing their causes (technical) and consequences (environmental and economic). We give several examples of educational uses of appliance repair: from workshops for curious people, within global networks such as Repair Cafe, to official subjects for engineering students, within official degrees at University of Extremadura.

Finally we describe how a regional company, La Hormiga Verde, in Spain, has based its business model on a collection network of electrical materials. They are repaired and sold; or destroyed, separated and selled globally by weight, by personnel at risk of social exclusion. Fablabs can collaborate with this type of company since we can help to further value the materials they generate through the process of design and manufacturing.

Keywords

Electronic waste, recycling, learning by repairing, sustainability, design for resilience.

1 Context of the proposal

The reflections collected here are the result of working within a public higher education and research institution, the University of Extremadura, in Spain, which allows us to be in contact with a wide variety of developments and experts; we are globally active and collaborate with dozens of companies and research groups. We believe that our vision can be extrapolated to many other places. It is a daily experience to see how the most advanced resources of institutions and companies are hardly used and yet protected, which is a clear waste of resources. This motivated us to promote, since 2014, a development community, Smart Open Lab (SOL) [2], based on shared resources and open knowledge. Bringing together different departments, research groups, companies and individuals, we have been working on the redefinition and reuse of resources, which motivates the writing of this article. In particular, we will focus on the problem of electronic waste and its possible revaluation, both economically and scientifically.

It is, unfortunately, common knowledge that humanity generates an excessive amount of waste. The consumption of resources, in the face of falling production and distribution costs, is leading the environment into a situation of great imbalance. We are crossing ecological tipping points, both in terms of minerals extracted or trees cut down, destroying the environment, and in terms of the pollution that

ecosystems can tolerate. This is destroying biodiversity and natural and cultural heritage. In addition, materials are being spread around the planet which, when concentrated, are very harmful to the environment, but which, when properly managed, are very convenient for human use, such as plastics, textile waste, mercury, lithium or lead. As long as there has been life on the planet, the waste of some can become the wealth of others.

In the 21st century, we can already find collection, repair and reuse networks that are responsible with their environment and their community, as we will describe below. Unfortunately, we must not forget that most waste, and even more so electronic waste, does not find its way back into the production chain, but ends up in the hands of opaque organisations in impoverished countries without adequate environmental protection systems. There are many documentaries and articles about programmed obsolescence and illegal e-waste trade. We are not surprised; every day we see more and more devices being thrown away, even if they are still working; the chain of unbridled consumerism continues; it is easier to buy a new device than to repair a used one; we have a convenient smokescreen that hides the environmental costs.

We believe that fablabs, as spaces for designing and developing solutions, should play an important role in this area in at least three different ways:

1 - By being an example of self-sustainability, spreading the word about how to improve, maintain and repair their own facilities.

2 - By being a common storage and distribution point for components and materials waiting to be reintroduced into the value chain.

3 - By being a place for training in technological self-sufficiency, both formal and informal.

We will describe each of these three points in the following chapters, leaving the cooperation with waste management companies for the last chapter. This article is mainly based on the author's experience of coordinating the Smart Open Lab fablab at the Polytechnic School of Cáceres [3] since 2014, which manages around 400 m2 divided into 8 spaces and machinery valued at around 200k€. It is essential to say that the most important thing about SOL is the more than 200 people who are associated with it every year. Very different people who contribute every day to improving both the spaces and the community itself. We are clearly in favour of accessible fablab models based on trust in people.

2 Self-sustainability. Maintenance and improvement of fablab facilities

Fablabs are "spaces for making almost anything", so their machinery is diverse and complex. A broken or disused machine not only fails to fulfil its function, but also takes up useful space. Not all fablabs, and certainly not ours, have the resources to pay for the intervention of official technical services for their machines. Many of our machines are relatively simple semi-industrial designs, made by small companies that do not even have continuity in time. We even had to install some of the machines ourselves, which we had to teach ourselves from the start. It would have been illusory to think that we would have had the resources for every installation, maintenance or repair that would have had to be carried out by external personnel and paid for by public bodies.

Throughout this article, I will recall the importance of a large, motivated and educated "glocal" community. From the first day of our opening, it was a shared responsibility to set up and maintain our machines and spaces. First of all, each user of our fablab pays a symbolic annual fee (currently €25/year for employees, €15/year for students, pensioners, unemployed, etc.). With this small fee, and thanks to the power of numbers, we have always had funds to cover the cost of repairs. This almost symbolic fee also helps to appreciate the resources that each person uses, as they are partly self-supporting.

Figure 1: Associated people improving spaces: moving, building or improving spaces.

Our main machines have been used thousands of times and have quite an intense life, not only because we push them to the limit by testing different materials and techniques, but also because they are often used by trainees, i.e. inexperienced people who are not yet familiar with the ideal processes. We can say that we have had to maintain and repair practically all of our machines.

Here is a short list of the most typical failures and how to prevent them; it is more of a warning to navigators based on our experience than an exhaustive list:

- FDM 3D printers: they fail a lot, although it depends a lot on the robustness of the printer design and the care of the users. It is very useful to have spare parts for sprockets, heads, heat resistors, motors, fine needles, etc.
- SLA 3D printers: they break down less than FDM printers. They produce a lot of waste: liquid and solid. It is advisable to have isopropyl alcohol, cleaning materials and a spare resin tray, as it deteriorates over time.
- Laser cutters: we use them quite intensively. They need frequent calibration and cleaning, including filters and cooling circuits. The lens or laser tube needs to be replaced from time to time. It is useful to have spare parts, at least for the lenses.
- CNC milling machines: we have already had a fire due to misuse, fortunately no personal injury, but we had to replace the entire extraction system and repaint the room. Like the laser machine, they require constant monitoring to stop work in the event of a fire. They need to be cleaned and lubricated constantly. The bridge needs to be realigned with the table from time to time. We always use a 3mm MDF board as a "martyr" on which to cut. It is advisable to have spare mills of the most commonly used sizes: flat and round tips (6mm, 4mm, 1mm in our case).

Figure 2: Our CNC mill after a fire in autum 2020. It was recovered by associated, including professional painters.

- Vinyl or film cutting plotters: the blades tend to get dull and need to be replaced, and the adhesive tape on which you are cutting needs to be changed from time to time. This is an inexpensive machine that requires little maintenance.
- CNC hot wire cutter: The wire often breaks, but it is easy to replace and inexpensive. It is a clean and fairly reliable machine.
- Sewing machines: It is important to use the right needle and thread for each fabric. They should be oiled from time to time. It is useful to have different needles and empty bobbins. Our machines are inexpensive and work quite well.
- Audio and video equipment: It is advisable to have duplicate cables for the most common formats: HDMI, VGA, jack, mini jack and XLR. Having adapters will solve more than one problem. Spare batteries (AA, AAA, 6F22, LR44, CR2032) and chargers for video or photo camera batteries should

be available. An AC-DC power supply with different heads and output voltages will solve the power supply problems of many devices.

- Handheld power tools: they are essential to us, not only for cutting parts that are not the right size for the machines, but also for finishing with a sander or drilling a hole with a drill that the CNC cannot reach. They often fail because of the cable, the switch or the graphite brushes. These are all affordable and repairable. Battery-powered tools need to be replaced from time to time, and these can be repaired by detecting and replacing faulty cells.
- Tin soldering irons: Tips need replacing from time to time, so it is better to have spares. Good quality soldering irons of about 30W, without temperature control, can last for decades, with thousands of soldering operations per tip.
- Computers: A clear order must be established for each user's documentation and files. Each user has their own directory and is responsible for their own data. Files are not left on the desk, just as papers are not left on the table... We make backups and restore the operating system with minimal software from time to time. Whenever new software is installed, you should be notified. It is strictly forbidden to install proprietary software without a proper licence. We are users, developers and advocates of free software.

Many of the machines require consumables, and every workshop needs basic materials that should never be missing (oils, sandpaper, tape, blades...). We recommend that you always have them, as they represent a small investment that will prevent the project from stopping for lack of a trivial item. They should be considered as ongoing costs for the workstations. We see processes as chains in which the breakage depends on the strength of the weakest link. Better safe than sorry.

We insist that the material costs of repairs be borne by the user community, as well as the time required to maintain and repair the machines. Recently, each new course for a machine starts with a day's maintenance of that machine and a description of typical breakdowns. In this way, every newcomer learns what is most important for the community: personal safety, not ruining the work of others and leaving the machines in the same or better condition than they were. In addition, a large community makes it possible to find not only who has the knowledge to solve a problem, but also who has the time to apply it.

We need to encourage fablab users to be consistent with "leaving the space better than they found it". The fablab: its spaces, its community and its processes must be in a continuous process of review and improvement.

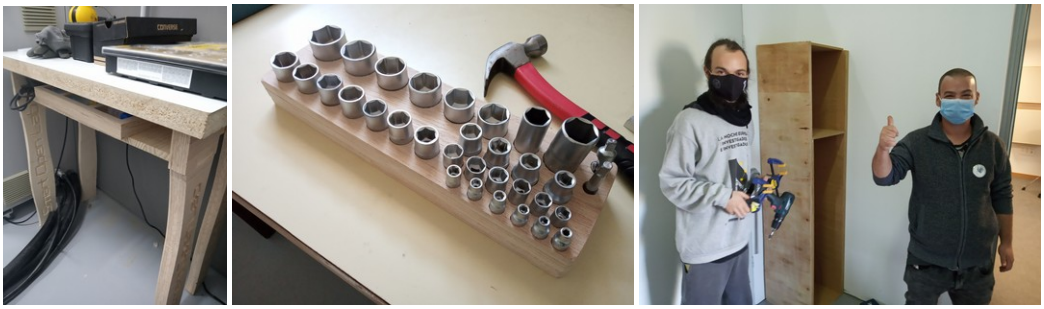
3 Sourcing, storage and possible responsible sources of the materials used in a fablab

In a workshop, it is not only the machinery that is important, but also the work and storage space, which is largely determined by the furniture.

In terms of health and safety, it is important to have office furniture for working while seated in a clean and noiseless environment. Equally, there needs to be space for standing work, with sturdy workbenches for working on parts with some noise and dirt. Ventilation and lighting are essential: it is better to work outdoors if you are going to create a lot of dust.

It is necessary to store a large number (several thousand in our case) of components: electronics, electromechanics, PPE, chemical products, screws, tools, spare parts, various materials... For us, the fablab must be like the laboratory of Thomas A. Edison's time: "A place where you can find almost all the existing materials in the world".

Figure 3: Examples of useful furniture made with wastes or cutoffs.



We have spent very little on furniture. 99% of our furniture is leftovers from the University itself, various institutions, companies or people. We have invested more in the transport of the furniture than in the furniture itself. It is worth renting a large vehicle if you want to save a fortune on furniture. In order to find the best use for each new/old piece of furniture over a period of time, it is very convenient to have storage space, which can be somewhat inhospitable.

Over the years, we have become a reference point for anyone who wants to dispose of something responsibly. Again, this wouldn't be possible without a large community committed to the idea of sharing resources. Employees of companies that produce waste, business people who get rid of "obsolete" industrial furniture, members of research groups who get rid of prototypes, or simply people who make a reform in their home. Every week they offer us new materials, most of which find a new use. For this reason, we see ourselves as a node in the circular economy; materials circulate through our facilities until they find a new use.

This is certainly true for the electronic components that are the subject of this article. It applies less to digital consumer electronics components, such as mobile phones or tablets, which suffer from enormous software obsolescence, than to more analogue electronic components, such as household appliances, medical electronics, laboratory instruments... We have received, repaired and redistributed: mixers, ovens, microwaves, toasters, lamps, musical instruments, amplifiers, cookers, vacuum cleaners, drills, saws, toys, spectrophotometers, centrifuges, electrocardiograms... For us, it is a pity to see things thrown away that still work or can be made to work again with a little effort, but it is a joy to find someone who needs and uses them thanks to our work. Partnerships with large electronic component recovery companies can be very fruitful, as will be described at the end of this article.

We must not forget the responsibility we have as small production centres with our own materials and waste. Most of our machines accept offcuts and it is our responsibility to use them up to their minimum useful size. A scrap of a large piece can be used to make several smaller pieces. This means you have to plan and run more jobs, and you are more likely to fail if you work closer to the edge. But it saves money and environmental costs. On the one hand, we can get offcuts from industries or people who discard them, such as carpenters, construction companies or fitters. On the other hand, we can always use the scrap for any training or tests. The message to every new employee is: "Don't buy new materials. Learn with what we already have, from less to more. The soda tests..." We're not strictly a materials store, so we appreciate it when members use the accumulated materials to make useful things to share with the community.

Figure 4: Example of collaborative work with wastes inside the Erasmus+ “Escuta: Empreendedorismo Social Comunitário Universitário Transnacional-Açores”.

4 Learn how to repair electronics in a fablab

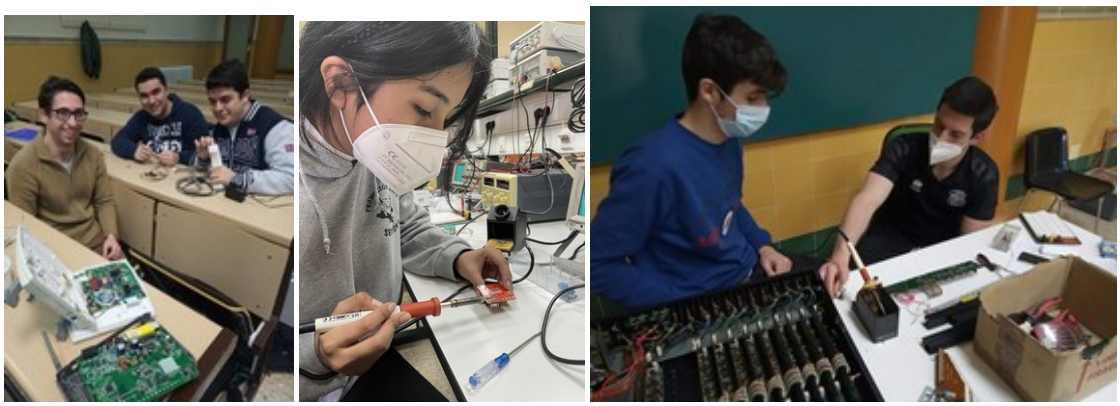
We believe that electronics repair has great educational potential. Both for the layman and for students of science and technology, repairing a device forces you to understand a little better how the world around us works. In most cases, the repairs are of the "electromechanical" type, i.e. they do not require skills or microelectronic tools; it is simply a matter of knowing how to dismantle the device with hand tools, identify the fault and repair it with few resources. Never before have devices been so complex, but never before have the networks of knowledge been so wide and open. Nowadays, not only do we have repair videos for almost everything on general platforms, but there are companies with specialised repair websites, with great tools and databases. An excellent example is IFixit [4], which also actively defends the right to repair, motivating legislative changes that are being translated into consumer protection laws in Europe. In addition, we can easily join global networks of repair cities through informal programmes such as Repair Cafe [5], which originated in the Netherlands but is global in scope. Our experience with both initiatives is very enriching.

To 'just' run a Repair Café, you need to get together a few repair experts who want to share their knowledge... Put simply, the Repair Cafe initiative is a movement of concerned citizens within a global community who organise open repair events. The impact is at a neighbourhood level, but the generation of global knowledge is paramount. The idea is that what can be repaired is not thrown away, and that everyone learns how to do it. This includes electrical appliances, clothes, furniture or small vehicles (bicycles, scooters). Of course you can organise it without being an official member of the community, we've done it that way, but it's much better to do it as a member as you get full access to the graphic materials and very useful tips to make your local Repair Café as successful as possible. We have organised it several times in the city of Cáceres. It has always been a great success, with an almost 100% success rate of repairs, dozens of things fixed in a short time. In our fablab it is not difficult to find someone who wants to lend a hand at these events. They are also a great way to promote the fablab outside the facilities and attract new members.

From a formal point of view and within an engineering school, the content related to electronics repair can easily be included in physics, electronics, computer science, communications or design courses. As a professor of first, third and master degrees in Telecommunications Engineering and Computer Science, I have been introducing content related to the repair, reuse and improvement of electronic components for several years. In addition, several teachers have used the fablab facilities from the outset to teach part of the content of official subjects, which offers a great wealth of material and perspectives compared to the purely academic laboratories of the Study Centre.

With the first year students of the Electronic Devices course of the Sound and Image Engineering in Telecommunications degree, we spend one hour a week repairing any device that arrives at the fablab or that the students themselves bring in. This teaches them a very practical use of the multimeter and basic soldering, with the responsibilities and precautions that go with it. In addition, they are confronted with an unknown problem that they must first understand and then solve, possibly iteratively. They are an excellent challenge for young people who are not used to putting their hands and eyes in the dough. Electrons are not seen; attention, logic and some expertise are required to solve the problems. The results are exciting and motivating. Despite the initial difficulties and doubts, the "ecstasy of success" is usually experienced when an everyday object can be put back into use after having understood it a little better.rs

Figure 5: First year engineering students repairing different kinds of electronic gadgets.



With the third year and Masters students, to whom I mainly teach electronic instrumentation (sensors and actuators) and programmable devices (FPGAs and microcontrollers), we mainly reuse and improve surplus circuits from research projects or industrial machines. In this way, they learn electronic design on objects that were previously functional, or that were no longer used for some reason that they can analyse. Either way, they learn the value of the discarded, which brings them face to face with the contradictions of the 21st century. In the (unofficial) evaluation criteria, I define that the best projects receive an extra symbolic score (0.05 points out of 10) if they are documented and uploaded to the Fablab website. These are relatively simple projects from a technical point of view, but they have a great didactic value. Some of them can be seen in our fablab's webpage [2].

Finally, it is worth mentioning that fablab's electronic material resources are regularly used by students for their diploma, master or doctoral theses. From thermionic valve amplifier circuits or motorised wheelchairs for engineering students, to internet-connected sensor insoles for people with motor problems for sports science students. Dozens of academic papers have already been written using accessible and largely recycled resources. Most are uploaded to the Fablab's website and open repositories.

5 Relationship with regional waste management companies

Waste management is a growing and large industry worldwide. Whether it is municipal or industrial waste, those managing it have a huge environmental responsibility and a very profitable business if they can reach fair agreements with the authorities and value what they collect. Citizens pay for the responsible management of their waste and there are many cases where neither government nor business can guarantee this. We must not forget that, unfortunately, most of our waste ends up being badly managed: piled up, buried or incinerated.

We believe that everywhere there are companies that are responsible for recovering what others consider waste. It is one of the oldest and least appreciated tasks. But it has great value, and more than one supposed "junk dealer" makes a pretty good profit on what he collects. Today there are networks of many different sizes and types of materials, from car parts to specific plastics. We deal with these companies on a daily basis: from the humble person who collects kilograms of various materials that we can no longer use, to the officially established waste manager who collects almost all kinds of materials on a large scale. We usually turn to both for materials and for responsible disposal of what we can no longer use or store. For example, we had to dispose of dozens of rows of desks that were fixed to the floor, obsolete and difficult to reuse, after more than 5 years of taking up valuable space and trying to get an institution or individual to reuse them. In the end, we decided to replace them with steel tubing.

In this article we focus on companies that collect "electronic waste", in particular a regional company, La Hormiga Verde [1], located in Villafranca de los Barros, Spain. The company can be classified as a WEEE (Waste Electrical and Electronic Equipment) management company with a double corporate social responsibility, since in addition to the work it does to achieve the objectives of minimising the

environmental impact caused by electronic waste, it also provides employment to people with disabilities or at risk of social exclusion.

The company has set up a WEEE collection network throughout the Autonomous Community of Extremadura for both individuals and institutions. It has placed bins in dozens of educational centres and organises competitions to reward the biggest contributors with recycled plastic furniture. With what it collects, it seeks firstly to repair and sell the most valuable equipment; secondly, it disarms the equipment to the minimum possible extent and separates it into components. The separation can be quite fine, as they have shredders, machines for separating plastics and metals, and cable strippers. They also have a small line for melting the recovered plastic to make sheets with thermal plates or ingots with injection moulds, very much in line with Precious Plastic [6]. With this they produce and sell simple urban furniture, which they machine and assemble using traditional methods.

Collaboration between fablabs and this type of company can go in at least two directions. Firstly, these companies are collectors of materials that can certainly be used by fablabs. From methacrylate, sheets of wood or resins that can be machined, to aluminium or copper chips that can be cast and moulded, to specific electronic components such as servomotors, capacitors or magnets. The company can carry out some selection, temporary storage and sales on request.

More importantly, it can help with the reuse of all surplus plastic from WEEE. Whether it comes from cable sheaths, casings or storage units (CDs, cassettes, videos, etc.), the plastic can be separated, crushed and re-melted to obtain materials with good properties. The result is a hard, waterproof and insulating material, which can also be attractive if a good colour combination is used. This is the so-called plastic wood. With the machinery currently available in the company, it is possible to obtain panels of approximately 450x350x15mm and blocks of up to 1800x80x40mm. This is how they make the products that can be seen in their online shop.

The main collaboration with fablabs may be through pure design and digital fabrication. Plastic sheets and blocks allow many shapes to be defined, but they tend to be too straight and the final object is quite heavy. In addition, cutting and assembly is usually done with traditional saws and screws, which is inaccurate and time-consuming. With a numerically controlled milling machine it is possible to machine curves, recesses and precise holes. With proper design, it is possible to define recesses and sockets that avoid the use of screws. This is where one of the main weaknesses of numerical control machines comes into play, namely the non-uniformity of the parts. In this case, the problem is the uneven thickness of each plastic sheet. This is a recurring problem, and our solution is to design for non-uniformity. This means that the parts where the piece is not uniform are not essential for the fittings and always remain on the inside of the object.

A few months ago we started a series of collaborations between the SOL fablab and Hormiga Verde. They provided us with more than 5 types of panels and the simple request to "redesign and machine what we already do to make it easier for us to assemble". We have already redesigned and produced small models of pen holders, planters and soap dishes. Up to now, the most valueable item we produced for the company are photo frames, of different sizes, which is a quite simple and profitable use of each panel.

Figure 6: Examples of materials and fabricated, initially simple, items usin “plastic wood” from La Hormiga Verde.

which we hope will be well received by the company. Our aim is not only to redesign objects with plastic wood, but also to combine materials in order to improve the characteristics of weight, resistance and appearance. Mixing materials is very motivating for us. This would make good use of fablab's design skills and machinery, as well as using materials that we have in surplus. The people in charge would charge for it, creating jobs for specialists in the so-called 21st century professions.

Both the idea of a community around a fablab and the idea of responsible collection of e-waste are replicable on a global scale, so we think it is valuable to describe possible ways of working together.

6 Conclusions

We have briefly described some of the ways we have these days to reuse some of the electronic waste that surrounds us.

As workshops full of complex tools we have a problem with the maintenance of our facilities that we must be able to solve ourselves. The solution we propose is a mix of accessibility, community action, and preventive maintenance. Community action must include the commitment of users to self-training and improvement of the spaces.

A fablab, in addition to a digital fabrication lab, should be a small materials management center. We must be responsible for our environment and how we produce and source materials. We have opportunities to reuse valuable materials nearby and we can learn a lot along the way. To do this we must weave networks of relationships with people and companies. We can and should be nodes of the Circular Economy.

Repairing electronics is valuable as a community resource and as an educational resource, both informally and formally. When we repair something we do three goods, no matter the order:

- A good for your environment. You rid Nature of more waste.

- A good for your pocket. You can spend less and better.

- A good for your spirit. You overcome apathy and learn something useful with your effort.

We encourage all concerned to join networks that seek to repair the world through local action and coordinated global effort. There is still much to repair and improve.

Acknowledgement

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