PLATE

Product Lifetimes And The Environment

3rd PLATE Conference
September 18 – 20, 2019
Berlin, Germany

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Ospina, Jose; Maher, Paul; Galligan, Anne; Gallagher, John; O'Donovan, Dermot; Schischke, Karsten; Knorr, Stefan: **Lifetime extension by design and a fab lab level digital manufacturing strategy: tablet case study**. In: Nissen, Nils F.; Jaeger-Erben, Melanie (Eds.): PLATE – Product Lifetimes And The Environment : Proceedings, 3rd PLATE CONFERENCE, BERLIN, GERMANY, 18 – 20 September 2019. Berlin: Universitätsverlag der TU Berlin, 2021. pp. 591 – 597. ISBN 978-3-7983-3125-9 (online). https://doi.org/10.14279/depositonce-9253.

Universitätsverlag der TU Berlin

3rd PLATE 2019 Conference
Berlin, Germany, 18-20 September 2019

Lifetime Extension by Design and a Fab Lab Level Digital Manufacturing Strategy: Tablet Case Study

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Keywords: Eco-design; Circular Economy; Digital Fabrication; Manufacturability; Decentralized Business Model.

Abstract: MicroPro Computers, an Irish SME working in the design and manufacture of computer equipment based on circular economy principles over the past 20 years, is successfully manufacturing a long-life miniature computer (the iameco D4R tablet), which addresses the three key areas of product design, manufacturability and sustainable business model. These factors are interlinked, and all are crucial to bringing the product to the market: A major barrier for local production of sustainable IT is the inherent complexity of mobile electronics, so innovative approaches are required to enable small-scale production. As part of the SustainablySMART Project, (H2020 – FoF) MicroPro is working with GMIT Letterfrack and Designing Berlin, to adapt the design of a green tablet, the iameco D4R tablet, for digital design and manufacture, using equipment typically found in a FabLab or similar non-commercial manufacturing environment. Combining a localized smart design and manufacturing approach with robust green credentials will allow for higher margins, as well as flexibility in terms of production numbers and costs, and provide a replicable production and business model for the green electronics sector

Introduction

MicroPro proposes a 'regenerative design' paradigm, that will ultimately give rise to the following:

- A reduction in the consumption of raw materials by using renewable materials and by extending the use lifetime of products and components
- A reduction in the generation of e-waste because of a) longer life and b) ease of recycling
- A reduction in the consumption of energy during manufacturing and during useful life

There are indications, that combing a localized manufacturing approach with robust green credentials which will allow for higher margins, and more flexibility when it comes to manufacturing costs. Euromonitor International published a report in 2012 (Euromonitor, 2012) which indicated a significant shift in consumer behaviour towards more environmentally friendly products. Factors such as climate change, health awareness and environmental issues, are influencing consumers to reconsider the most important factors guiding their purchasing decisions. Nearly 70% of respondents across the globe said they were 'somewhat to very willing' to spend more on a green product, compared to the same product without green features.

MicroPro Computers has a long history of design and manufacture of computer equipment based on sustainable and circular economy principles. This design strategy has been developed over the past 20 years and include the design and manufacture of iameco desktop and laptop computers. These case studies are well documented in previous articles and reports. However, despite successful prototype development, and some small-scale sales, it has been impossible to sustain the production and marketing of these computers, due to the high costs associated with outsourcing design changes and

manufacture of computers. The conclusion is that small-scale, localised design, production and marketing of innovative computers if dependent on outsourcing design and manufacture, proves financially unviable

MicroPro is currently participating in the SustainablySMART project with the express intention of developing a new approach to design and manufacture, based on localised digital design and manufacture, that could make commercialisation of its ecological computers viable.

Eco-Design Principles

MicroPro has developed, designed and manufactured a number of prototypes for desktop, laptop and more recently tablet computers over the past 20 year. Through these practical experiences, MicroPro developed a comprehensive and proven eco-design approach, which included a range of elements, relating to design, choice of materials, parts and components, and post-sale services to customers.

MicroPro's aim is to reduce environmental impact not only "in operation", but over the entire lifecycle of the product. Both the iameco V3 desktop and the D4R laptop were manufactured primarily mainly from wood and recycled materials. The D4R Laptop was estimated to have 66% less CO2 emission, use 65% less fresh water in manufacture, and use 87% of materials that could be reused or recycled, with respect to equivalent commercial laptops.

Maximising reuse and extending operational life

In addition to the environmental gains made by selection of materials and components, a key circular economy strategy is design for upgrading and for ease of repair and for reuse. Iameco computers are designed to be easily disassembled using tools commonly available. This enables quick and affordable repair, upgrading and also the reuse of the housing, parts and components. This design strategy has been applied to all models. The disassembly of the iameco v3 desktop, for example, could be carried out in 11 seconds using conventional tools. The design allowed for flexibility in the repair and replacement of parts and components. The D4R laptop included a generic "universal motherboard", that allowed diverse components to be connected to it. The housing was designed to accommodate some variation in the size and shape of new components.

Additional eco-design considerations

As partner in the SustainablySMART Project, MicroPro has undertaken the design and manufacture the iameco D4R tablet, based on findings from its previous models. MicroPro also undertook to scope the possibility of design for reparability by repair shops and on a DiY basis, of design for longevity of wear-prone components (such as the battery), of design for reliability and design for robustness. MicroPro aims to achieve ease of manufacture by developing a design that is appropriate for manufacture in a digital fabrication environment, accessible to SMEs or in Fab Labs, by practically testing the manufacturability in a semi-industrial environment

Design iterations for the iameco D4R tablet

The iameco D4R tablet has been developed through a series of design iterations:

Iteration 1: The Alpha Prototype (AP)

The AP is designed to incorporate all of MicroPro's eco-design principles of upgradability, updateability, reusability, repairability, recyclability, ease of disassembly, long life and elimination of most plastics. The AP embodies these principles and is designed to anticipate future changes of components, so the chassis can be used again and again and have different lives. It has also been designed so that the mainboard and ancillary components can be replaced using simple tools. Use of glues or plastics other than those embedded in essential components were reduced where possible. The housing was screwed together using standard Phillips type screws. Design ensured natural ventilation and prevents overheating. Connectivity is maximised. The wooden frame provides a protective standoff for the display. A kill switch is provided for Bluetooth, Wi-Fi, microphone and camera enhancing security. The AP is manufactured primarily from maple and has an interior aluminum frame for robustness and stability. The AP is fully functional and

manufactured to a high specification. It exceeds Project requirements by providing fully functional electronics. Assembly of the electronics was carried out in-house by MicroPro. The manufacture was outsourced to a commercial engineering workshop that uses digital design and CCR manufacture. Commercial outsourcing was an intermediate step in the process, aimed at ensuring that the AP was correctly manufactured, and that drawings, specifications and assembly were accurate and fit for purpose. The AP was not the definitive prototype but aimed at providing a baseline for further design improvements of the housing, frame and electronic design, as well as manufacturing strategies, which have been the basis of subsequent iterations.

Figure 1. CAD drawing of the AP.

Iteration2: The Beta Prototype (BP)
The BP is designed and manufactured using the AP as baseline. Development took place from March to September 2017. The manufacture of a 2nd prototype was not originally envisaged in the project, but subsequently agreed by the consortium. It has proven to be a valuable way of progressing the final design. For the sake of continuity, MicroPro employed the same prototyping company to produce the BP as produced the AP.

The main aim of the BP, was to iron out design short comings in the AP. MicroPro improved the AP design by streamlining the wooden housing and the aluminum chassis making the device less bulky and appealing, lighter, thinner and more robust. A new sliding back cover was introduced (without screws or fasteners) for ease of access for removable battery, and a fingerprint sensor There was also a material change of the seal-inlay to cork to reduce moisture and dust penetration. Additional ventilation holes were added to maximise the life of the battery and electronic parts and the number of parts overall was reduced (simplification).

The BP aimed at providing an improved template for design fabrication, leading to the production of the Kappa Prototype.

Figure 2. The Beta Prototype.

Iteration 3: The Kappa Prototype (KP)
The KP was designed and manufactured using the BP as baseline. It was developed from September 2017 to March 2018. The manufacture of the KP, the 3rd iteration of the iameco D4R tablet, was also not originally envisaged in the project, but likewise proved a practical and effective method for arriving at the final design.

The KP incorporates all of MicroPro's eco-design principles of upgradability, updateability, durability, reusability, repairability, recyclability, ease of disassembly, long-life, carbon capture and elimination of most plastics. By using a wooden chassis instead plastic it not only incorporates carbon capture (carbon from our time) but allows us to modify and change the chassis. The KP is designed to anticipate future changes of components, so the chassis can be used again and again and have many different lives. It has also been designed so that the mainboard and ancillary components can be replaced or repaired using simple tools. The battery can be replaced in 30 seconds.

Use of glues or plastics other than those embedded in essential components have been successfully avoided. The housing is screwed together using 4 x standard Phillips type screws. Design ensures natural ventilation and prevents overheating. Connectivity is

maximized. The wooden frame provides a protective standoff for the display.
The KP is manufactured primarily from walnut and has an interior recycled aluminum frame for robustness and stability. The KP is fully functional and manufactured to a state-of-the-art electronics specification. Assembly of the electronics was carried out by MicroPro in-house. Re-design and manufacture of the KP was carried out by MicroPro and GMIT in the university's own engineering workshop, using CAD design and computer-controlled routing, and has ensured that final drawings, specifications of housing and frame are fit for purpose. The metal frame is being manufactured in Designing Berlin's own facilities.

Design improvements to the KP

Design for Manufacturability

The AP and the BP were designed and manufactured by a commercial prototyping company under MicroPro's direction. These prototypes were designed in CAD and the CAD files of both were provided to GMIT Letterfrack for review, in order to assess the ability to machine the prototype on the Homag CNC at GMIT campus.

GMIT Letterfrack has introduced the concept of Design for Manufacture (DFM) that is the practice of designing products with manufacturing in mind. Embedding this principle will allow for simpler manufacturing, assembly and/or design of the proposed product with the aim of reducing waste and minimising production costs.

The correct implementation of DFM will lead to reduced manufacturing costs, reduced lead-time and improved quality. DFM should also help to minimise waste and maximise yield from raw materials, which lowers production costs as timber waste from production is not recoverable for re-use. DFM is an important consideration when working under the Ecolabel logo, which considers products from the extraction of the raw materials, to production, packaging and transport, right through to your use and end of life. Not all DFM principles are applicable to all production of the iameco D4R tablet. Currently, these principles can only be related to the manufacture of the wooden housing and the metal frame, but not the electronic or metal components, which are sourced from external suppliers, over which MicroPro has little or no control.

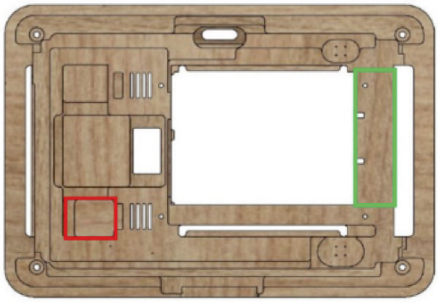

Figure 3. BP wooden frame interior Section.

Choice of Materials for the KP

MicroPro's preference from the start was for solid wood. This was guided by an initial survey of customer preference undertaken at the start of the project. In selecting the wood, the following considerations were taken into account:

- Use a species with closed grain (e.g. maple or beech)
- Use timber with straight grain, free of knots and defects
- Grain direction should be perpendicular to surface to minimise movement (radially cut)
- Reduce moisture content to maximum 10% (to minimise distortion in service)
- To deduce tendency of cupping in service, it may be worth using glued strips of solid wood.

It was also considered important to use ethical procurement when specifying timber materials. Only timber from certified sustainably managed forests would be used. Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) schemes are those most recognised for ensuring chain of custody of sustainably sourced forest material. It would also be possible to use off-cuts from the furniture industry and second life woods, although these were not used in any of the prototypes produced. MicroPro decided to use **walnut** as the material for the Kappa as it has a deep lustre and warm and attractive grain.

KP Wooden Frame Design n

The design of the wooden frame for the KP was based on an analysis by GMIT of the frames design and produced for the AP and the BP. This phase involved detailed design work on the wooden chassis, aimed at simplifying the design in order to reduce the tooling complexity and time required.

Multiple design changes were required for the KP to adapt it to manufacture in a Fab lab environment. This is explained in detail in the paper produced by MicroPro for the Going Green Electronics Conference in February 2019, so will not be repeated here

Further consideration and research

Originally, the BP prototype took a total of 163 minutes approx. to machine on the CNC, with the iterations to the KP design this has been reduced to a total of 118 minutes. The sanding of the Beta was estimated to be 180 minutes due to the difficult areas to reach. The redesigned elements of the KP reduced the sanding process to 90 mins approx., depending upon individual grain pattern and species selection. The lamination process that created the blank was done by manual clamping and therefore does not provide an accurate estimate on the time it requires to produce in batched or higher quantity production runs. However, the time it took to dimension, plane, and finally calibrate the blank manually was about 75 minutes per blank.

This is a total of 283 minutes for creating the KP's unfinished wooden chassis (based on a production of a single unit). This brings the total time of wooden chassis in its current form to 308 minutes with a water-borne lacquer finish. This will be further improved and reduced in the implementation of the Small, Batch production, which is currently underway.

Metal frame design and manufacture

Metal Frame design improvements

The metal frame from the AP and the BP were designed and produced by commercial prototypes, who had access to the required manufacturing equipment. The initial KP frame was also produced in this way. The production of frames in this way would not be commercially viable for marketing the tablet.

The BP metal frame (produced commercially) however had to be modified at GMIT to match changes in the wooden frame and the electronics. Initially this was achieved by designing and printing a re-designed frame in plastic. The frame was then manufactured commercially for the first KP version.

Fortunately, for the Small Batch Production (explained below) MicroPro identified a metal designer and fabricator who had been working with Fab Lab Berlin, Designing Berlin. After a meeting a partnership was formed, and Designing Berlin went on to review and improve the metal frame design and manufacture it.

The overarching four objectives in the redesign of the metal frame: reducing the weight of the metal frame, reducing the visibility of the frame, improving its modular and upgradable features and simplifying the manufacture, to be adapted to typical Fab Lab equipment. Additionally, updated electronics had to be integrated. The final objective involved fixing the new electronic components onto the surface plate to identify the precise location of the relevant components. The results were then fed back to the 3D model of the revised KP design.

An updated electronics setup allows the frame to be visually narrower than the initial KP version (which was a design objective). The main reason for that is a different mounting method for the touchscreen and the actual screen.

In order to keep the CNC machining of the part simple, all features can be machined with basic 3 axis CNC machinery from only 2 sides. The required side cut-outs for the connectors are turned into independent, modular parts. Otherwise they would require 5 axis machining or 3 axis machining from 4 more sides

Various modular parts are mounted in the actual frame and can be exchanged without screws. In case future electronics offer new interfaces, the modular frame parts can be redesigned accordingly and exchanged along with the electronics. The mainframe stays as it is.

The weight reduction of the frame is improved by adding several triangular shaped holes, that

results in a thin wall, lightweight frame. Where the user touches the tablet, that strategy would result in a strange haptic as well as dirt attracting surface. Those areas have only one long cut-out with nicely filleted transitions. The final weight is about half of the KP version, roughly 150g.

Figure 4. New metal frame for the KP, improved by Designing Berlin.

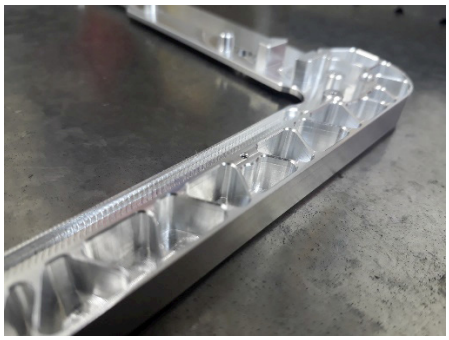

Figure 5. Detail of material reduction design in KP Metal Frame.

Small batch manufacture of the D4R tablet

Towards the end of the SustainablySMART Project (May – October 2019), MicroPro and Project Partners took a further step in advancing the commercialisation of the D4R Tablet, by sampling a small batch manufacture. This involves the production of 30 working units of the Tablet, that will be tested and certified by Grant4 Com to demonstrate compliance with EU market regulations. For this final step, MicroPro is carrying out the entire design and production process working with FabLab equivalent bodies. For this to happen, it was necessary to identify an additional non-commercial contractor that would review and improve the metal frame design and produce the 30 frames for the proposed small batch. With the help of Reuse-IT (Berlin), a Berlin FabLab maker, Stefan Knorr (trading as Designing Berlin) was identified as having the necessary skills and equipment, but also commitment, to work on the project and produce the required metal frames for the initial small batch. The wooden frame would be reviewed, improved and manufactured by GMIT Letterfrack, and the electronic components would be improved, sourced and assembled by MicroPro.

This final review of the metal frame design led to overall design improvements in the final version. The weight of the metal frame was reduced by around 50%, and a number of operating details improved. The review of the design of the wooden frame design by GMIT also resulted in some improvements and required a re-calibration to take the new metal frame into account, as well as improved electronics. The electronic design was also upgraded, to encompass the ever-rising standards of computer components on the world market and need for improved multi-functionality from the initial Kappa design.

Evaluation of the D4R tablet

In order to gain added value from the sample small batch manufacture, MicroPro and Partners decided to undertake a Customer Evaluation exercise, to be rolled out during the final three months of the SustainablySMART Project (August, September and October 2019). This will involve the identification of a number of private companies, universities and public computer outlets in some Partner regions, who will carry out a short evaluation of actual D4R Tablets, for a limited period of time. These agencies will collect consumer information and feed it back to MicroPro, aimed at establishing customer reaction to the product.

The Key target groups that will be targeted are:

- Private companies with an interest in ecological products
- University students and lecturers
- The general public

A number of agencies have been identified for the Evaluation exercise that are representative of, or able to access the 3 Target Groups in a number of Partner regions. The Questionnaire and interviews proposed aim to secure the view of potential users regarding the design, materials, weight, functionality and pricing of the tablet.

A viable design and manufacturing strategy

A main objective in the SustainablySMART project has therefore been to demonstrate that digital fabrication in a local, non-commercial digital fabrication workshop is a potential solution to the viability challenges so far encountered.

The use of digital design and fabrication per se does not generate viability, and indeed commercial prototype developers already employ digital design and fabrication as a method for producing prototypes (for example, the company that produced the original AP and BP models was a commercial prototyping company using digital fabrication). But this company would not be able to manufacture the final prototype at a commercially viable price.

The final stage of the SustainablySMART Project, and in particular the Small Batch Production, has demonstrated that it is feasible to design and manufacture a fully operational state of the art tablet within SME and FabLab equivalent facilities, as long as non-commercial associates with the right equipment, skills and attitude are identified. This allows the SME to achieve some relaxation of the tight financial constraints that limit commercial outsourcing.

The partnership composed of MicroPro, GMIT Letterfrack and Designing Berlin have proved the viability of the model with the implementation of a small batch production (30 units) of the iameco D4R tablet The assembly of this Team has been central to making this non-commercial process viable and could be the main basis for future manufacture of the iameco D4R Tablet. Also, it demonstrates that a more decentralized model for manufacture, repair, upgrading and production of the tablet, as described in part 7 above.

The SustainablySMART Project has been successful in demonstrating that locally based non-commercial digital design and fabrication can be the basis for more viable manufacture of iameco D4R tablet and possible other iameco models.

We believe this is a major step forward in making sustainable computer manufacture a possibility.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680604