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Small fish in a big pond: product longevity design strategies for smart speakers

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Extending the lifetime of the product, as one of the strategies for design for sustainability, may increase the value of the product in use, repair, recycle and disposal phases for a longer lifetime thereby decreasing demand for new manufacturing. However, employing these perspectives may be challenging and requires long development processes. In the current structure, small scale companies have a potential to be a significant actor in transition for sustainable manufacturing and design due to their agile development skills. We will present empirical data collected from eight participants regarding five small scale companies who design and manufacture long-lasting connected smart speakers. Key findings and implications highlight that small scale smart product producers strive to maintain control over design decisions in order to enhance the potential for long-lasting products; such companies thus need to be empowered towards distribution and decentralisation of design and manufacturing. To do so, (1) local manufacturing of the hardware is needed; (2) distributed and decentralised repair services need to be available to distribute the responsibility and increase the resilience of the product; (3) new types of intermediary relationships such as collaborating with local incubation centres and local initiatives should be encouraged; and (4) future designers may also need to practise their production skills and include open-source hardware and software development in their projects.

Keywords: design for longevity; distributed economies; small-scale production; connected products

1 Introduction

Product design for sustainability is challenging to implement in current mass manufacturing ecosystems for complex electronic consumer products, which are mature and distributed but not decentralised. On the contrary, hopeful, and innovative practices are currently being enacted in the small scale, in distributed and decentralised production ecosystems. In this paper we examine the promising characteristics of existing small-scale companies and discuss how to increase their resilience in designing long lasting products.

Understanding the manufacturing and design processes of small-scale companies and their current collaborations sheds light on current production ecosystems that diverge from conventional mass manufacturing. Based on the abilities and limitations of these companies, we will discuss how design and manufacturing systems can be transformed and how the resilience of small-scale companies can be strengthened to support the production of long-lasting smart products. Such alternatives are important because there is increasing demand for technological products combined with a lack of an infrastructure for collecting and separating e-waste, resulting in the lack of e waste management (Hunt, 2017).

Connected products as a subcategory of Information and Communication Technology (ICT) products consist of a combination hardware and software. Raff et al. (2020) defines a connected product as one which fulfils its function by wirelessly connecting to another product and sending and receiving data. Examples of this are smart light systems (Raff et al., 2020) or smart speakers that need to be connected to smartphones to function. In design research, such products can be analysed in terms of not only function, but also experience, meaning and appearance, a framework that is more holistic and encompassing, but also complicated (Lui et al., 2022). For the designers and manufacturers of such products, the different requirements of software-, hardware- and product design dramatically increase the complexity, especially when considering strategic design for sustainability. At the same time, connected products, as assemblages of software, components, materials, meaning and new production techniques, are seen as having potential to combat e-waste and obsolescence (Özçelik et al., 2022; Hunt, 2019) and to employ new modes of designing and manufacturing consumer technologies that serve as environmentally preferable alternatives to conventional mass production and consumption. These alternative production modes - and their implications for design - have been conceptualised in recent years as distributed manufacturing (Vezzoli et al., 2021; Rauch et al., 2016; Srai et al., 2016; Johansson et al., 2005). We were prompted to conduct this study by the intricate nature of connected products, coupled with the possibility of extended product life cycles. Our aim was to investigate the interconnections and pinpoint primary obstacles to designing towards distributed economies by focusing on the production ecosystem and how it impacts product design: that is, the interactions of a company with other actors in a product-service system (cf. Vezzoli et al., 2021).

In this paper we thereby present empirical findings regarding five small-scale companies who design and manufacture long-lasting connected sound products. We will map their design and production ecosystems and explain how they relate to and shape each other. We suggest potential intervention points where such producers can enhance their resilience in long-lasting technology production. We do so, in order to fill the significant gaps in design research on distributed manufacturing, positioning our examination between product design for circularity (e.g. den Hollander et al., 2017) and cleaner production management.

2 Background

Technology-centred thinking (Van der Velden, 2018) that seeks technical advancement, positions connectivity as a part of the solution. For example, connected products can increase the visibility of the product in the use phase, informing the design process through data in use and opening a space for radically new products for a circular economy (Hunt, 2019). Especially in the case of personalised

products, connectivity can be a means to address repair, remanufacturing and recycling related problems by storing information about the product (Hunt, 2019). However, this connectivity can also result in social unsustainability due to the manufacturing of the electronics (Patrignani & Whitehouse, 2014; Patrignani & Whitehouse, 2018), and the management of the e-waste (Tansel 2017) and is currently not sufficiently studied. This is particularly relevant when the connectivity is the integrated part of the product that has a detrimental impact on the product's lifetime. For instance, the primary function of the product may have a longer lifespan, but the obsolescence of connected components can lead to the product being discarded and reduce its longevity. Furthermore, easing the disassembly of technological products not only increases the chance of recycling the e-waste (Tansel, 2017) but also enables part replacement, which can increase the lifetime of the product. This may relatively decrease the demand for new production and volumes of e-waste. Consequently, connected products require special consideration in terms of sustainability, especially with regards to durability.

Slowing technology production and the pace of consumption and disposal (Lebel, 2016) is critical to decreasing environmental harm. Having longer lasting products is a premise that can decrease the need for new production, thereby decreasing the amount of labour, energy and raw material needed. Similarly, the concept of the circular economy (Ellen Macarthur, 2013) advocates extending the lifetime of a product by protecting its value throughout its life phases after production. Well-known approaches such as durability and robustness (den Hollander et al., 2017) , enabling product exchange and creating multiple use cycles (Rexfelt & Selvefors, 2021), repair and maintenance (Terzioglu, 2021), recycling and disposal (Choi, 2018) concepts aim to keep the value of the product longer. A recent study by Jensen et al. (2022) found three strategies to manufacture longer lasting products: focusing on high performance of the product, strategies that impact customers' perspectives of longevity (e.g. limited seasonal trends, transparent production, or after-sales services) and the vision of the company (e.g. solving obdurate problems which will help them to stay relevant in the market).

Notwithstanding how the outlined approaches are promising for centralised economies (by this we mean conventional mass manufacturing), Santos et al. (2019) highlight that large-scale production and large distribution networks make changes towards sustainability and fewer negative environmental impacts costly and time consuming. Therefore, with the development of Industry 4.0 technologies (e.g. laser cutters or 3D printers), small scale companies are seen as promising organisational structures due to their flexibility and high ability to adapt to sustainability requirements (Hunt, 2019). The concept of "distributed economies", which refers to small organisational units that share the same location with their end users who have control over essential activities (e.g. peer to peer activities or craft production that a user performs as a prosumer), also embrace small scale organisations networked in novel ways as promising organisations (Santos et al., 2019; Johansson et al., 2005).

These types of companies can produce non-standard products which increase the variety of innovative solutions oriented towards sustainability. However, the lack of product standardisation might require unique treatment during maintenance and repair, and specific instructions and documentation might not be provided (Hunt, 2019). These factors may decrease the lifetime of the product. To tackle this, enabling the customer to have the right to take care of essential activities of the product such as repair and maintenance (Santos et al, 2019) and having decentralised and distributed economies that depend on light distribution networks to reach customers directly without intermediaries could be better alternatives.

These organisation types bring new possibilities as well as responsibilities to all the actors. For example, the user is seen as a responsible, active actor within circular systems (Bakker et al., 2021) alongside manufacturers, companies and designers. Recent approaches have investigated the ways to expand their role beyond emotional attachment (Chapman, 2005). With all these different perspectives, a wide space is opened up for the design discipline and designers, which needs further understanding.

Since design is highly dependent on its organisational structure, experiences of small-scale companies and further possibilities will be discussed based on empirical data regarding sound products. In this paper we will thus expose the interdependencies and promising characteristics of small-scale companies.

Despite their small scale, the design activities, capabilities, and barriers of such companies have important implications, reflected, for example, in recent calls by the European Union (EU) to reshore manufacturing, particularly in the complex consumer electronics industry. Besides concerns over the over-reliance on foreign imports - making the EU vulnerable to supply chain disruptions as seen during the COVID-19 pandemic - the need for greater self-sufficiency in the production also stems from the wish to ensure that the manufacturing processes are sustainable and just. This is also in line with the EU commitments to reduce its carbon footprint and transition towards a carbon-neutral society; such a vision is compatible with conceptualisations of circular- and distributed economies.[1]

3 Methodology

As a product category we have chosen sound products, as they are (1) a fitting example of the combination of hardware and software, (2) they are mature products, and (3) they form a meaningful part of users' daily lives. This paper introduces experiences of five small-scale companies that aim to manufacture long lasting and sustainable products.

The findings are based on semi-structured interviews and field notes. The interviews were conducted with employees that all have direct influence on the design of the companies' products and lasted between 30 minutes and two hours. Due to the sizes of the companies, the roles of the employees are not always clearly defined and varied between designer, product manager, owner and engineer.

Table 1. List of participants

	Participant	**Duration**
Company A	Two designer/co-owner	1:21:09
Company B	a designer/co-owner	1:50:17
Company C	Two designer/co-owner	1:22:02
Company D	a designer co-owner	1:08:11 0:57:04
Company E	a product manager	0:28:34

[1] https://cordis.europa.eu/programme/id/HORIZON_HORIZON-CL4-2021-RESILIENCE-01-29

Detailed information is provided in Table 1. We used thematic analysis to highlight different approaches. Additionally, we portray the structural schema of the companies and how they relate with different actors to understand their experiences and their network in the ecosystem.

4 Findings

In this section we first summarise the empirical data. The companies are micro- and small-scale as well as semi-distributed, by which we mean manufacturing and production is partly distributed between multiple actors; they are anonymised as Company A, B, C, D, E. First, we will explain the organisational structure of the company, and then we describe their design and manufacturing process.

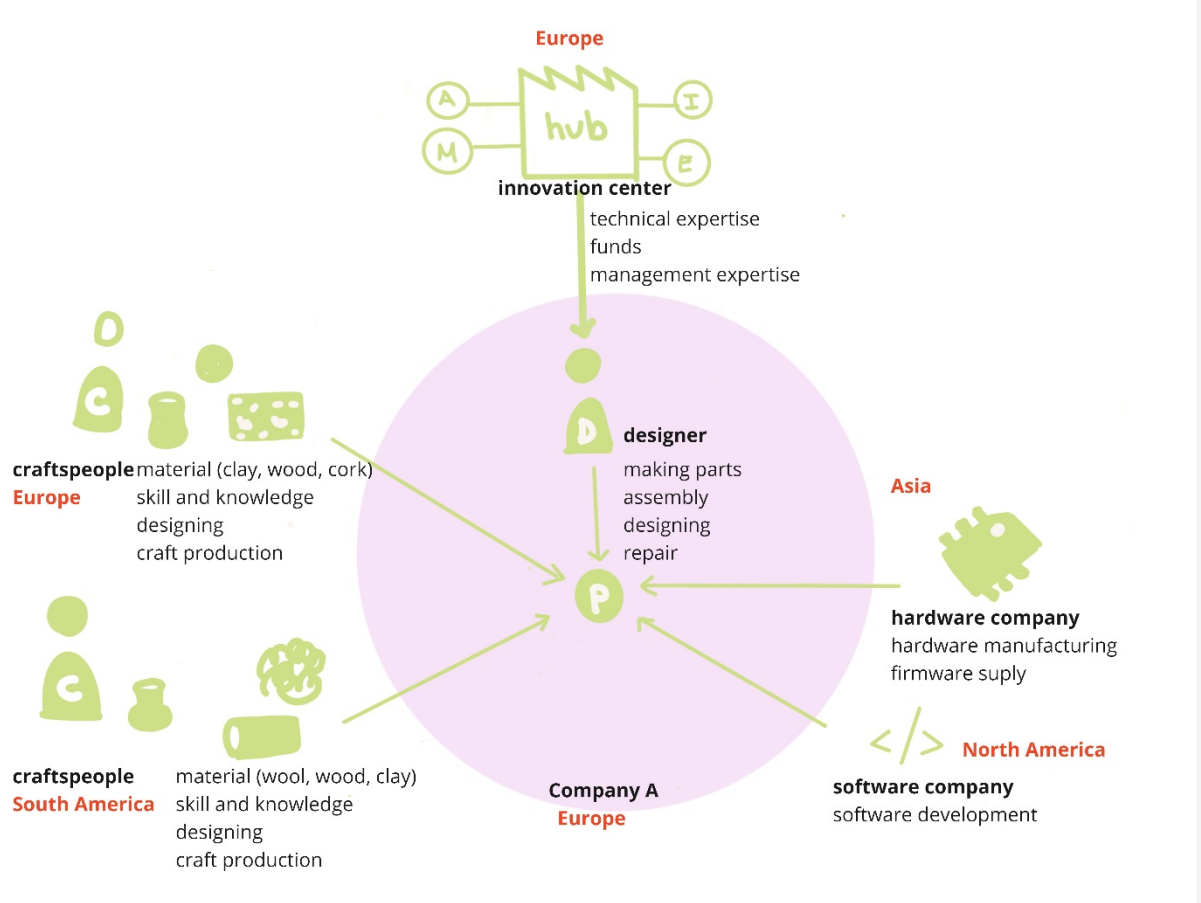

Figure 1. Design and production ecosystem of company A. Source: Author's drawing.

Company A produces connected clay speakers and employs 2-3 people. They do batch production and have until now produced two different series. The designers of the products are also co-owners of the company. The development of the products was funded via crowdfunding and a startup incubator focused on sound products. They value craft production higher than mass production of their product. Therefore, they use locally sourced materials and local production methods and combine them with electronics (including the speaker) that are produced in Asia. The clay exterior of the speaker is produced in collaboration with local clay craftspeople. Their vision is to create a revival of

craftsmanship and to restore prominence of traditional handmade products in the industrialised world, thereby bridging the gap between craft and technology. Further, they have also collaborated with acoustic engineers to tune the acoustic properties of the product. The electronics are produced by an Asian producer in small batches. Due to the product's organic form, standard components would not fit; thus, they needed custom made components. While sourcing components, they experienced difficulties finding a company that produces them in Europe at affordable prices. Similarly, they had difficulty sourcing them from Asia due to the specific manufacturing requirements; however, they found a manufacturer after extensive search.

The remaining infrastructural elements, and hardware as well as the assembly of the product, are conducted in the local workshop. Shaping copper pipes, cutting the wood pieces, and soldering the components are done by the designer themself. Similarly, the repair of the product is also done in their local workshop. They highlighted that repairing the product is easy for them since they do not glue the components (they use the glue to only combine the wood and the clay parts); however, for a user it would be difficult to repair the product since it does not use standard infrastructure.

The interviewees aim to reflect the company's cultural values and visual aesthetics through their product. They defined their product as an “artistic and unique design” that could be a “collectors` piece”. They see their product as “cultural ambassadors” of audio equipment. The fact that a product is produced from a certain region also creates an emotional bond between the user and the product. For example, some of the users express emotional bonds to the product since it is made in their home country.

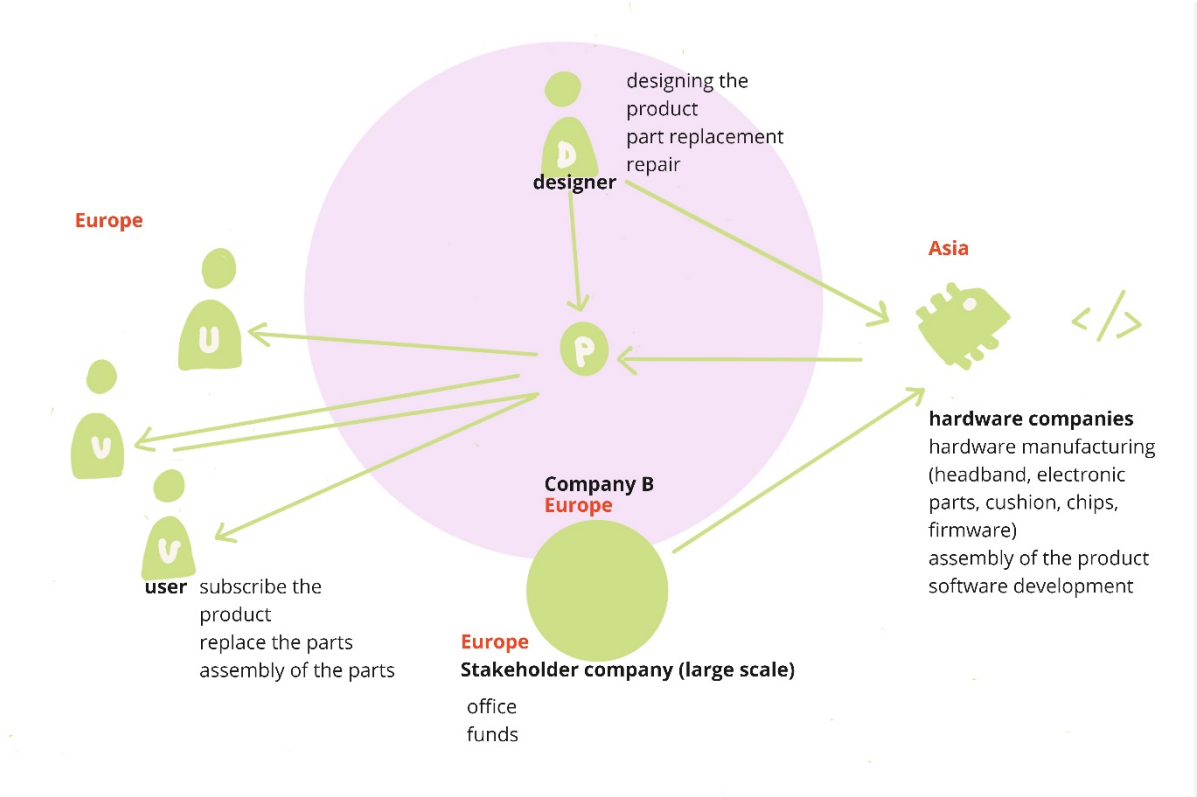

Figure 2. Design and production ecosystem of company B. Source: Author’s drawing.

Company B produces connected headphones and employs 4-6 people. Having a limited number of products is one of the strategies. They have three product types, connected headphones, headphones with a cable, and noise cancelling headphones which are all only provided in one colour (black). Besides a classical one-time payment purchase, they also offer a subscription service which allows users to use the product via a monthly fee. In this service, maintenance and repair is included, where users can order new parts that are needed while continuing to use the parts which have not deteriorated. These decisions were made based on the results of user focus group interviews that they conducted during the development process. In this they found that their customers would not mind that some of the parts are reused / redistributed as long as they get new ear cushions. Giving the user the possibility to replace parts is economically viable as they are sent as letter mail instead of a package, making it cheaper in terms of shipping cost. Following this, they leave the assembly to the user, which helps with increasing inclusion of the user in the process and division of responsibilities (e.g. in the case of malfunction users can replace each part themselves). Similarly, in the decision-making process, the modularity level of the product is determined according to the skills of the users and their capacity to replace the parts of the product. There is also a limit for the user (e.g. opening the inside of the headphones) to intervene in the product. In terms of aesthetic styling, they cared about finding “the optimum balance” between a DIY aesthetic and technological look. Due to the limited amount of products the company sells, they do not have their own disposal system and are therefore subject to the city's disposal legislation; broken parts that are sent back to them therefore go to the “trash can”.

The product and the different parts are manufactured in Asia. The fact that the company has non-conventional demands for their production (e.g. not using glue in the general assembly of the product, and only in some locations and in a limited amount to ensure the product is airtight) and only needs small quantities, creates difficulty and resistance among the manufacturers. Furthermore, reusing parts from headphones that were sent back (or are in for repair) which have components inside requires compatibility with newer parts (e.g. when only one of the ear cups is malfunctioning, it should be compatible with other parts). They increased their bargaining power towards manufacturers by collaborating with a large-scale company and using their manufacturer. However not all factors that can lead to obsolescence can be solved, due to the manufacturer and the company having different visions for sustainability. For example, for one production batch, a hardware design which was handled by the manufacturer led to an incompatibility with an older model of earcups, making it not suited as replacement parts. Similarly, some headbands were not compatible with the noise cancelling cups. The company had an iterative product design process, which helped them to learn and further develop the product's against unexpected problems. Additionally, the product requires high quality material (e.g. surface scratch protection) to ensure resilience. While this comes with a high cost, the company is willing to pay for it, as in the long term it will help them keep the parts in circulation longer. Due to uncertainty regarding the pace and progress of technology, they are making "future-proof" decisions, such as investing in the latest forms of connectivity and technology; as technology is constantly evolving and diversifying, they are prepared to pay a premium for the most cutting-edge hardware that offers greater storage and advanced capabilities to cater to potential future requirements and advancements.

Last but not least there is a lack of knowledge in Europe. Even if they wanted to work with European countries, they could not find up-to-date knowledge and hardware production in Europe, nor is it cost effective.

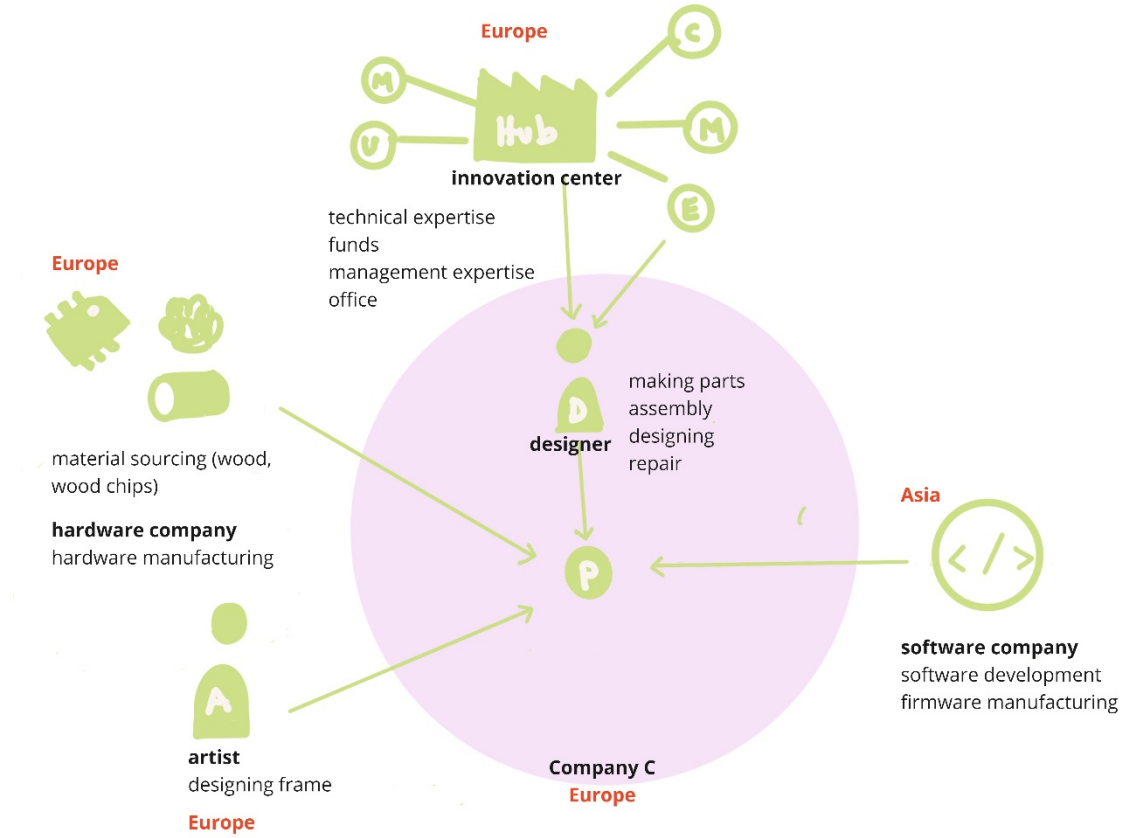

Figure 3. Design and production ecosystem of company C. Source: Author's drawing.

Company C is a start-up company that produces connected speakers and employs two people. Their first batch (20-30 products) is produced and currently on sale. The manufacturing process of the product takes place in the workshop which is provided by a start-up incubator of this they are part. While developing the product, they have collaborated with local acoustic and finance experts who have sound industry experience. Furthermore, they collaborate with local artists, which gives their product a second function as an art piece.

They are locally producing the product and some of the material is locally sourced (e.g. sustainability certified wood and waste wood chippings for filling). Vacuum formed boxes, metal parts that need to be bent, and production of the electronic components and acoustic components are made in Europe which increases "control over" and availability of the components. The wooden parts of the products and the assembly of the product are made in their workshop by the designers. Therefore, designers use and develop their skills for manufacturing, dis/assembling, and selling the product, which increase the possibility of the repair, refurbishment and upgrade of the product. This potential remains as long as the components and tools are available to them, e.g. in case of repair, the plate (the back part of the speaker) can be changed if needed. The high price tag of the product requires that they use qualified components and real wood. They try to ensure the quality and durability of the product with stress tests. While they do not have the financial resources that are required to produce their custom electronics in Asia, they only source specific modules and a mobile app from Asia to provide the connectivity. It does help them to decrease the cost and the responsibility to deal with software updates. They stated that their mindset, which their education supported, is to create sustainable

products. Further they highlight that as a start-up, being long lasting and sustainable makes it easy to acquire more financial support.

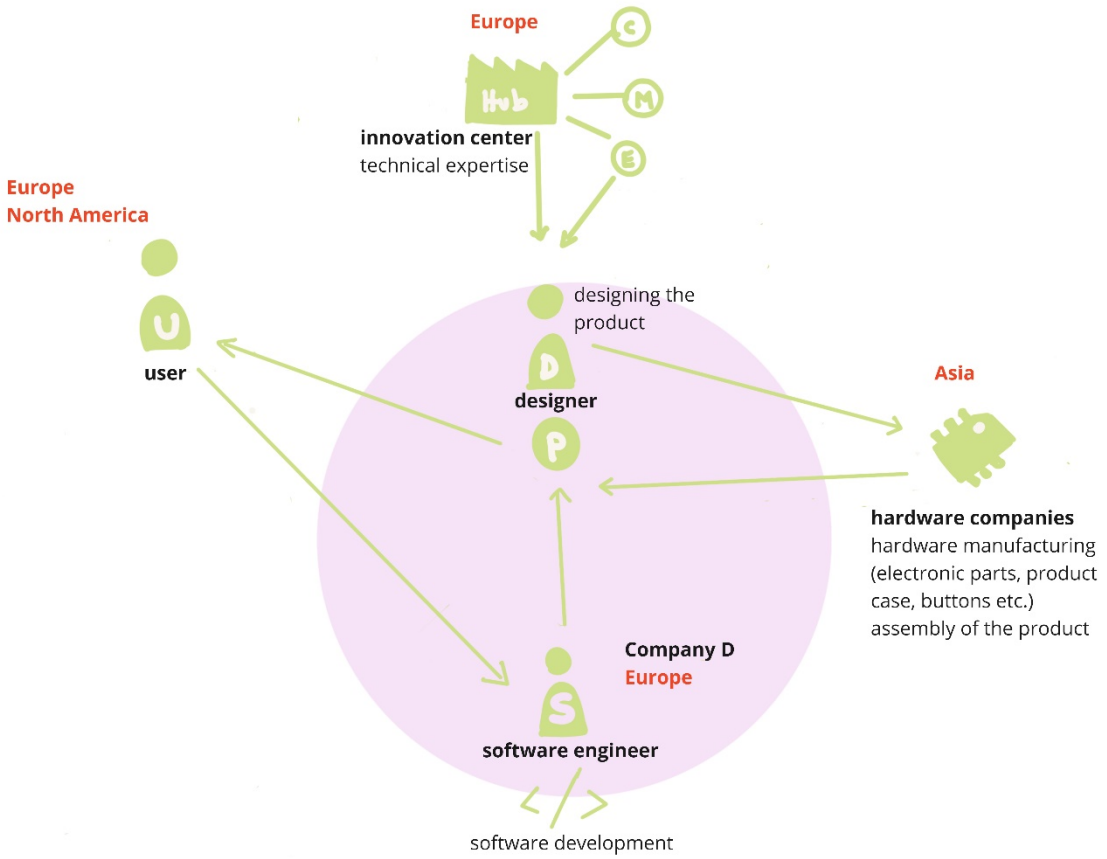

Figure 4. Design and production ecosystem of company D. Source: Author's drawing.

Company D produces connected speakers that allow children to stream appropriate audio content and employs 5-6 people. The product is mass produced in Asia. However, since they do not order a large quantity of their product, they cannot have a long-term relationship with manufacturers so that affects their capacity (e.g. using only one colour and material). They choose standard hardware and electronics. They aim for durable and robust products which they assure by testing, such as drop tests and vibration tests. They also aim for accessible product structure. Repairability of the product is increased by using standard screws and other standard components, e.g. for the battery. Using only one type of material - plastic - was helpful for the designers to design an assembly process of the product without using glue. They also decreased the interdependencies of the different parts to allow for easy replacement of the components. These were strategic decisions of the company since they own the responsibility for repair and refurbishment and at the same time, they target children users who have different use behaviours. As they state, providing repair helps them to keep a good relationship with their users, so that they can continue to exist in the market. The repairability is not planned to be done by the users; the interviewees explained the reasoning behind it as "legal responsibilities of the company" and distributing the replacement parts might create a "logistical nightmare". The products repaired by the company go to charity to have a second life. Moreover, they are dependent on the incumbent disposal infrastructure, which, given their small size, means that broken parts go to the normal municipal "trash cans".

Simple geometric tokens or figurines (depending on the age group) which are linked with certain songs that come with the product enable kids to choose their songs. The software part of the product is under constant development depending on the users' feedback. The extension of the development depends on the firmware that has been put in the product and the capacity of the company. "Future-proof" firmware decisions can help up to a certain time. The software development is done by the company itself and since it is a rather small team, upgrades take a longer time. At the same time the user can reach out to the software expert remotely and that can help with troubleshooting. Moreover, since they use one of the main streaming services, they also have legal responsibilities to be compatible with those services.

In this company the designer was the main responsible to design the product who went to the production area and was actively involved in the manufacturing process. Since they are currently at the second iteration of the product, the company had much insight. Furthermore, the designer had an active role in user testing, user interaction and interface design for the app.

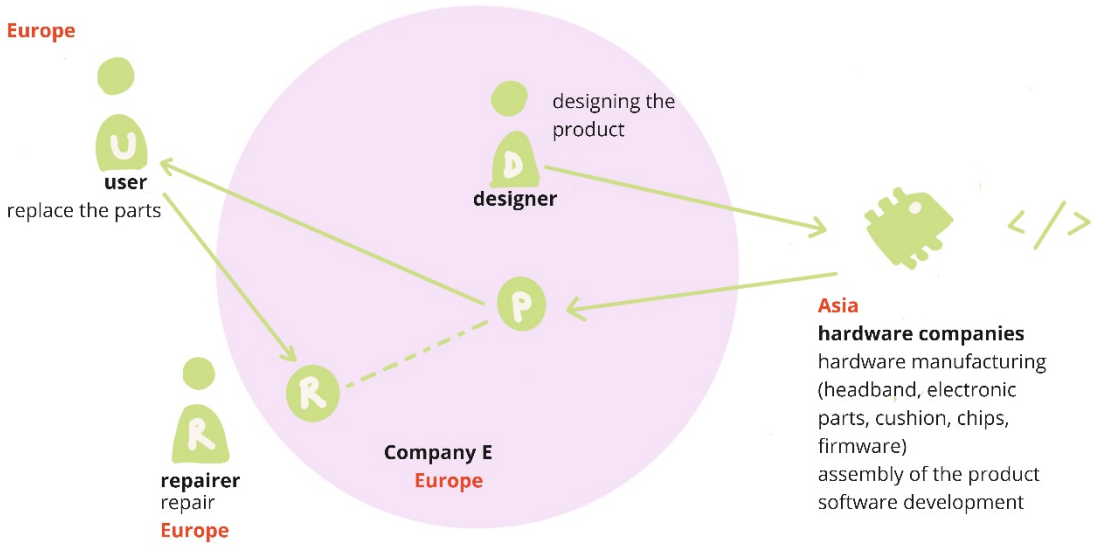

Figure 5. Design and production ecosystem of company E. Source: Author's drawing.

Company E produces connected earbuds and is prominent in certain markets due to their highly sustainable non-audio products. Company E is a niche company which employs approximately 130 people, thus larger than the companies presented above. They have established knowledge regarding sustainable production, longevity and repair of electronic products. However, they have recently started to produce earbuds. They have a large distribution network and accumulated experience of sending replacement parts even though these are not related to their sound products. They are collaborating with an Asian manufacturer who has expertise with the audio product.

One of the main challenges for this company is creating an adequate product that lives up to the standard the company set for themselves in other categories. Here having replaceable batteries while at the same time being resilient against sweat would be important. The product requirements create a conflict. Easy disassembly requires screws; however due to acoustic requirements they have to use

glue in certain areas. It is challenging to combine all conflicting requirements on a small-sized product (earbud). Therefore, they are trying to balance the product qualities while planning the repair and acoustic quality. If the malfunction problems require low effort and their customer demands to buy the spare part, they provide the spare part and related information. If not, they ask the customer to send the product to their repair service. While doing that they provide instructions for each part. If it is a problem that can be complicated or the sales of the spare part would be low, they ask the customer to send it to the repair centre.

	Product appearance, material and features	Hardware sourcing, assembly and repair	Software maintenance, upgrade, firmware sourcing and software services
Company A	• Craft production • Co design with craft artist • Represents local aesthetic taste • Organic form • Local material use • Batch production	• Assembled in the workshop facility of the company (soldering the components) • Repaired in workshop facility of the company by company co-owner • Local non electronic component sorcing and appropriation (Tweaking the copper tubes • Sourcing non standard electronic component from Asia	• Sourcing software services and related firmware from Asia and America.
Company B	• Modular product • Resilient surface coating • Light-weight transportation • Production in Asia • Mass production • Reusing the parts • Subscription model	• Replaceable parts by users. • Produced, and assembling in Asia. • Repaired in the workshop facility of the company by company co-owner	• Sourced high capacity firmware
Company C	• Craft production • Co-design with painters • Collaboration with local part producers • Using local material	• Repaired in workshop facility of the company by company co-owner • Local electronic and component sourcing (amplifiers, cards) • Local non electronic component sourcing (speakers)	• Separate software module and software service are sourced from Asia
Company D	• Mass production in Asia • Durable and robust product	• Repaired in workshop facility of the company by company co-owner • Refurbishment activities in workshop facility of the company by company co-owner	• Constant software update by company • Sourced high capacity firmware • Designed their own software
Company E	• Mass production in Asia • Modular product • Replaceable parts by users	• Replaceable parts (by the user) • Repair service at the Repair center by technician • Produced in Asia	• Sourced in Asia

Figure 6. Summary of promising characteristics of small-scale companies. Source: Author's drawing.

5 Discussion

In this section we discuss the promising characteristics of the small-scale companies that aim to design and produce longer lasting connected products. After giving a brief summary of their characteristics (see Figure 6), we discuss promising intervention points through the lens of decentralised and distributed economies (after Johansson et al., 2005 and Vezzoli et al., 2021), examining the production

ecosystems and interactions among the company and other actors. We will summarise our insights regarding the barriers and future promising directions under the themes of manufacturing, product design, designers and users.

5.1 Manufacturing

Even though the small-scale companies are more flexible in terms of their organisational structure and design decisions, they are strongly bound to centralised mass production systems in terms of hardware and firmware sourcing. The currently dominant patterns of technology development and manufacturing are therefore a key challenge for longevity and sustainability, inhibiting the development of local knowledge and production of hardware and firmware. Sourcing the hardware from Asia due to accumulated knowledge and cheaper cost of hardware development and manufacturing is preferable and sometimes the only option (e.g. company A had difficulty finding specific components that they need to fit in their speaker form). This decreases the companies' control over the components' lifetime which drastically limits the opportunities for longevity, since the same component might not be available for a longer period of time.

Moreover, the current way of producing high volumes of components in Asia makes it difficult to advocate for specific hardware production in low quantities. For example, having specific sustainability or longevity requirements (e.g. producing compatible elements for replacement) which require manufacturers to design non-standard or non-mainstream components is often not possible. Friction between companies and the manufacturers occurs when manufacturing a small number of components since the manufacturers are not compensated for changing their way of production. The companies do not have enough bargaining power to push for more sustainable or long-lasting hardware production. Some of the companies have developed an additional strategy to tackle this friction by collaborating with a large-scale company as an enabler to source their hardware in the way that they want.

Locally manufacturing the products, utilising traditional production techniques and skills, empowers these small-scale companies. Local expertise shapes the product, which also means that in later stages (e.g. in the case of malfunction of the product) the required expertise can be found locally. Here again, distributed skills and distributed design (Santos et al., 2019) increases the chance of creating longer lasting products.

Assembling the product in the company is a prevalent characteristic. It offers the opportunity to upgrade the product components, replace a component and repair the product. However, this direction leads the companies towards providing centralised repair and replacement systems. The repair and assembly knowledge is accumulated in the company, and documentation of the process is not available to the user (e.g. they state that it is easy to repair the product if one knows how.) These companies state that they are willing to repair the product as long as they exist; however, since they are economically fragile the company itself may not endure. Therefore, repair and service responsibilities of these companies should be decentralised and distributed as well. To support the process, companies might consider making documents regarding product repair openly available. Further, they could collaborate with larger component suppliers to support the need for part replacement.

Local actors such as craftspeople, artists, engineers, or material suppliers can be strengthened by enabling co-creation of the product. At the same time a local economy is thus created around products. As a significant intermediary, the local incubator can have a critical role in enabling collaboration among these local experts. Furthermore, small-scale companies must participate in governmental disposal and recycling systems. They do not have the ability to handle their own production waste independently. In this case, use of natural materials such as wood and clay decrease the environmental harm and provides an advantage for these companies.

5.2 Product design

We observe that most of the products of the companies presented here have a high price tag. These alternative longer lasting and sustainable products seem possible in the high price range, which is not in line with making longer lasting products and sustainable products available for medium and lower income groups. We can see that Company B managed to overcome this to a certain degree through local subscription methods by using a convenient transportation system (e.g. letter post) and a modular product, allowing them to offer their product at a comparable price point. Similar approaches can be implemented for speakers, but unfortunately it is not promising for earphones due to hygiene concerns and product size.

Products could provide aesthetic value and hardware capacity at the same time, which increases the price tag drastically; therefore, potential renting or subscription models are promising. As an example of the aesthetic characteristics of the product that is designed for a subscription model, company B highlighted they aimed to keep balance between a D.I.Y aesthetic and a 'technological' appearance. It can be seen as an example of "system aesthetic" (Ceschin et al., 2010) which knits together different elements of the product, system and service (e.g., the replacement of the parts). Company A prefers to present certain distinct aesthetic characteristics since their product aims to reflect the aesthetic taste of specific cultures, which increases the emotional value of the product (e.g. people from that country may see the product as a representation of their country). Similarly, company C collaborates with local artists to have an artwork on the product which diversifies the aesthetic taste and gives an opportunity for creativity. This helps designers to move beyond a mass customisation aesthetic and makes it possible to explore aesthetic preferences. As a future design direction, it is possible to further diverge from mass production material culture by taking advantage of material surface imperfections through inherent material properties, production effects, and everyday wear and tear (Pedgley et al., 2018).

5.3 Designers

In these companies' designers have different roles, limitations and opportunities compared to large-scale companies. In most of the study cases the designer of the product is also responsible for production, assembly, and repair of the product, including the selection and sourcing of the hardware and components. Furthermore, the designers are the actors who can make strategic decisions related to longevity and sustainability. Their personal and company values emphasise sustainability as a "mindset" and design driver, to create longer lasting or sustainable products. Most interviewees highlighted that their education has played a significant role in shaping their mindset. Furthermore, funding that has been provided for more sustainable start-ups has also played a critical role. The designers have control over the design decisions towards longevity, however they do not have enough budget that can compensate and materialise those decisions.

5.4 Users

A key characteristic of distributed manufacturing is the involvement of diverse stakeholders including end-users in cooperative and collaborative manufacturing, which enables e.g. production-on-demand and products that better align to user needs (Vezzoli et al., 2014; Srai et al., 2016). Moreover, inclusion of users in repair and maintenance activities is significant to extend the lifetime of the product since the user is seen as an active agent in current circular economy models (Bakker et al., 2021; Selvefor et al, 2018). Including the users and facilitating maintenance and repair (Terzioglu, 2021; Ackerman et al., 2018), exchange (Selvefor and Rexfeld, 2021) and disposal (Choi, 2018) activities distributes and decentralises the responsibility so as the possibility of extending lifetime of the product increases. Only one of the companies in this study, however, Company B, moved beyond including user feedback and conducted usability tests for replacements of the product parts considered. There is a clear need for inclusion of users if efficient product take-back system is desired. (Terzioglu, 2021) as well as extended lifespan of the product.

6 Conclusion

In order to enhance their potential to contribute to sustainable transformations, and also learn from their experiences, we conducted an inquiry into the design and production process behind connected products. While doing so, we examined particularly the small-scale companies that are already putting effort into creating longer lasting products. We present their current experiences and identify the main challenges that hold them back in their journey towards sustainable products. We present promising intervention points in response to the need for supporting small-scale sustainable technological product design.

The lifespan of products, especially smart electronics, depends on various entangled factors. In current society we need longer lasting connected products and designing them so that they can last longer is therefore a key responsibility for the design discipline that needs greater emphasis. Designing and manufacturing long lasting products requires knowledge, life extension strategies, ability to reorganise the organisational structure, and a specific mindset which is focused on producing long lasting products. However, in this paper we approach the problem by seeing longevity of the product as a phenomenon that is dependent on negotiation among various actors and requirements. Therefore, we examined the decision mechanism system and the impactful actors during the process of design and manufacture to inform product design practice and research.

Compared to large scale companies, small scale companies can be more flexible and apply different strategies and processes; they are therefore promising agents towards sustainable futures. At the same time, they are economically fragile. Therefore, decentralisation and distribution of some of the responsibility is needed to make sure the product will last.

In this study, the promising intervention points can be listed as follows:

- Local hardware production would increase companies' agility and autonomy.
- Enhanced designers` skills in making, assembling, and repairing the product empower them in sustainable production ecosystems as significant decision makers.
- Novel interactions among the actors in ecosystem, who share responsibility for repair, production of the product, knowledge transfer, and hardware sourcing, as well as

collaborate shaping the aesthetic of the product, also imply the benefit of novel intermediaries who support interactions and skill development.

- Novel interactions among the actors in ecosystem facilitate the longevity of the products, where actors share responsibility for repair, production of the product, knowledge transfer, and hardware sourcing, as well as collaborate shaping the aesthetic of the product. Therefore, we highlight the benefit of novel intermediaries who support interactions and skill development.

Overall, in capacity building in sustainable production, local manufacturing and local design will increase the design decision-making of small-scale companies to design longer lasting smart products and increase their resilience complexity.

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