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Second-degree frugal innovation in the Belgian healthcare system

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Abstract

The innovation space created by designers within healthcare is meant to empower users (e.g., nurses, patients and therapists). Due to the variety of users and systems involved, this is a complex task. Often products fall short or do not bring the empowerment they promise, eroding "our sense of independence" (McDonagh & Thomas, 2010, p. 182). In this context, the concepts of *frugal innovation* and *sustainability-as-flourishing* have been implemented. Specifically, we asked 10 design teams to redesign idiosyncratic *hacks* generated by local healthcare professionals with the goal of upscaling into marketable products-systems for flourishing, without losing the goodness of fit. Even though the process produced very interesting business ideas, that still would fit with the idea of frugal innovation (in terms of cost reduction and locality, for example), some tensions have been highlighted and discussed in the paper.

Keywords: Frugal Production; Frugal Innovation; Second-degree frugal innovation; Sustainability-as-flourishing; Hacks; Healthcare.

Introduction

The innovation space created by designers within healthcare is meant to empower users (e.g. nurses, patients and therapists) but due to the variety of users and systems involved, this is a complex task. Often products fall short or do not bring the empowerment they promise, eroding "our sense of independence" (McDonagh & Thomas, 2010, p. 182). In this context, we see two innovation pathway extremes. (1) The creation of unique products - sometimes *hacks* - deriving from a bottom up and inclusive approach, often connected with open-source licenses, the maker movement and aligning to the "bare minimum" needed by the users (De Couvreur & Goossens, 2011). These solutions can be seen as the *perfect fit* for one user-context, but they remain limited in volume and accessibility to other users. (2) The creation of industrial, mass-produced and *universal* designs. Here, the potentially large target group and high volume of pieces to be produced puts pressure on industries which results in an erosion of the primary goal of product *fit*, with an alignment to the average *one-size-fits-all*, which might not perfectly fit anyone (Nelson & Stolterman, 2012; Braun, 2002). Even though these bottom-up (1) and top-down (2) dynamics cross paths sometimes, as is the example of the lead users' innovation (von Hippel, 1986), we still search for a

combined pathway that allows the production and distribution of solutions for healthcare and well-being that, firstly meant for one user-context, should not lose the *goodness of fit* when delivered to many.

As later described, the concepts of *frugal innovation* and *sustainability-as-flourishing* might provide some insights from a practice-based design perspective. Specifically, we explore how to upscale idiosyncratic *hacks* generated by local healthcare professionals into marketable products-systems for flourishing, and what is the perception of this design pathway of the various stakeholders, starting from the designers themselves in this study. A sidetrack explores the potential roles of a tool for business modelling towards flourishing (flourishing business canvas) in this process when conducted in Belgium. The work done, at its first development stage, is later described with the help of empirical illustrations developed as a collaboration between two higher education institutions in Belgium (Howest and Ghent University).

Frugal Innovation and Sustainability-as-flourishing

Hossain (2018, p. 2) defines frugal innovation as "a resource scarce solution (i.e. product, service, process, or business model) that is designed and implemented despite financial, technological, material or other resource constraints, whereby the final outcome is significantly cheaper than competitive offerings (if available) and is good enough to meet the basic needs of customers who would otherwise remain un(der)served." Frugal Innovation can also be identified through three characteristics: (1) substantial *cost reduction*, (2) implementation of only the *core functionalities* and (3) the achievement of an *optimized performance level* (Weyrauch and Herstatt, 2016). In literature we find references to either Frugal Production or Frugal Innovation, where we perceive the first as the end-result of a process, the Frugal Innovation one. The link between a Frugal Innovation path as Sustainable Business Models innovation can be envisioned especially when it comes to sufficiency. Bocken et al. (2014) explicitly point out the strong link between frugal innovation and sufficiency, i.e., "encouraging consumers to make do with less" (p. 42).

Important studies about frugal innovation in the healthcare sector have been conducted, with a major focus of a FI process for the Bottom-of-the-Pyramid (BOP), developing markets and under scarcity consditions (Ramdorai, Herstatt, 2015)(Bianchi et al, 2017). In this paper, the focus lies in what has been defined a Second-degree frugal innovation, meant as a frugal innovation process taking place in developed markets and considered different from the one happening in developing markets (Winkler et al., 2019). In this sense, to explore how young designers and design agencies internalize the concept and pathway of frugal fnnovation seems to be relevant and aligning with previous propositions (Hossain, 2018).

A new construct in the sustainable model innovation research field is sustainability-as-flourishing. It requires a transformation of and new collective beliefs and values (Schaefer et al., 2015). As Schaefer et al. (2015) explain, sustainability-as-flourishing is an emergent outcome of a dynamic systems construct of a future state well beyond mere survival. Key ideas from sustainability-as-flourishing are that profit is a result rather than the purpose of a viable enterprise (Drucker, 1974). From this, we understand an effective learning and design practice towards different innovation and business modelling pathways that set designers, manufacturers, entrepreneurs on a path to actively strive to enable sustainability-as-flourishing, within the limitations of current system conditions, while simultaneously contributing to changing those conditions over time (CEL, 2017; Laszlo et al., 2012).

The Flourishing Business Canvas (FBC), is a business modelling tool aligned with sustainability-of-flourishing ideas and has its roots in the Strongly Sustainable Business Model Ontology presented by Upward and Jones (2016). It is "a collaborative visual design tool that, by providing a common language

for an organization's stakeholders, allows them to effectively work together to describe their enterprise's business model and imagine future preferred ones" (Elkington and Upward, 2016, p. 131). In particular, when it comes to frugal innovation, we expected that the questions contained in the FBC and related to biophysical stocks and ecosystems services might trigger students to go through the whole lifecycle of the product and consider carefully the resources their product would require and thus taking a more systemic perspective. We also expected that the process of answering the 16 questions can generate narratives of potential relationships as to how the business will function in the co-creation and co-destruction of systemic value with its key stakeholders and enterprise goals. These narratives are thus constructed by the questions prompting linkages between the firm's Perspectives (People, Value, Process) and the socio-ecological and socio-economic Contexts (Environment, Society, Economy) in which the firm will operate.

Methodology

To explore our question (how, from a practice-based design perspective, to upscale idiosyncratic *hacks* solutions generated by local healthcare professionals into marketable products-systems for flourishing), we conducted a 2-steps study based on a *research through design* approach. (D1) 35 cases of idiosyncratic solutions - also defined as *hacks* or *open user innovations* - for well-being have been developed by students of Industrial Product Design of Howest University College, Belgium. These cases focused on product development and have been co-designed with specific allied health professionals in 10 diverse local health organisations through medical *fablab* techniques (see Figure 1).

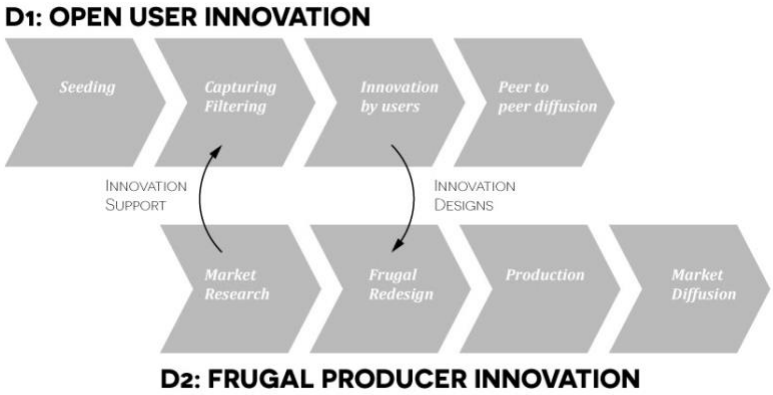


Figure 1. Framework of open user innovation (adapted from von Hippel, 2016).

(D2) The *hacks* have been submitted to 10 teams of students of Industrial Design Engineering of Ghent University, Belgium, becoming the starting point for the creation of marketable product-services defined as *frugal producer innovations*. These innovations have been generated starting with the focus on the core functionalities and their optimal performance level which, as described earlier, are typical characteristics of frugal production. Deliverables include a full business model description.
To support the students in this translation (from *open user innovations* to *frugal producer innovations*), the FBC has been adopted with the intention of providing a systemic view, on a BM-level, due to the fact that it brings into the experimentation process a normative and systems perspective that extends well beyond short-term financial viability that would enable a sustainable future as advocated by Bansal (2019). In other words, we expected to support students in translating product-oriented solutions for well-being into flourishing product-services-businesses. Additionally, the FBC has been previously used in

similar studies (Hoveskog et al., 2018; Karlsson et al., 2019; Karlsson et al., 2018; Ostuzzi & Hoveskog, 2020).

Three main data sets have been utilized in this first experimentation. (1) The design process of the 10 students teams that lead to frugal producer innovations; (2) a short survey to explore students' understanding of the frugal innovation process and (3) interviews with the design agencies that accompanied the students in their design process. In the following section we report on the main methodologies followed during the study.

1. Design process: from hacks to frugal producer innovations

The students have been asked to follow a specific design pathway, aimed at moving from *hacks* to *frugal innovations*. The first step consists in identifying the *core functionalities* of the given product.

To better explain our methodology, we analyze the design process of one specific case: the *daily oral hygiene storage box*. The starting design challenge phrased by the healthcare center itself is to "increase the independence and self-confidence of patients who cannot independently go to the bathroom for daily care. Design a mobile storage box so they can do their daily care in bed". In phase D1, design students developed a hack as first-aid solution for the end users.

Figure 2. Result of phase D1, the *hack*)

As shown in Figure 2, the hack consists of a simple self-made box with different departments. The hack is made by using a laser cutter and simple prints of figures to show the patients what device (e.g., toothbrush) should go where. If we look at the hack through the characteristics of a Frugal Production, the creation of a simple outcome that can be considered the *minimum viable product* needed to satisfy certain needs, we notice the hack could be improved concerning some core functionalities, as usability (e.g., some safety issues can be related to the sharp corners), ease of use (e.g., the device is hard to clean and is formed by several component, possibly hard to assemble).

In phase D2, by taking into account the frugal innovation characteristics (core functionalities, cost reduction and optimal performance level), students re-designed the hack into a product comprehensive of business model (Figures 3 and 4).

Figure 3. The redesign of the hack, now called "Fraai", the first product of the company "MENS"

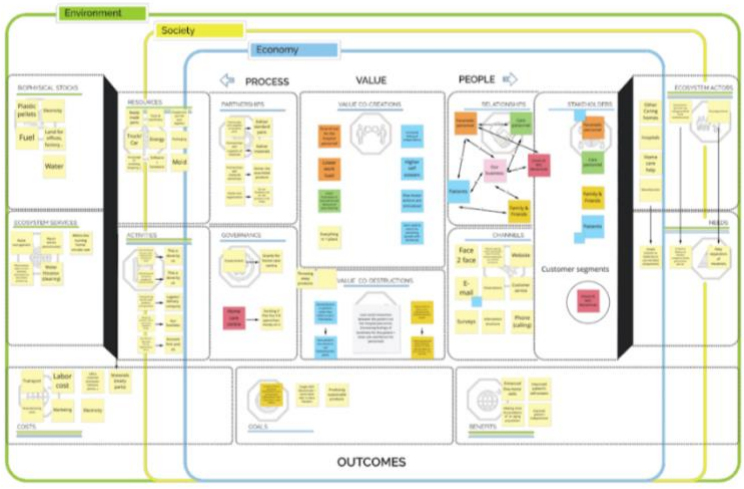


Figure 4. FBC as utilized in phase D2 of this experiment: to translate a hack into a BM, following the innovation paths of frugal innovations

To be more precise, the first step in the design pathway is to identify and analyse the fundamental criteria (at product-level) in order to understand what to focus to improve the existing hack and translate it into a frugal producer innovation (figure 5).

Figure 5. Students identified 5 fundamental criteria of the product to be brought to the market. They then evaluated them, in a radar view, by comparing their desired level (to be reached at the end of the course) with the received hack and an existing benchmark.

According to the students the hack did not reach what they see as the final *desired level* for any of the 5 identified fundamental criteria, as shown in Figure 5. This implies that, while the BM is designed, the hack should also be improved. This is due to the systemic relation between them, which asks to proceed in parallel while acknowledging the influence they have on each other (e.g., while aiming at bigger volume of production, a simplified design for assembly should be designed, which requires different assembly technologies to be implemented, which implies a higher price per piece, which in return does not align with the starting point idea of "minimum viable product" as represented by the hack). The following steps of the design pathway have mainly focused on asking the students to keep the desired level into consideration while taking any design choice, both on product and business model level. As mentioned, the main deliverable of the pathway was a product redesign, a business plan inclusive of financial, marketing and production plans.

As a result, in this case the students managed to keep the product extremely simple - simpler than the starting hack: it now builds upon many standard components (where before specific components were made through laser cutting), can start being produced at a low volume (and eventually be upscaled without a need for redesign), makes use of local facilities for production and assembly (see Figures 6 and 7), etc.

Figure 6. Comparison of the hack (left in the image) and the frugal producer innovation (middle in the image) in terms of simplifying and use of standard components. The third option (right in the image) is a possible upscales version, where again components are not standard. The image is an extract of the Business Plan developed by the students.

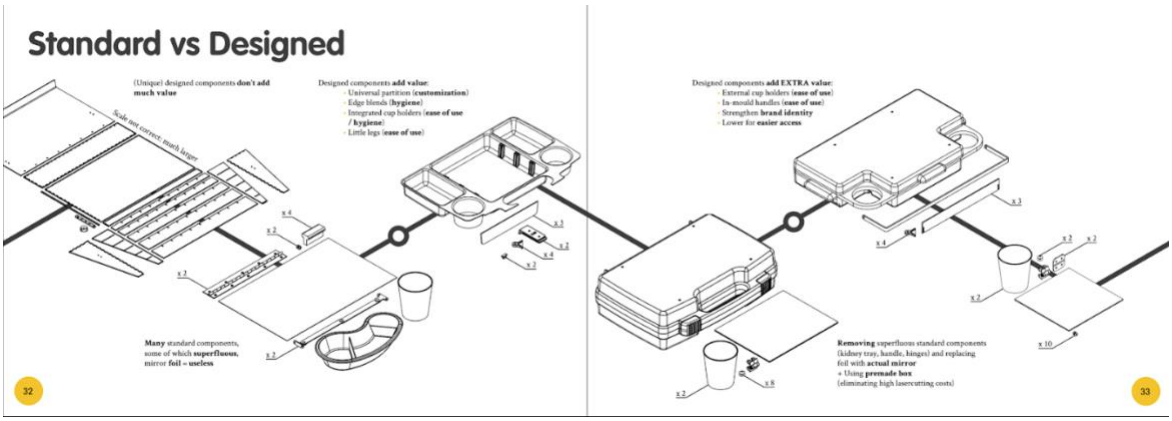


Figure 7. Comparison of the hack (left in the image) and the frugal producer innovation (right in the image) in terms of simplifying and use of standard components. The image is an extract of the Business Plan developed by the students.

2. Survey

At the end of the course students have been asked to anonymously fill in a survey about the design pathway they followed. Specifically, the main focus of the survey was to verify how students understand frugal innovation and in what ways they included it in their design process. The survey built on 19 questions, below we give a summarized overview of the most important one:

1. How would you describe frugal innovation?
2. In what ways did you design a frugal innovation?
3. Was the focus on the core functionalities useful? If so, in what ways?
4. How did you experience the use of the FMC (flourishing business model canvas)?
5. Would you design directed to frugal producer innovations in healthcare in the future?
6. Which production techniques did you implement while producing in a frugal way?
7. Did you envision changes in time of these techniques (due, for example, to bigger volumes of production)?

3. *Interview*

While in phase D1 healthcare centra supported the students, in phase D2 the students got support from local design agencies. In this trajectory five design agencies have been involved. After the trajectory took place, we conducted open interviews with two of them to gain insights on their perception of the frugal producer innovation in healthcare (a topic new to them too). Next to that we explored their willingness / perceived possibility to possibility to design in a frugal way in the future. The interviews were held at the end of the project, took place online and have been recorded. Field notes have also been used as supporting material.

Results

1. Design process: from hacks to frugal producer innovations

In Table 1 we see the exemplification of the design process followed in this study. Only one case is reported in the text, as illustration of the general process, while the rest of the cases can be found in **Annex 1.**

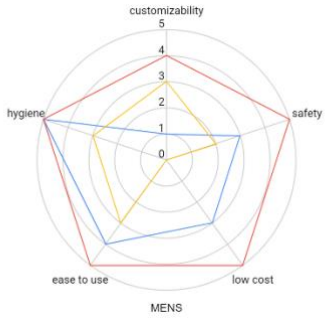
<table>
<tr><th>Hack or open user innovation (D1)</th><th>Core functionalities and their evaluation, as identified by the students</th><th>Frugal producer innovation (D2)</th></tr>
<tr><td>  </td><td> 
</td><td>  </td></tr>
<tr><td colspan="3">Description: A toolkit to facilitate independent oral hygiene for hospitalized patients</td></tr>
<tr><td colspan="3">Frugal implementation strategies:
• Assembly in sheltered workplaces
• Delete overdesign of hack: increase use of standard components compared to the hack
• Use standard box instead of producing a new box (cost reduction)
• Designed for disassembly (replace broken parts)
• Use of 3D printing (low cost for small series), print in place (no assembly)</td></tr>
</table>

Table 1. Overview of the frugal innovation process for one of the 10 cases. In the passage from 'hacks' to 'frugal innovations' students have been asked to explicitly focus on a set of core functionalities, which they used a direction to reach the final desired level.

Each team of students defined a set of core functionalities, based on the specific needs they derived from the design brief and interviews with stakeholders. They then plotted each criterion in a radar format in order to evaluate if the current hack answers to the identified core functionalities, and – if not - what the level they want to reach on each specific functionality (desired level). Next to that, one relevant benchmark was also plotted on the radar. The evaluation has been conducted in a qualitative and ordinal way. As can be seen in annex 1, none of the teams believe the received hack is reaching the desired level on all core functionalities. The students illustrate that the hack should be improved on multiple (product-) levels before it is reaching the expectations. Six teams do acknowledge that the hack is reaching the expectations for at least one characteristic. Interestingly for all 10 cases, no team considers the hack as already reaching the optimal level. Note that the hacks have been co-designed and thoroughly tested in phase D1. Considering this, it might seem that students assigned with a new challenge have the desire of

improving it, even when not explicitly needed, possibly only as mean of re-appropriation of the project itself (Ostuzzi et al., 2016; Ostuzzi et al., 2017).

When we compare the benchmarks with the desired level, we see two cases where the level of the benchmark exceeds the level of the hack on all criteria. This means that the teams consider the benchmark better suited (as it is closer to the desired level than the hack on all criteria) than the developed hack. We could ask ourselves if that means that the team did not validate the design of the hack itself.

2. Survey

A total of 26 (out of 40) students completed the online survey. Following, we report some extract of the students' answers.

Students describe frugal innovation (question 1) as "*to remain as local as possible*"; "*just the minimum, without compromising the design*"; "*a local innovation, not only thinking of our company, but also of the ethics surrounding the places where you outsource, for example*"; "*a way for a company to create an internal structure that takes the environment into account, for example by producing locally. However, this seems to me to be a side issue for companies in real life*"; "*The aim of frugal innovation is to reduce the complexity of a product and its production"; "less is more"; "making a functional design without unneeded designing or adding expensive or complex features.".* (Note: quotes have been translated from Dutch). From the analysis of these answers, few recurrent topics emerged: locality (mentioned by 10 students on 26), cost reduction (7 students), avoidance of overdesign (7 students), focus on core functionalities (11 students) and sustainability (5 students). Each of these topics is nevertheless still loosely defined, for example locality is interpreted in different ways, that span from "local production", to "local innovation" and "local economy". Future investigations might explore in depth the here listed emergent topics.

When asked in which ways (how) did they design in a frugal way (question 2), they mentioned *"by using as few and simple components as possible."; "by strongly reducing the number of components and creating a short chain production."; "by appropriating a hack or solution in another context."; "no unnecessary features were added to the product. It was asked to be able to fix the product properly and it was designed that way. It's as minimalistic as possible."* (Note: quotes have been translated from Dutch). Again, from a broader analysis, students again converged on certain themes, for example: simplifying the existing hack (mentioned by 15 students on 26), used standard components (4 students) and produced locally (7 students).

About the focus on the core functionality (question 3), 16 students out of 26 confirmed the focus helped them to explicitly identify and define the fundamental criteria before starting the redesign, 17 students declared the focus and visualization (radar) of the core functionalities helped them to communicate with the stakeholders and make sure everyone is onboard. Finally, 13 students confirmed that it helped them to compare the final design with the initial design criteria. As an answer to the question in which way the FMC supported the design traject (question 4), students mentioned it *"helped us to determine what to consider and to keep the overview in the design process"; "gave a clear overview of the different elements to consider"; "This helped us to get a good overview about all the things to consider. With the FBC we also have to think about the environmental aspects, this makes the business model a sustainable one: economic, social and ecological."; "made it easier to start the project".* (Note: quotes have been translated from Dutch). About designing in the future for frugal producer innovations (question 5), 1 student answered "*surely not*", 1 answered "*this is a difficult aspect, as not many companies (in my opinion) design*

their products and run their businesses in a frugal manner. These companies can easily contact foreign suppliers because they are cheaper and can do the job faster.". The remaining students (24 out of 26) answered "*yes*" providing sometimes different reasonings, for example "*yes, but not as a startup. Only if the company already exists, and the frugal innovation is applied to a new product.*" or "*yes, due to the lack of very innovative and low selling prices for these devices*''; "*I think consumers would be interested in frugal innovations, but I don't think it's realistic as a company to capitalize on this right away. I personally found it difficult to market a healthcare product without incurring large costs."*; "*Even though I personally find frugal innovation interesting, the economic aspect continues to have too important an influence (for example, an external person advised us to produce in China because it is cheaper). When production is done locally, the costs are usually higher than when production is done in inhumane conditions in a country (think of China), which automatically makes the selling price skyward. On the other hand, reducing the number of parts will also reduce costs, but this has a smaller impact than the production region.*". Overall, it seems interesting to note how the frugal innovation pathway, when applied in this context, while opening some opportunities it really challenges the dominant status-quo creating some interesting tensions, discussed in the next section.

Finally, on which kind of technologies did they use to reach frugal producer innovation (question 6) student enlisted: injection moulding as service from external companies (10 students), 3D printing (9 students), CNC machines (4 students) and metal folding (3 students). Other mentioned technologies are thermoforming, bending, metal punching, use of standard components. All technologies have been identified locally, since this was one of the demands of the design pathway.

3. Interview

The interviews with two different design agencies increased the perception of a possible tension between frugal innovation, commercial design and business development. They experience frugal innovation as redesigning an existing hack / customized solution designed for one specific person. According to them, Frugal Innovation is "*adapting existing solutions to the needs of the specific target group."*

Both believe in the concept of Frugal Innovation in developed markets but have difficulties to imagine this concept being implemented in their own organization. *"A good idea is a start, but when there is no budget, it is hard to continue the process. You need a man in the market".* "Frugal Innovation can exist next to other marketing strategies, but it has a completely different business plan. You need to be skilled to distinguish the specific cases that have the potential to be upscaled, do so and with the profit you make invest in smaller projects."

Discussion

Our analysis showed that the participants in this project had overall a positive attitude towards the development (second-degree) frugal innovations in practice. However, both the student work and the interviews with the design agencies showed that there is a major mind-set shift needed in order to fully realize the potentials of frugal innovations. This is in line with Tiwari et al (2016) who state that a major challenge is to motivate designers and other responsible stakeholders responsible for product development to embrace a frugal mind-set and design frugal processes. In our analysis, we observed friction between the "desired level of performance" or minimum viable product, and the level reached by the students, often with a tendency to overdesign. As stated by Tiwari et al. (2017) there is a tendency towards complexity and adding additional features that might not always be needed. Of course, it is hard to define a-priori the *desired level*, since it strongly relates to the specific context. One possibility, to be

explored in future studies, is to invite different actors (e.g., healthcare organisations, patients, designers) to translate their expectations for the *desired level* of performance (product- and business-wise) on a common language, as the radar shown in Figure 8. This resonates well with Tiwari et al. (2017) who emphasize the need for careful need-assessments in order to achieve competitive frugal design. In particular, in line with Tiwari et al. (2017), this conversational step could help the designers in: (1) conducting a "zero assessment" on the *desired level* of performance, (2) directing ideation and creativity, (3) testing to identify overdesigned features, (4) supporting communication throughout the whole design process.

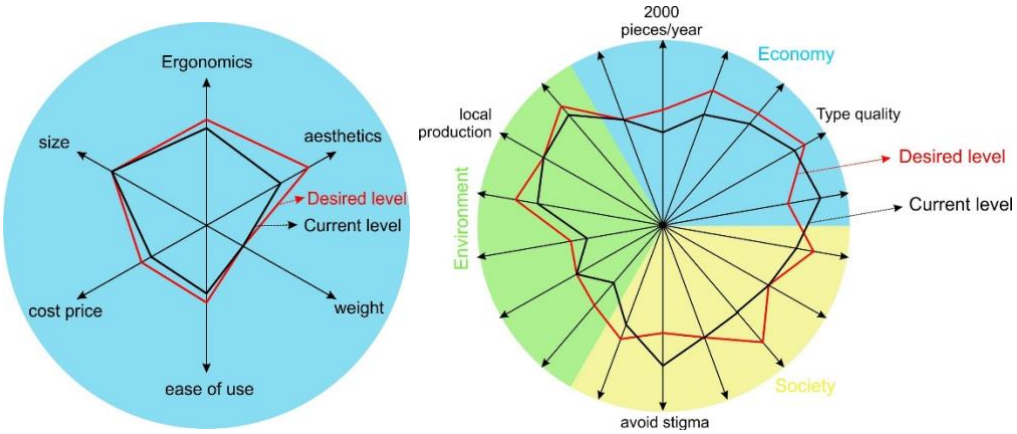


Figure 8. The radar diagram is proposed to work as common language between different actors of the innovation process. By communicating on the "desired level of performance" the minimum viable product can be identified and kept as reference by the designer. Furthermore, the radar should act on two levels: the product level and the business model one and include all costs (financial, environmental and social ones).

The second radar could be built upon the 16 questions used to move designers through the process of modelling a Flourishing Business story (Upwards and Jones, 2016). Nevertheless, a limitation of this visualisation can derive from the fact that in a radar plot all the variables represented on axes start from the same point and are considered having the same importance. We acknowledge that in reality this is not the case. Therefore, we consider the axis of the radar and their importance to be subject to discussion, between the different actors, during the design process. Furthermore, it is our intent to use the radar only for plotting ordinal distinctions, that can refer to a previous design - being a benchmark, a hack or an iteration on them - in order to define if the specific performance assessed is considered in *better* or *worse* alignment with what is defined as being the desired/sufficient level of performance or minimal viable product. Bocken and Short (2020) point out the difficulty in definition and agreement of right level of sufficiency (aka frugal) targets, which is also one of the challenges which students also experienced when using the radar, which - as previously mentioned - often was subject to a higher level of desired level to achieve, also when not seemly needed.

The use of the radar in combination with the FBC, especially in the context of frugal innovation, has a potential to trigger designers towards sufficiency-driven products and business models. This can for example, contribute to avoiding overdesign and complexity and (Bocken & Short, 2016, p. 42). Bocken et al. (2014) explicitly point out the strong link between frugal innovation and sufficiency. By adding the FBC in the process with its systemic-normative view, students are triggered to explicitly consider systems of environment, society and economy as part of their process which also help them to think in terms of

sufficiency and focusing on needs rather than promoting wants. Using the FBC, students create and experiment through artefacts and potential BM's as ways to synthesize and describe how the future business creates and captures value aligned with sustainability approaches. In the particular empirical illustration, described in this paper, we saw that students did include both social and environmental aspects in their development (i.e., MENS is producing in a local social working place; almost all components are standard in order to facilitate maintenance, reparation and to lower costs). This illustration aligns with what Bocken and Short (2016) highlight that a sufficiency-driven (aka frugal-aligned) business model would also require sustainable production methods and supply chains which allow a fair distribution of benefits across the stakeholders in the system including benefits for society and environment. Many of the students opted for local partners and circular approaches. Our research also confirmed the insights from Tiwari et al. (2017) who indicate that the existing business structures and practices are not really favoring frugal mind-set and solutions. This was clear from the interviews with the design agencies which did not see the frugal approach as suitable in the long run. Students also indicated that they got advices for setting the production in China as this is cheaper which also indicates the friction between the existing mind-sets and approaches and the frugal principles. It also showed that frugal is often equaled with simply being cheaper which is problematic as Tiwari et al. (2017) points out. In this sense, while the projects developed by the student engage with different levels of frugality (not only low financial cost, but for example locality, which could be seen as an attempt to reach lower environmental costs), it is true that students identified in the low (financial) cost of frugality a major barrier for a company to engage with it. Nevertheless, the topic of inclusion of social and environmental costs in this design pathway, as well as its combination between product and business model level, remains to be better understood.

Another important aspect that was indicated by our research is the importance of involvement of local partners. The work of Tiwari et al. (2017) advocates for the use of local partners when it comes to frugal innovations aimed at developing countries. However, our results also show that many of the students relied heavily on local partners and the ideas of locality when it comes to their hacks and in their business models. This aspect could also be linked with the adoption of digital manufacturing techniques (3DP and CNC) which allow for low volumes of production and higher variety in pieces produced. These technologies are highly accessible in Belgium, at a relatively low price. Only standard components have not been necessarily sourced locally.

Another observation from our results is that the FBC with its different building blocks which are grounded in natural and social science brings a multi-level, multi-disciplinary discussion to recognize the interconnection among natural and social systems which also reinforces the key ideas of frugal innovation, where key needs are met only with the essential resources required. This allows students to create potential systemic narratives and visualizations (artefacts) to show the impact of designing a minimum business value constellation that connects to people in the community, and all in a bio-ecology for whole system well-being.

While this paper indicates an interesting perspective on frugal innovation (and specifically a second-degree frugal innovation) and a set of tools that could trigger it early in the design process, the question still remains how far the customers, firms and institutions within the healthcare industry can be expected to adopt frugal product solutions and the related sufficiency, flourishing business models. Additionally, another legitimate question that requires further investigation is what kind of changes and wider reforms are needed to the economic system in order to transform the common mind-set which might hold back the willingness to adopt frugal and sufficiency approaches in the context of developed countries. Furthermore, more work is needed to expand this research and explore its applicability to other sectors.

Finally, further practical application and validation of this approach for developing frugal innovations and sufficiency business models is needed.

Acknowledgments

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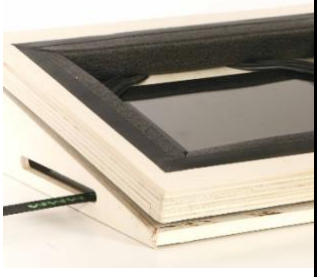
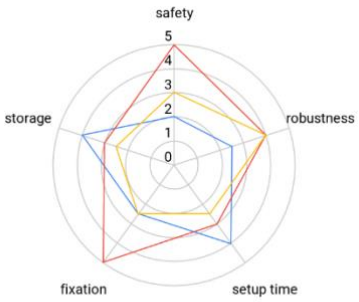
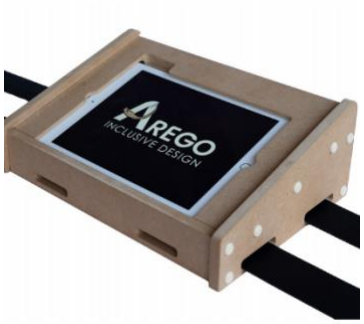
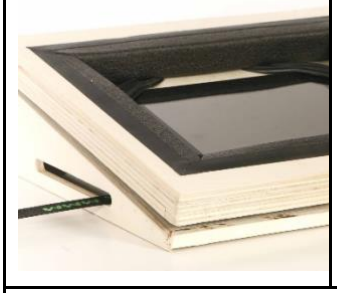
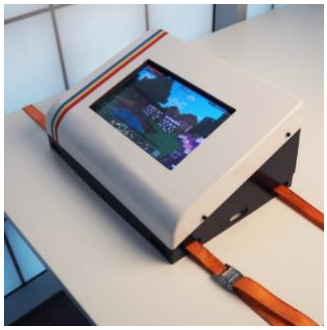
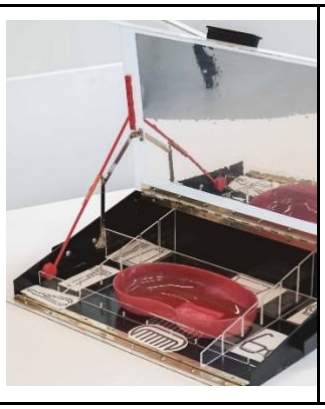
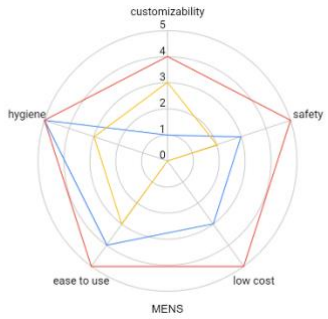
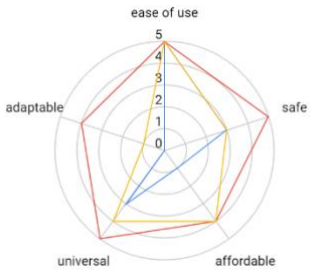
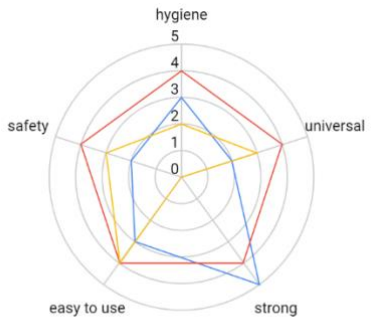
Annex 1

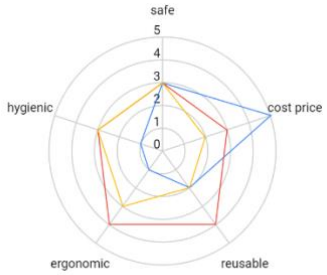
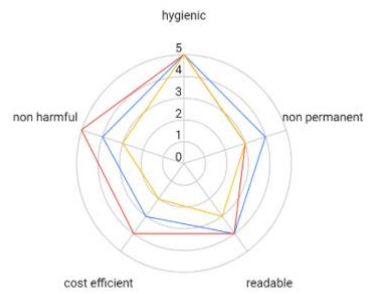
Num	Hack	Core functionalities and their evaluation, as identified by the students	Frugal innovation
1			

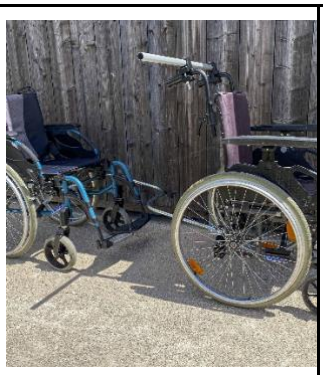
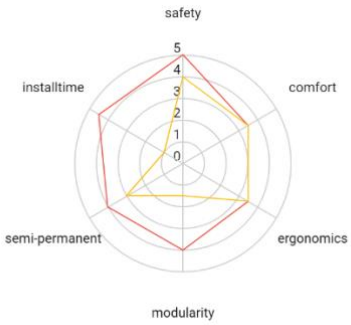
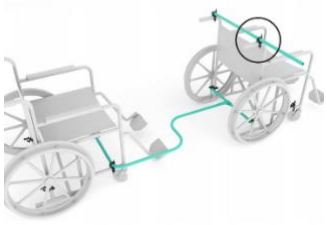
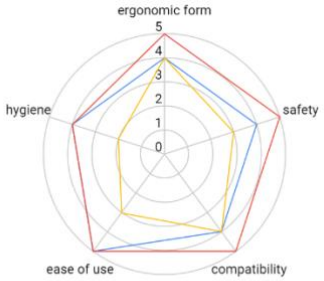
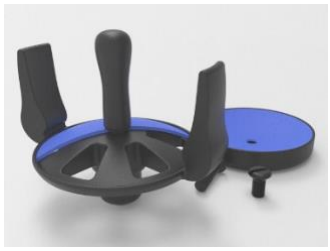
	Description: A tablet holder for people with a cognitive and physical impairments		
	Frugal implementation strategies: • "At Arego we innovate in a frugal way. This means that our TH2020 and future products are designed **without non-essential features** and are reduced to their absolute necessity without losing the optimal performance level." • "using high-quality **materials** that are **easily accessible**, like birch multiplex, no compromise is made in the durability of the products." • Use of standard components for screws, safety buckles, thread, toam tape etc • Production in local sheltered workplace		
9			
	Description: A tablet holder for people with a cognitive and physical impairments		
	Frugal implementation strategies: • Use of recyclable materials • Local production for main components		
2			
	Description: A toolkit to facilitate independent oral hygiene for hospitalised patients		
	Frugal implementation strategies: • Assembly in sheltered workplaces • Delete overdesign of hack: increase use of standard components compared to the hack • Use standard box instead of producing a new box (cost reduction) • Designed for disassembly (replace broken parts)		

<table>
<tr><td></td><td colspan="3">

- Use of 3D printing (low cost for small series), print in place (no assembly)

</td></tr>
<tr><td rowspan="3">3</td><td>  </td><td> 
</td><td>  </td></tr>
<tr><td colspan="3">Description: Electronic device that provides visual feedback that prevents freezing while walking</td></tr>
<tr><td colspan="3">Frugal implementation strategies:
• Repurposing of leftover material
• Simplify the product
• Local production
“We will also engage ourselves to design and innovate frugal. This is done by producing local, work with local suppliers, use frugal production
techniques and by setting an example for other businesses. Next to creating a strong local network we will focus on reducing the features of the product to its barebones. We do not want to overload the product with features that are not relevant and keep the product as simple and usable as possible. Boosting the local economy is another aspect we will play upon. We want to give people an opportunity to earn money and provide for themselves or their families.”</td></tr>
<tr><td rowspan="3">4</td><td>  </td><td> 
</td><td>  </td></tr>
<tr><td colspan="3">Description: A bag holder that connects the urine bag to an infusion pole, to increase freedom of walking of patients in the hospital.</td></tr>
</table>

	Frugal implementation strategies: • Mirror design: use the same component 2 times so only 1 mold is needed • Use of standard components • First series is 3D printed • Design for disassembly
7	  
	Description: A bag holder that connects the urine bag to an infusion pole, to increase freedom of walking of patients in the hospital.
	Frugal implementation strategies: • First focus on production for 1 supplier, then expand • 3D printing for small series • Use of standard components
5	  
	Description: A device that offers a temporary tattoo as substitution to traditional wrist bands used in hospitals.
	Frugal implementation strategies: • Simplicity of concept: print on skin: maximum reduce of waste • “Through the idea of frugal innovation, we hope to reduce waste drastically.” • Partnership with other company to eliminate own production • Optimizing the performance level concerning their 5 core functionalities: non harmful, hygienic, non-permanent, readable and cost-efficient

	• Future plan: design their own printer where over designed features of the existing printer are eliminated.
6	  
	Description: A connecting device, that enables one attendant to transport several wheelchairs at the same time.
	Frugal implementation strategies: • Use of standard components • Hack standard components (small adaptations) • Local production • Production on demand
8	  
	Description: A set of joystick handles for electric wheelchairs.
	Frugal implementation strategies: "Frugal innovation is an engineering and design principle we apply in our various use cases. The term refers to reducing a product's form and functionality to its bare essential aspects, leaving only the most important criteria that are most meaningful to the user, as well minimizing production and distribution complexity. We can use this minimalistic approach to design to greatly reduce costs, maximize essential performance, and improve sustainability. *Every big or small step towards sustainability is a step in the right direction!*"

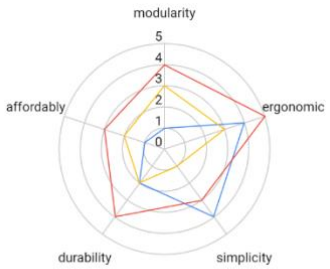
	• Decrease complexity of production and lower the costs • Simplifying existing hack towards more simple production • Use standard components instead of customised products • Local 3D printing, selection of PLA because of low environmental impact
10	  
	Description: A set of joystick handles for electric wheelchairs.
	Frugal implementation strategies: • Use of 'frugal production techniques' • "Keep the environment in mind" • Sell locally • 'Local suppliers' • 'Simple and straightforward design' • 'Focus on the core functionalities" • 3D printing

Table 2. Overview of the frugal innovation process. In the passage from 'hacks' to 'frugal innovations' students have been asked to explicitly focus on a set of core functionalities, which they used a direction to reach the final desired level.