DESIGNING A D4R TABLET FOR FAB LAB LEVEL PRODUCTION

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Abstract. MicroPro Computers has been working in the design and manufacture of computer equipment based on circular economy principles over the past 20 years. In SustainablySMART (H2020 – FoF) MicroPro is working with GMIT Letterfrack and other partners, to adapt the design of a green computer (the iameco D4R tablet) for digital design and manufacture, using equipment typically found in a FabLab or similar non-commercial manufacuing environment. The iam of developing this approach is to enable viable and replicable commercialization of green tablets for an initially small but potentially growing market. Combining a localized smart manufacturing approach with robust green credentials could allow for higher margins, as well as flexibility in terms of prodcution numbers and costs, and provide an importnt model for the green electronics sector.

1. INTRODUCTION

The introduction of tablets into the world computer market has resulted in significant growth of the use of this technology, which is forecasted to increase unit sales from just under 400 million in 2010 to just under 500 million by 2019.[i] A consequence of these trends is the increased consumption of some not-yet recovered critical raw materials (indium for displays, rare earth elements for speakers and LED backlights, tantalum for capacitors etc. etc.) and generation of electronic waste (e-waste). Devices ultimately become obsolete and need to be replaced. {[ii]} While the recycling of e-waste is a commendable approach to dealing with the issue, the current paradigm of designed-in technical obsolescence needs to be challenged MicroPro proposes to "change the paradigm" to a more sustainable approach based on the principle of the circular economy:

MicroPro is leading a change to '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 [[iii]}

There are indications, that combing a localised manufacturing approach with robust green credentials could allow for higher margins, thus also more flexibility when it comes to manufacturing costs: Euromonitor International published a report in 2012[[iv]] 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 progressing the design and manufacture of computer equipment based on sustainable and circular economy principles. These have been developed over the past 20 years in the practical design and manufacture of iameco desktop and laptop computers. These developments are well documented in previous articles and reports. [[vi]] However, in spite of successful prototype development and marketing in small numbers of computers, MicroPro has found it difficult 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 by outsourcing design and manufacture makes commercialisation financially unviable

MicroPro is particpating in the SustainablySMART project with the express intention of developing e new approach to design and manufacture, based on localised digital design and manufacture, that aims to make commercialisation of its ecological computers vaible.

2. ECO-DESIGN PRINCIPLES

MicroPro is a small company based in Rathfarnham, Dublin. Since its inception in 1991, it has been working on the design and manufacture of environmentally friendly computers. In 1999, MicroPro produced its first green computer, the MicroPro XPc, designed to European Eco-Label standards. This was sold in small numbers directly from its workshop. In 2003, as partner in the LIFE Environment Project HEATSUN, MicroPro designed and manufactured the iameco V1 desktop computer. Over the following years, with the support of the Irish EPA's Cleaner Greener Production Programme, MicroPro designed and manufactured the iameco V3 integrated desktop computer. This model secured the EU Eco-Label for integrated desktop computers in 2010 (EU Eco Label license number IE/13/001. This PC was manufactured and sold in small numbers by MicroPro and other retailers. In 2014, as a Partner in the ZeroWIN Project (FP7), MicroPro designed and manufactured a further prototype for the iameco D4R laptop. This model was widely praised in the sector media and won several design awards [.[vii]] However, it could not be manufactured and marketed at a competitive price due to the high cost of commercial outsourcing. 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.

2.1 Reduction of environmental impact

MicroPro has adopted the European Eco-label as its main benchmark for the environmental impact of its equipment, in the belief that the Eco-Label enccompasses key areas of sustainability, including energy efficnecy, reduction of elecromagneric emissions, sound pollution, hazardous materials and chemcical and also ecorugaes reuse and recycling and consumer awareness. However, MicroPro intended to improve on this standard, by additional measures, such as the minimisation of plastics, the use of renwable, carbon-capturing and recycled materials, to reduce the CO2 footprint of the device. MicroPro's aims to reduce environmental impact not only „in operation", but over the entire life-cycle of the product. Both the iameco V3 desktop and the D4R laptop were manufatured primarily mainly from wood and recycled metals. The D4R Laptop was estimated to have 66% less CO2 emmission, use 65% less fresh water in manufacture, and use 87% of materilas that could be resuded or recycled, with respect to equivalent commercial laptops.

2.2 Maximisng reuse and extending operational life.

In addition to the environmental gains made by selection of materials and components, a key circular economy startegy was design for ugrading, and for ease of repair and for reuse. The computer was designed to be easily dissambled using commonly available tools. This enabled quick and affordable repair, upgarding and the reuse of parts and components. This design strategy was applied to all models. The dissassembly of the iameco v3 desktop could be carried out in 11 minutes, without special akills and using conventional tools. The D4R laptop included a generic „universal motrherboard", that allowed diverse components to be connected. The housing was designed to accomodate some variation in the size and shape of new components.[viii]

2.3 Additional eco-design considerations:

As partner in the SustainablySMART Project, MicroPro undertook to design and manufacture an iameco D4R tablet, based on findings from its previous models. MicroPro also undertook to evaluate lessons learnt from development of the 2nd generation Fairphone and the modularity proposals made by Circular Devices (Partners in the SustainablySMART project). 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 aimed at a design and manufacturing process that could be careied out in a digital fabrication environment, accesilble to SMEs, or in Fab Labs. This possibility would be tested in practice in the Project.

3. DESIGN ITERATIONS FOR THE IAMECO D4R TABLET

3.1 Iteration 1: the Alpha Prototype (AP).

Development took place from 2016 to March 2017. The AP is designed to incorporate all of MicroPro's eco-design principles of upgradability, updateability, reusability, repairability, recyclability, ease of disassembly, longlife 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 many 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 was reduced where possible. The housing was screwed together using standard Phillips type screws. Design ensures 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 out-sourced 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 designed and 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.

Fig. 1: CAD drawing of the AP

3.2 Iteration2: the Beta Prototype (BP).

The manufacture of a 2nd prototype was not originally envisaged in the DoA of the Project, but subsequently agreed subsequently by the consortium. It has proven to be a valuable way of progressing the final design The BP is designed and manufactured using the AP as baseline. Development took place from March to September 2017. 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 correct design short-comings in the AP and improve design and manufacturability aspects. MicroPro impoved the AP design by streamlining the wooden housing and the aluminium 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 final iterations, the Kappa Prototype (KP).

Fig. 2. The Beta Prototype

3.3 Iteration 3: the Kappa Prototype (KP).

The KP was designed and manufactured using the BP as a 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 AP and BP prototypes were produced in a commercial manufacture environment, but were progressively adapted for production in a small non-commercial fabrication environment, or FabLab equivalent. Commercially produced designs (CAD drawings and specifications) were adapted by GMIT Letterfrack to allow their manufacture with the equipment available to GMIT. Alteration to the metal frame design was also required. GMIT was able to redesign the metal frame, but does not have the equipment to manufacture it. The modified metal frame was therefore manufactured initially from plastic through 3D printing. For the final version it has been remanufactures by a commercial prototyping company from recycled aluminium. This again is a temporary solution, and MicroPro and Partners aere currently exploring the possibility of manufacturing this frame in FabLab.

The KP incorporates all of MicroPro's eco-design principles of upgradability, updateability, durability, reusability, repairability, recyclability, ease of disassembly, longlife, carbon capture and elimination of most plastics. By using a wooden chassis (instead plastic) it incorporates carbon capture (carbon from our time) and also allows for subsequent modification of the design. The KP is designed to anticipate future changes of components, so the chassis can be used many times and has an extended life. 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 maximised. The wooden frame provides a protective standoff for the display.

The KP housing is manufactured 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.

Localised digital manufacture is the final stage in production process and crucial to making the tablet commercially viable, and ensuring quality. The KP is the final model for the iameco D4R tablet and provides a template for future fabrication (although there is some scope for some modification before the end of the Project).

4. DESIGN PROCESS FOR THE KP

4.1 Review of CAD drawings of previous iterations.

The AP and the BP were designed 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.

The main input by GMIT Letterfrack into the production process has been to introduce 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.

Key DFM principles are:

- Minimise the total number of parts and sub-assemblies
- Develop a modular design
- Use standard components
- Design parts to be multi-functional
- Design parts for multi-use
- Design parts for ease of fabrication
- Avoid separate fasteners
- Minimise assembly directions and methods
- Maximise compliance
- Minimise handling (machine time, multiple operations)

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.

4.2 Review of the Design of the BP

Once tye AP and BP were completed GMIT Letterfrack, under MicroPro's supervision, undertook a review of both, with the main aim of developing a final iteration suitable for manufacture on a CNC machine and other automated equipment available to GMIT. The review also considered improvements to aesthetics and minimizing post-production finishing requirements.

To get a better understanding of the processes involved in the manufacturing of the BP, an exact copy was produced, to highlight the areas of inefficiency. The following is a list of processes that were identified from this study, along with observations from the original Beta prototype.

Fig. 3. BP image

Areas identified for redesign - Exterior

The exterior areas of the BP that were identified for redesign are as follows:

- The parts highlighted in red below (Figure 2) are difficult to reach when it comes to the sanding stage, due to the concave form and approximately doubles the time it takes to sand the exterior.
- The sections highlighted in green are largely short grain and therefore are not structurally sound.
- The metal housing of the buttons and ports were fastened with glue and required a redesign to eliminate the need for adhesives (Figure 4).
- The battery lid was catching on the battery, as there was not enough clearance for safe removal.
- The various ports such as HDMI/DC seen in the right-hand image below were not correctly aligned and consequently were not functioning properly.

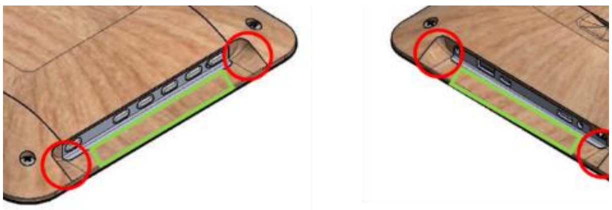

Fig. 4. BP Tablet Exterior

Areas identified for redesign – Interior

- The internal section (Figure 5) of the BP consists of numerous pockets with varying levels, which significantly increases the manufacturing time.
- The opening for the battery was not correctly aligned from a plan view and required adjusting.
- The lens was fastened with glue and required a redesign to eliminate the need for adhesives.
- Additional allowance for cabling was advised for the KP following review of the internal section, see section highlighted in red.
- The section highlighted in green was identified as inadequate as it is largely short grain therefore not structurally sound.

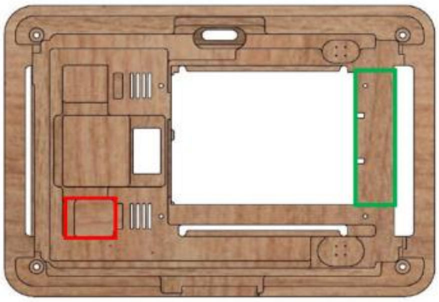

Fig. 5. BP Interior Section

Areas identified for redesign - BP battery cover

Part of the battery cover is difficult to sand when it comes to post-processing stage, due to its steep nature and being mostly end grain, which increases the manufacturing time (Figure 6).

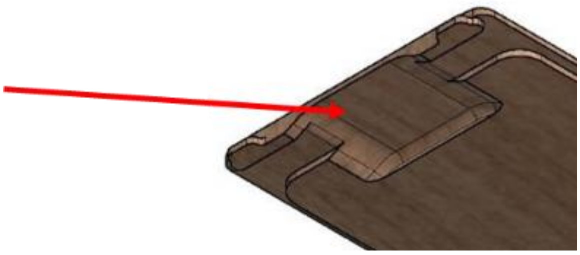

Fig. 6. BP battery cover

4.3 Choice of Materials for the KP

There is a range of materials that could have been used to manufacture the housing, within the parameters set by MicroPro. These included: solid wood, laminated wood, solid wood combined with veneers, composite material, plywood and other biomaterials There are also aesthetic, cost and in-service durability issues that were considered when choosing a suitable species of timber. Also that there may be certain advantages that can be achieved by using veneers with a suitable substrate.

MicroPro's preference from the start was for solid wood. This was guided by a 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 KP as it has a deep lustre and warm and attractive grain.

4.4 KP Redesign

Having reflected upon the issues observed in the BP a KP design was then developed.

KP tablet – exterior.

The following is a list of the design improvements within the Kappa following this review.

- The areas highlighted by the letter (A) in (Figure 7) now have a convex form, meaning the overall exterior can be sanded via power tools. This iteration reduced the sanding time from 95 mins to 45 mins approx., i.e. depending on unique grain pattern / minor defects within the wood.
- The sections highlighted by the letter (B) in (Figure 7) are now combined with the front metal frame chassis, alleviating the short grain sections within the Tablet and the use of adhesive.
- The overall thickness of the wooden chassis was increased to enable the battery lid to move freely over the battery.
- The various ports such as HDMI/DC seen in the right-hand image below (Figure 7) were realigned, along with removing some additional material to enable the cables to function correctly.

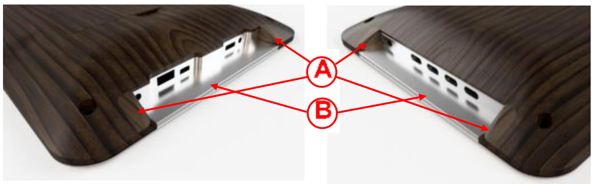

Fig. 7. KP exterior section

KP tablet – interior

The main objective with the internal section was to try to reduce the machining time, so that the manufacturing process becomes more viable, whilst maintain an adherence to quality at all times. With CNC machining, when the cutting tool meets a corner it must stop. Therefore, the speed at which it is traveling must slow down and come to a halt and likewise the tool requires additional time to meet full capacity when beginning a new cut. To increase the speed at which the internal section of the wooden chassis is processed, the following iterations were made to the KP design:

- The areas highlighted in red in the image left –hand side below (Figure 8), indicate material that has been removed following the BP review and the image on the right-hand side below (Figure 8) shows additional material highlighted in green. The reasons for adding and removing material was for realignment of components, clearance for parts which were under strain in the BP, strength and levelling the number of steps / pockets within the chassis.

- The number of pockets has been significantly reduced, to enable the cutting tool to move more freely.
- The BP version had numerous radii, as small as 1mm, which meant that the machining required numerous tool changes. By making the smallest radius 2.5 mm within the internal section of the wooden chassis, it removes one tool change from the machining process.
- The four corners within the Beta version restricted the cutting tool when it came to roughing out the bulk of material via the CNC. By enlarging the radii and creating a more gradual transition within the form of the chassis, it enables the cutting tool to move more freely.

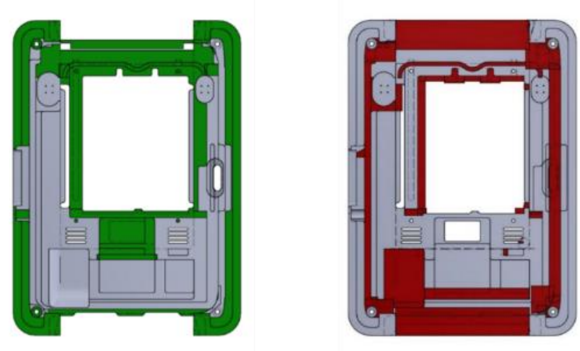

Fig. 8. Kappa interior section (schematic layout)

As highlighted in the BP review, design modifications have now been addressed as outlined below.

- As emphasised previously, the section marked (A) (Figure 9) is largely short grain and required a redesign. The KP design has a reinforcement metal plate, with additional metal plate on top, which acts as a washer. This enables the main plate underneath, to have larger holes where the screws meet, allowing the wooden chassis to expand and contract as necessary.
- The opening for the battery was addressed and is now correctly aligned.
- Additional allowance for cabling was also addressed.
- Cable tidies were added to the chassis to hold cables in place. (B) (Figure 9)
- The lens fixing was redesigned and is now attached with the addition of a metal plate. However, this is still not the final solution and requires further iterations. (C) (Figure 9)

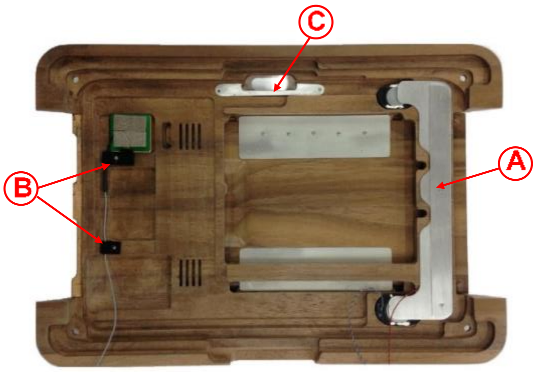

Fig. 9. KP interior section and comparison with BP details

Internal section of the battery cover

- The area highlighted in the Beta review on the inside of the battery cover has now a more gradual slope. This reduces the time it takes to finish the internal section of the battery cover, (Figure 10).

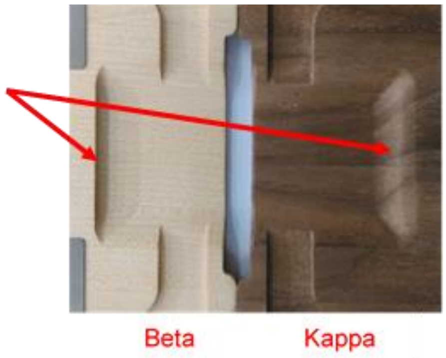

Fig. 10. KP & BP interior battery cover

Process Diagram of the KP

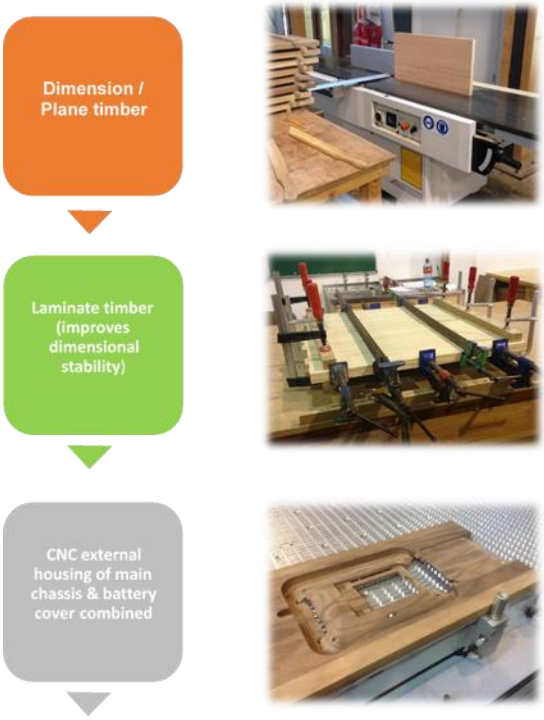

Fig. 11. Process Diagram (Part 1)

Fig. 12. Process Diagram (Part 2)

Finishes

Given the demands of the project schedule, the time for exploration of finishes was limited. However, two potential finishes were considered, a water-borne lacquer and an orange oil for its eco qualities. However, due to time constraints it was decided to use the lacquered option as it was considered more durable and was the fastest option for batch production. The time required to

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. It is expected that this would be further improved and reduced as production volume increases.

Moisture content of timber will be an important consideration in order to minimize movement of the wooden housing in service. Prior to machining the Kappa, the timber was climatized over the course of four weeks (Figure 13). Initial moisture content of the walnut was 9.4% and at the time of machining this was brought down to 8.3%. Preparation and storage of raw materials and finished product would need to be considered prior to full production beginning and would require further exploration and testing to establish optimum conditions.

Fig. 13. Acclimatizing timber prior to machining

5. METAL FRAME DESIGN AND MANUFACTURE FOR THE KP

5.1 Metal Frame design improvements

The metal frame for the AP and the BP were designed and manufactured by a commercial prototyper, who had access to the required equipment. The cost of the frames reflect this equipment and skills required, and would not be commercially viable for marketing the D4R tablet.

In order to redesign the tablet based on the BP design, GMIT found it necessary to also re-design the metal frame, to better accommodate the design improvements to the wooden housing. These improvements included aesthetic considerations like rounding the profile of the frame, but also redesign to improve ease of disassembly

The tablet housing was further integrated into the metal frame, and the USB connection housing was redesigned. Further ports were also incorporated into the frame for more USB connections and the power supply. In addition, screws and fixings were further aligned.

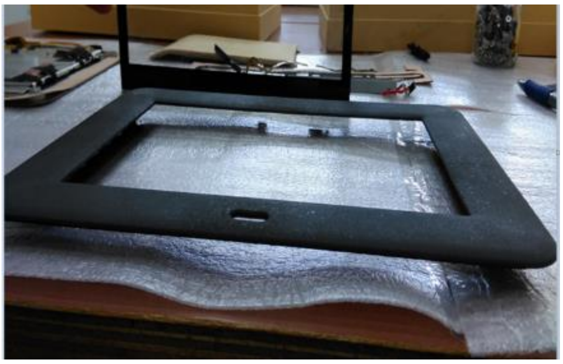

Fig. 14. Frame prototype 3D printed in plastics – front view

Fig. 15. Frame prototype 3D printed in plastics – connectors' slots view

Fig. 16. Metal frame improvements

Fig. 17. Final KP Metal Frame

5. ELECTRONIC SPECIFICATIONS IMPROVEMENTS FOR THE KP

The redesign of the KP also improved on the BP with respect to the electronics specification. The main improvements were as follows:

- Intel Quad Core 1.83GHz, 10.1" with 4G/128G
- Wi-Fi - 802.11B/G/N/AC wireless 2.4G/5GHZ
- 1*MicroUSB, 1*USB2, 1*TF CardSlot, 1*HDMI, 1*Earphone jack,1*SimCardSlot
- Built in 4.0 Camera: front 2.0 MP, rear 5.0 MP
- Modular GPS and Kill switch - optional
- Modular fingerprint sensor - optional
- Docking Station, Additional Battery, Handheld Belt
- Software: Android or Microsoft

6. TESTING OF THE KP

Verification of the technical performance of the Kappa Prototype will be done by test measurements usually required for CE compliance.

Partner Grant4Com will contribute input on the regulatory requirements of the KP and other standards that will have to be met before it can potentially go into production and market, including:

- EMC Testing according to:
- EN 301 489-1 V2.1.1 (General) + Draft EN 301 489-17 V3.2.0 (BT WLAN) + Draft EN 301 489-52 V1.1.0 (Cellular)

These include emissions, immunity and ESD testing

- RF testing for:
- 3G according to EN 301 908-2
- Bluetooth according to EN 300 328 V2.1.1
- Wi-Fi 802.11b/g/n according to EN 300 328 V2.1.1
- Wi-Fi 802.11a/ac/n according to Draft EN 301 893 V2.0.7

- SAR testing for portable device according to EN 50566

- Safety testing according to EN 60950-1:2006 + A11:2009 + A12:2011 + A1:2010 + AC: 2011 + A2:201

- Battery is in compliance with IEC 62133

Testing for RoHS Directive 2011/65/EU compliance.

7. PRODUCTION STARTEGY FOR THE KP

The iameco D4R tablet prototype has been successfully designed and manufactured as part of the SustainablySMART project, going through three design iterations, and work on this stage as completed in March 2018 (Maher, 2018)[ix]. The AP and BP were produced by a commercial prototyping company under MicroPro's direction, andthe KP by a research team at GMIT Letterfrack in consultation with MicroPro.

The iameco D4R tablet incorporates MicroPro's tried and tested eco-design principles of upgradability, updateability, reusability, recyclability and ease of disassembly. The iameco D4R tablet is designed to anticipate future changes of components, so the chassis can be used repeatedly and have many different lives. It has 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 are avoided. The housing is screwed together using standard Phillips type screws. Design ensures natural ventilation and prevents overheating. Connectivity is maximised. The wooden frame provides a protective standoff for the display.

The iameco D4R tablet is manufactured primarily from maple, and has an interior aluminum frame for robustness and stability. The tablet is fully functional and manufactured to a high specification. The manufacture of the two initial prototype housings has been undertaken in a commercial engineering workshop that uses digital design and manufacture. Commercial outsourcing was an intermediate step, aimed at ensuring that the tablet is professionally designed and manufactured, and that drawings, specifications and technical aspects are fit for purpose. A third tablet prototype (KP) produced in March 2018 is aimed at providing a template for digital fabrication (with scope for some modification and improvements during the project development, by GMIT Letterfrack College). Assembly of the electronics has been undertaken by MicroPro in-house.

The production of a high-tech device such as a tablet, which at least has to meet or be close to performance and size of similar products on the market, relies on significant share of standard, high-volume components, which are mainly the electronics parts. Other parts, such as housing and structural elements can in principle be produced locally in a digital fabrication workshop or similar like environments. Consequently the tablet production has to be a split production of externally sourced standard parts and internally manufactured customized parts. An overview depicting the business relation according to the business model developed in SustainablySMART is depicted in **Error! Reference source not found.**8.

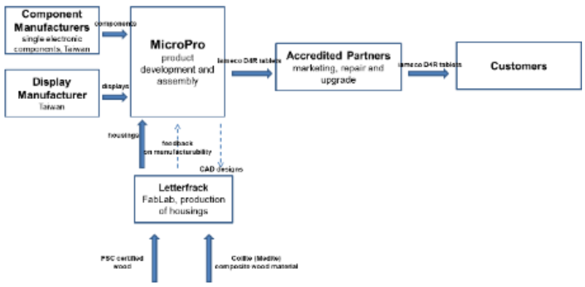

Figure 18: Involved actors and material streams (according to business model developed in WP6 of Sustainably SMART)

This figure reflects the demonstrator production in cooperation with GMIT Letterfrack and no other

FabLab partner. The component and display manufacturers act as conventional suppliers, GMIT Letterfrack as a manufacturing service provider which provides also design for manufacturability support. Not depicted in this chart is the manufacturing of the metal frame, which has been done by a commercial manufacturing service provider.

For the moment, MicroPro envisages that future production will be carried out at GMIT Letterfrack, on the basis of a partnership agreement. This might require some internal changes at GMIT Letterfrack to allow the College to enter into such a commercial relationship. The legal basis for this relationship likewise would have to be agreed. It might require GMIT Letterfrack setting up an arm's length commercial subsidiary.

It is expected that GMIT Letterfrack will be able to produce a small but growing number of tablet housings to order. MicroPro would apply a "crowdfunding" approach, as developed by Fairphone[x] and request pre-payment of tablets from customers as part of a broad marketing campaign, before undertaking fabrication in numbers. If this arrangement does not prove to be satisfactory, MicroPro will explore the viability of working with other commercial or non-commercial fabricators, that are prepared to fund production in advance..

During the first part of the sustainablySMART project, MicroPro concentrated on developing the specification and design of the tablet, and on identifying the manufacturing equipment and process required to produce the iameco D4R tablet. As MicroPro has no previous background of working with digital design and manufacture, a decision was made early on in the project to work with an experienced commercial product design and manufacturing company based in Central Europe to produce the initial design and first iterations of the prototype.

Development involved two iterations of the tablet prototype (AP and BP) which were designed and manufactured commercially. This original manufacturer used CAD design and also professional routing and milling equipment for production. Two prototype models were produced in this way, the Alpha and the Beta, both fully-functioning tablets. The Beta technically was closer to achieving the design and manufacture expectations of the project, but was still not fully adequate for digital design and fabrication.

MicroPro then carried out a survey of local commercial and non-commercial fabrication facilities, in order to decide what organization would be most appropriate for the design and manufacture of the final D4R tablet prototype.

The criteria for selecting this partner was:

- They should be local company, to ensure commercialization was logistically viable
- Extensive CAD design expertise as it would be working from commercially produced CAD drawings (the Beta version). It would have to be able to read, interpret and amend the drawing to suit the level of equipment available.
- Deep knowledge and experience of the production of wooden elements on a CCR and of milling, sanding, and other operations required to produce a finished tablet
- Routing, milling and sanding equipment able to produce a finished wooden frame accurately and of sufficient standard to be marketed.

After visits to various commercial fabrication companies and FabLabs MicroPro decided to work with GMIT Letterfrack to produce the final (Kappa) version of the D4R tablet.

GMIT Letterfrack was established in 1987 in partnership with Connemara West (a community and rural development organisation based in North-West Connemara). The campus specialises in furniture design, manufacturing technology and teacher education and is Irelands National Centre for Excellence in Furniture Design and Technology. Programmes are aligned with industry and thus boosts exceptional facilities from CNC technology, robotics, 3D printing, Laser as well as all the standard equipment found at a commercial workshop.

GMIT Letterfrack were tasked with evolving the BP version of the D4R tablets wooden chassis to its latest version within the KP. The main iterations were on the internal sections of the chassis in terms of manufacturing efficiencies. There were some iterations on the exterior of the tablet, these however were for functional and strength shortcomings within the BP .

The D4R tablet requires a high level of skill, equipment and equally an in-depth understanding of wood and its unique properties. An understanding of both wood and machining strategies failings and strengths is essential in designing the tablet via CAD software. Equally programming the CNC files requires an in-depth understanding of wood in terms of limiting the amount of post processing. Once all files have been tried and tested and correctly running the machining process is a matter of repetition. The following is a list of machinery and equipment and the processes that they were used for in the production of the Kappa prototype.

Material break out and preparation for CNC Machining

1. Rip saw (Dimensioning raw material in width)
2. Crosscut saw (Dimensioning raw material in length)
3. Planer (Planing face side and face edge, i.e. to surfaces at 90 degrees)
4. Thicknesses (Planing material to its required dimensions)
5. Panel saw / Beam saw (Accurately dimensioning planed material in length and width)
6. Sash Cramps (Cramping laminations together)
7. Speed Sander (Accurately dimensioning material to thickness as well as providing a sanded surface.)

CNC Machining

8. 3 Axis Weeke CNC (3D machining of the tablets wooden chassis)

Post Processing

9. Bandsaw (Removal of waste material from the tablet chassis)
10. Edge sander (Sanding the edges of the tablet chassis)
11. Orbital sander (Sanding the exterior of the chassis)
12. Spray booth / Spray gun (Finishing of the tablets chassis with water base lacquer)

Upon conclusion of the manufacture of the KP, GMIT Letterfrack carried out an assessment of the manufacturability of the D4R tablet. The challenge of reducing the considerable machining time whilst maintaining an adherence to quality at all times was successful to a degree via machining techniques and design iterations. The machining time was reduced by approximately 28% from the BP version and post processing time was reduced by 50%.

<u>6.2 Potential role for FabLabs in manufacture of iameco D4R tablet</u>

The final iteration of the iameco D4R prototype has been produced in the GMIT Letterfrack fabrication workshop, which is not a commercial fabrication workshop, and can be said to be similar to some advanced FabLabs. Compared to most FabLabs GMIT Letterfrack assembles more sophisticated equipment and know-how in the field of wood processing than a typical FabLab. This workshop, given its background, equipment and skills, has been able to satisfactorily manufacture the housing for the iameco D4R tablet prototype.

The metal frame, however, cannot be produced by GMIT Letterfrack. A plastic version of the frame was manufactured using additive manufacturing, but this is not considered suitable for the finished prototype or product, and a commercial metal frame is in the process of being produced by a private company.

In order to produce the iameco D4R tablet, it is likely that a digital fabrication workshop with the level of equipment and skills present in Letterfrack would be required. From our research to date, it would appear that most Fab Labs are not equipped to manufacture a device like the D4R tablet (e.g. Limerick FabLab) because they do not have the necessary equipment, skills or service arrangements to allow production on a commercial basis.

However, enquiries with two other Fab Labs in Germany, indicate that at least one other (Berlin Fab Lab) believes it has the equipment and capacity to produce the wooden housing and posibly the metal frame. It is still the question of how the required skills would be contributed, and workable non-disclosure and contractual agreements would be entered into to achieve manufacture in the required numbers. Again, this will be explored further during the remainder of the SustainablySMART Project

8. PRODUCT/SERVICE STRATEGY FOR THE IAMECO D4R TABLET

Until the details of potential working arangements between MicroPro and GMIT Letterfrack are finalised, it is difficult to estimate what level of production could be achieved with this arrangement. It is likely that any production udnertaken would have to be based on pre-orders, on the models used successfuly by Fairphone. It is also possible that negotiations with FabLabs such as Berlin FabLab may produce alternatives fro mnufacture, that would serve to increase this market over time. These are questions that MicroPro intends to address over the rfemained of the SustainablySMART Project and in any follwo-on projects that may be develolped.

However, the model proppoosed by MicroPro is not limited to innovation in terms of design, specfication and appraoch to manufacture, but extands to a service model, linked to the design of the prodcut. The rationale for **innovation in the service domain** is as follows: MicroPro sells to business consumers and in the business to consumer (B2C) market space. The company aims to offer take-back and refurbishment operations platform in place (refurbishment and repair operations will initially take place at their main headquarters in Dublin).

In order to deal with increasing number of sales in other regions and outside of Ireland, MicroPro proposes to identify a number of suitably qualified enterprises who will agreed to act as Service Agents in the countries where market penetration is proposed. These partners will have experience of the sector, can identify retailers in their catchment area, and will have existing access to target consumer segments. These Agents will also provide feedback on client responses and observations, which will inform future marketing approaches and product and service design. They will provide after-sales support, repairs and upgrading required to service non-Irish iameco users in their own catchment area. They will be linked to MicroPro through a franchise (or similar) agreement (which will involve a franchise fee being paid to MicroPro with the bulk of the fees being retained by the franchise holder). They will also be bound by an IPR agreement. In future is proposed that these partners/agents could carry out part of the assembly process in their own countries, after receiving the "barebones" units from MicroPro.

IPR of the iameco D4R tablet would be protected through an EU patent, to enable this development. . Initially MicroPro will act as central distribution point for the fully assembled iameco tablet, but as the service network develops it will be able to produce a "barebones" systems (i.e. housing shells void of hard disks and RAM modules), manufactured in Letterfrack or at an equivalent fabrication workshop, which will be shipped to franchise holders to populate with primary system components.

It is also possible that local Service Agents could work with local Fab Labs that are adequately equipped and skilled, in the production of barebones shells and entire tablets. This possibility will be explored if suitable Fab Labs are identified, that have the necessary manufacturing capabilities.

A change from a traditional retail "direct selling" model to a lease based business model, or some other sales model that will guarantee return of the equipment to MicroPro at end-of-life, will be proposed (this is known as a product service system, PSS). An investigation of lease-based business models, which will facilitate transition to a PSS, will be investigated.

Preliminary research shows the most viable model would be the use of exiting Leasing companies for this purpose. These companies market the product and secure orders, then using their own capital to fund the manufacture of the required products. They then make the product available to clients on a leasehold basis.

Other options for ensuring the implementation of the repair/upgrading/take-back model could be:

- A long term repair warranty for part and repairs
- A long-term upgrading agreement, ensuring regular upgrades in exchange for a periodic fee
- A return deposit-based agreement between MicroPro/distributors and the consumer.

In this instance, the consumer could receive various scales of return deposit based on the return of the system to MicroPro for upgrade or refurbishment.

9. CONCLUSIONS – ACHIEVING A VIABLE DESIGN AND MANUFACTURING STATEGY

MicroPro's main objective in participation in the SustainablySMART project has been to research, develop and implement a more effective and sustainable model for manufacture of its iameco range of ecological computers. The test case for this development has been the iameco D4R tablet.

MicroPro has started out from the premise that Digital fabrication would be way of reducing logistical problems and costs, which had made earlier prototypes financially unviable.

This lack of viability was mainly arising from the costs of outsourcing, but also from the lack of control that the SME had over design, manufacturing and re-manufacturing options.

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 maodels 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 project therefore is exploring two alternative options for "non-commercial" digital fabrication of the iameco D4R tablet:

- Option 1: A digital workshop, belonging to an academic institution (a furniture design college), that also had in-house design and machine operating skills in its graduate students and staff

- Option 2 - A digital workshop in a Fab Lab that has the necessary equipment and possibly the required skills to produce the final Prototype (KP) for manufacture.

The experience of the project has been that Option 1 is technically feasible. The question remains whether it is institutionally feasible and whether such a workshop is in a position to be a manufacturing partner for commercialization. This will require further research and discussion, and possibly structural modification in the University Department operating the workshop to allow it to undertake this role.

Option 2 is still being explored, and one loacl Fab Lab visisted (University of Limerick Fab Lab) does not have the equipment or the skills or the structure and staffing to facilitate such production.

Enquiries with better equipped Fab Labs in Germany indicate that it might be possible for Fab Labs outside of Ireland to perform this role. If so, this is unlikely to be the main basis of manufacture, due to logistics issues, but this Option could lead to a more decentralized model for manufacture, repair, upgrading and production of the tablet, as described in 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.[xi]

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