Paper submitted to:

R&D Management Conference 2016 *"From Science to Society: Innovation and Value Creation"* 3-6 July 2016, Cambridge, UK

An integrated sustainable approach, based on peer production and collaborative product development, to deliver commercial products: an entrepreneurial opportunity

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Abstract:
The purpose of this research is to provide empirical support for the adoption of an integrated approach, based on collaborative product development and peer production combined with 3D printing, to deliver more sustainable, cheaper but competitive marketable products. In particular, the experimental study is conducted in the context of mobile forensics, an emerging market where few expensive incumbents' products are present and alternative solutions are needed. The technical viability and economic feasibility of the prototype, developed in this research, validate the proposed integrated approach. This could be a game changer in the mobile forensics as well as in other sectors, thereby offering start-up opportunities and promoting an innovative and sustainable methodology to develop and deliver marketable products, towards the paradigm of Open Sustainable Innovation. While the device developed and tested in this research has similar features to existing products, the methodology, implementation and motivation are original.

Keywords:
Peer production; collaborative product development; open innovation; 3D printing; sustainability; investment analysis.

1. Introduction

The recent trend of producing small quantities of custom designed, low cost finished goods comes from the model of mass customization, as postulated in the "think global and produce local" concept (Gershenfeld 2012). To better respond to this novel trend, an (i) open approach for hardware and software development, (ii) peer production and (iii) distributed 3D printing manufacturing are increasingly used (Parvin 2013; Wittbrodt et al. 2013).

The open innovation concept changed the traditional vertically integrated mode for internally developed outputs, to achieve a new paradigm of innovation based on collaborations among several participants involved in the final productions (Antikainen, Mäkipää, and Ahonen 2010; Carlsson et al. 2011; Enkel, Gassmann, and Chesbrough 2009; Helfat 2006; Chesbrough 2003; Schwerdtner et al. 2015; Michelino et al. 2015; Huizingh 2011; West et al. 2014; Dahlander, Frederiksen, and Rullani 2008). An open innovation approach is more effective with a detailed division of labor during the idea generation, R&D and production phases (West et al. 2014). This approach can be applied to the design of the product, the software development and the production layers, which are the pillars of the commons design economy (Moilanen 2012; Von Hippel 2005; Von Hippel 2010). The benefit is the possibility to use "crowd wisdom", created by social aggregations of individuals (Surowiecki 2005; Felin 2012; Garcia Martinez and Walton 2014). The collaboration of different researchers, to develop a final product, means that the distinction between manufacturer and customer is disappearing, thereby building new collaborative networks (Koch 2004; Vujovic and Ulhøi 2008). Actually, this cooperation is understood to be an effective mechanism to increase innovation efficiency and creativity (Antikainen, Mäkipää, and Ahonen 2010; Grimaldi, Cricelli, and Rogo 2012). In this vein, both hardware design and software development can be realized and continuously improved thanks to the work of researchers and online volunteers (Bonaccorsi and Rossi 2003).

Peer production is intended to be a collaborative activity, aimed at sharing productive goals (Benkler and Nissenbaum 2006). This productive methodology is based on self-organized communities, which easily interact, thanks to information technology advancements and cooperatively producing a final product. Towards this end, recent advances in 3D printing technology make the production of components possible with commercially available desktop 3D printers (Kostakis and Papachristou 2014). These 3D printers are able to fabricate goods with custom shapes and color (Espalin et al. 2014). Thus, people can collaborate online, not only for product design, but also to determine the final product specifications for the fabrication process. Collaborative product development and peer production, powered by 3D printing technology are transforming traditional manufacturing methods towards a "third industrial revolution" (Berman 2012). Actually, customization, at low costs for everyone, is enabled by the adoption of these methodologies, and will provide enormous value to the "commons" (Pearce 2015). This practice also provides a more sustainable, i.e. less harmful for the planet, production and distribution (Gershenfeld 2012); the product design is developed internationally, while printed locally. Therefore, transportation, inventory costs, time, wasted materials and energy costs are almost non-existent or are significantly reduced. This is because only the essential raw materials are used locally (Nozick and Turnquist 2001). More specifically, 3D printing allows for the design and fabrication of a product directly from a computer connected to a printer, by following a series of steps. First, the design is developed by mean of a

Computer Aided Design (CAD) 3D model; subsequently, it is converted to a Standard Triangulation Language (STL) format. The file is then transferred to a prototyping system, generally referred to as Computer Aided Manufacturing (CAM), where the structure is divided into layers. Finally, it is sent for fabrication to a desktop 3D printer. This profound shift in manufacturing, from remote factories to local 3D printing, is not only economically and environmentally viable but may also enable new capabilities in customization. Additionally, 3D printing can unlock "latent entrepreneurship" as new opportunities are emerging for ambitious entrepreneurs to bypass barriers to enter in the market, which includes an initial capital investment, mass production requirements, prototyping costs, and distribution organization (Wohlers 2014). Today, 3D printing can be used for both prototyping and for general manufacturing. Reports indicate that the annual sales growth rate for the 3D printer manufacturing increased 24% in 2010. Moreover, 20% of that production were real products and not prototypes (Wohlers 2014). Therefore, the approach described herein is sustainable, as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [26], thereby exploiting open innovation and peer production towards the achievement of the Open Sustainable Innovation (OSI) (Arcese et al. 2014).

A literature review shows that the economic and technical feasibility of an integrated approach, based on OSI for peer production with 3D printing in a competitive market has not been studied yet. To address this need we empirically tested this integrated approach by developing a prototype, called *CellIntel*, to be used by professional mobile forensics examiners. This hardware tool is used to forensically extract both system and user files from the mobile device of a criminal suspect or victim. This device would compete with market competitors and offer entrepreneurial opportunities. Thus, the aim of these research is to demonstrate how, in the case study of mobile forensics, the use of peer production and collaborative design approaches permit to obtain a product that is cheaper, more accessible, more sustainable and economically viable for a start-up company.

This research paper is structured as follows. In Section II, we introduce the field in which we tested the product development and its operating environment. In Section III, we provide an overview of the developed prototype, with details about collaborative development, peer production and 3D fabrication techniques. Section IV provides an economic analysis of the product's feasibility. In Section V, we report field-testing results for the prototype. Section VI details the limitations of the research and, finally, Section VII addresses final thoughts and conclusions about the research and possible future developments.

2. Mobile forensics: state of the art

The last twenty years have experienced exponential growth in mobile communications, and the number of mobile phone subscribers has been recently estimated to be in excess of five billion, with a notable increase in sales in developing countries (Arthur 2014; eMarketer 2014). Mobile technologies have become an integral and pervasive part of common life, thanks to the increasing power, functionality and capability to collect and share information on small size devices (Hayes 2015).

Unfortunately, the propensity for criminals to use mobile phones for their nefarious activities has also increased dramatically. Therefore, these devices have become even more valuable sources of evidence due to the incredible amount of information stored internally (Farjamfar et al. 2014).

Traditional computer crimes, including hacking and intrusions, are now invading the mobile world (Ghosh 2004). In particular, with the integration of highly developed communication features and with the increasing capacity in data storage and functionality, the distinction between mobile phones and personal computers has become blurred. For these reasons, the use of mobile forensics in private and public investigations, has increased (Hayes 2015). In recent years, researchers and practitioners alike understand the importance of mobile devices as a key source of digital evidence, which can be essential to the successful prosecution of criminals (Jang and Kwak 2015; Ferrara, De Meo, Catanese, et al. 2014; Ferrara, De Meo, Fiumara, et al. 2014).

This field of study is part of digital forensics, which has been defined as: "*The use of scientifically derived and proven methods toward the preservation, collection, validation, identification, analysis, interpretation, documentation and presentation of digital evidence derived from digital sources for the purpose of facilitating or furthering the reconstruction of events found to be criminal, or helping to anticipate unauthorized actions shown to be disruptive to planned operations*" (Palmer 2001). Mobile forensics includes forensic imaging, which is the creation of a bit-for-bit copy of a mobile device's memory during an investigation.

There are numerous investigative solutions, which are commercially available for mobile forensics, based on heterogeneous design criteria. Some of the most notable solutions include Paraben's Device Seizure (Paraben 2015), Oxygen Forensics Suite (Oxygen 2015) and Cellebrite's UFED (Cellebrite 2015), which extract data from digital devices. The initial price, subsequent maintenance costs, large dimensions and sizeable weight are common with all of these forensic technologies. Among them, the main competitor in terms of product maturity and market share is Cellebrite's UFED, offered for around $20,000 with approximately $3,000 to $4,000 in annual maintenance costs. Despite these high costs, the product can be found in several organizations. The unit is portable, but still heavy and cumbersome to be considered portable for professional activities. The limited selection of mobile forensics solutions means that prices are expected to remain high for the foreseeable future.

3. A new approach for product development

The possibility to develop and offer a state of the art device for mobile forensics, at a lower price and smaller dimension, is attractive. Offering a cheaper device is an objective not just for economic reasons to challenge existing competitors, but also to address the needs of private investigators and smaller institutions. In addition, an easy and fast production process will facilitate the worldwide distribution of these devices. Finally, to make field investigations easier, the device must be easy to use and portable. Therefore, in this study we sought to develop a mobile forensics toolbox with improved field usability and customer accessibility, which was economically feasible to startup a new venture.

In order to achieve these objectives, the following steps have been undertaken: (i) offering a new "open" approach to software development and hardware design, inviting other entities to collaborate with the researchers; (ii) developing a new way for production and assembly, i.e. peer production with 3D printing; (iii) allow more people to have access to these products by reducing costs; and, finally, (iv) designing a compact, hand portable device.

To accomplish these goals, we decided to select off-the-shelf electronic components, apply an open approach to product development and use a 3D printer for the production (Mertz 2013), thereby enabling peer production and open innovation. Therefore, the prototype described in this paper represents an example of OSI (Arcese et al. 2014), as it can be easily manufactured and assembled worldwide, which (i) eliminates the inventory, transportation and delivery costs, (ii) reduces the production costs and time and, finally, (iii) reduces pollutants emission by lowering energy consumption. This study serves to offer empirical evidence related to the successful implementation of this new integrated approach in the field of mobile forensics, which could be emulated by others and could represent a game-changer in other sectors.

3.1. *Hardware prototype*

In this section, the hardware design is described and electronic components listed, in order to get a comprehensive overview of the final product. The prototype, developed for commercial usage, is an electronic portable device used to acquire and store forensic evidence. The device can image both Android and iOS devices, thereby covering the 95% of United States market share and 90% of European Economic Community market share (Kantar 2015). An open approach is used for both hardware and software components, in order to involve external entities in the product development (Bonaccorsi and Rossi 2003).

The components used are readily available in the market, while the external case of the imager was produced with a 3D printer to achieve our objective of creating a low cost, peer produced device. In the following subsections, the prototype components are described, although the in depth details were not disclosed as the aim of this research is to provide evidence of the possibility to enter the market with this new approach and, therefore, we are looking to effectively start up and sell the product in the near future.

3.1.1. Prototype electronics

The electronic parts are housed in the casing, produced with the 3D printing methodology. To keep costs low, the device is built using off-the-shelf components that are cheap and easily available. The average prices of the electronics components are listed in Table 1.

Table 1. Costs for the 3D printed casing components for the *CellIntel* prototype.

Components	Mass	Production time	Cost
Electronic box	17 g	4h, 12 m	$ 3.40
LCD Screen box	21.8 g	2h, 38m	$ 2.56
Top of the box	16.4 g	2h, 10m	$ 2.14
TOTAL	55.2 g	9h	$ 8.1

3.1.2. Case design and realization

The imaging device was designed while having several key characteristics in mind for the final product, which are (i) low cost; (ii) touch screen; (iii) smaller than competitors; (iv) lighter than competitors; (v) easy to assemble; (vi) ability to connect to different mobile devices; and (vii) manually assembled.

The decision to use 3D printing technology to produce the device allows a minimal initial investment for the production equipment, low unit cost, and custom design.

The project started with the acquisition of two desktop 3D printers, which not excessively expensive; these generally cost in the region of $3,000 to $10,000. As the precision and the surface finishing of a 3D printer increase, the price rises too, but for the project’s needs, the above mentioned price range is workable. The design of the casing was produced using 3D CAD (Figure 1).

Figure 1. CAD rendering of the *CellIntel* prototype connected to a mobile device.

Given the peer production methodology, screws and bolts are avoided and the assembly of the different parts is planned to be done with manual interlocking, by applying a small force. The prototype case consists of three parts: (i) a case to house electronic components and batteries, with openings designed specifically for connectors and a board; (ii) the second 3D printed part is mounted on top of the previous part and it is used to house the LDC; and (iii) the third part locks the screen in place.

The desktop software Solidworks (release 2013, Dassault Systems) created the file used by the 3D printer. The software was also able to provide information regarding the price and the timing to complete each unit. In Table 2, the specific cost for each component is listed. The casing material is acrylonitrile butadiene styrene (ABS), a thermoplastic polymer used for the production of 3D objects, and the printer used for the first casing was a low-cost device, costing $3,000 (Makerbot Replicator 5th, US). For the second casing prototype, a second more expensive ($10,000) commercial 3D printer (S250 Tiertime, China) was used. This printer system uses the fuse deposition modeling (FDM) (Stratasys 2015), an additive manufacturing process that works by laying down the plastic filament in layers, unwound from a coil and hot-extruded (Masood 1996). The printing outputs are the same in terms of functionality between the two solutions, but the second printer provides a superior precision level and smoother surface finishing, which is more suitable for entering the market and for competing with the incumbents.

Table 2. Costs of the off the shelf electronic components.

Components	Cost
LCD screen	$56
SSD 2.5"	$86
Motherboard	$50
3D printed casing	$8.1
TOTAL	$200

3.2. Software prototype

The proposed novel device operates using a Debian Linux build operating system (kernel 3.4.90). An interface written in the Java programming language runs on top of the operating system, providing the user a simple one-click method to execute programs and scripts installed on the device, which automates the process of evidence acquisition. The choice of Linux as the operating system facilitates the open innovation approach also for the software side. The in-house developed software described here was developed by a community of volunteers working together with the researchers, a cooperation that facilitates the implementation of future updates. With the support derived from an open source software community, it is possible to create a collaborative group of experts working on the software updates for the mobile forensics device.

The starting point for the prototype's software was the software developed in-house, which would later be used to extract data from Android and iOS devices. Subsequently, external participants could contribute to software updates required for new smartphone releases. The user interface, developed with Java, was developed to be user-friendly for greater appeal and usage. It is designed with a touch screen interface, thereby making the device more user-friendly and more contained.

4. Economic analysis

The finished prototype demonstrated the feasibility of the proposed integrated approach, which included open innovation and 3D printed enhanced peer production, to deliver the same features of the main competitors. However, the objective of this research is not only the validation of a state-of-the-art mobile forensics imager device, but also to demonstrate its economic viability by offering it at a drastically lower price than competitors, while having a reasonable margin to start-up in the market. In order to assess the economic feasibility of this new product in the market, a Net Present Value (NPV) analysis is conducted (Remer and Nieto 1995). The inputs needed to perform a NPV analysis are: (i) duration of the project; (ii) free cash flows; (iii) cost of capital; and (iv) tax rate. In this work, the information used to calculate the free cash flow for each year of operation are: (i) revenues; (ii) costs of units sold; (iii) employees' wages; (iv) initial capital investment for the equipment and its (v) depreciation.

The usage of peer production implies the elimination of national and international transportation and delivery, which generally accounts for almost 10-15% of the overall costs (Nozick and Turnquist 2001). This is made possible by producing the final product with commercial parts readily available, a common desktop 3D printer that produces the components locally, and an easy manual assembly. The design of the hardware and software takes place online through the collaboration of loosely affiliated collaborators through open innovation approach, i.e. crowdsourcing (Howe 2006; Schemmann et al. 2016; Franzoni and Sauermann 2014). The production of the final product can be achieved by local branches worldwide.

In our testing, we developed a durable and resilient prototype with both the Makerbot printer (Makerbot 2015) and the S250 Tiertime printer (TierTime 2015), although differences in the surface finishing are noticeable and the latter one is preferred for the final production. The time required for the production of the mobile forensics imager is nine hours plus one hour for the final assembly. Therefore, with one 3D printer, each day it is possible to fabricate two finished products, and approximately 40 per month. The raw material for the 3D printer estimated cost amounts to $8, while the components costs are equal to $192, for a total cost of $200 for the final product. In this research, we proved that it is possible to sell the product for a much lower unit price than competitors' one, which is $999 instead of $10,000 on average. This price is significantly less than competitors' prices but it also allows a reasonable markup, which is the difference among revenues and costs, for start-upping a new venture.

Deciding to buy the most expensive 3D printer used for superior surface finishing ($10,000), we estimated that the break-even point of units sold with our suggested price, tells us for which amount of produced good sets the NPV equal to zero. The lifetime of the printer is supposed to be 3 years, which is a conservative span of time for the printer working full time considering that the warranty period offered in Europe for this product is equal to 2 years. Thus, the initial investment is equal to $10,000 with an annual straight-line depreciation of $3,333.

An appropriate cost of capital must be apportioned for the evaluation of the project with the NPV methodology, as postulated (Cappa, Facci, and Ubertini 2015; Zadeh et al. 2013). From the research (Damodaran 2012), we can estimate that the cost of capital for the computer service sector nowadays, updated to September 2015, in the USA, represents the biggest market to deploy our product, is equal to 7.64% and the tax rate is equal to 40%.

Performing a simulation makes it possible to assess the number of units to be produced and sold to reach the break-even point. In this case, without considering employee's wages and hypothesizing that the creators can run the project without remuneration, the break-even is reached by selling at least seven units per year. Thereby, to be profitable the company must be able to sell more units than that, and from the eighth unit sold each year, the money will be available to generate remuneration for the software and hardware developers and, after that, profits for the company. In a second simulation, having a person working full time on this project and covering the production and distribution functions, earning a yearly salary of $50,000, the break-even point will instead be equal to 68 units (Table 3). Therefore, after the sale of 69th unit, the company will be able to generate profits. According to (Sedacca 2011), the 3-D printing is cost effective on production runs of 50 to 5,000 units, and our study confirms this result. This is a reasonable annual amount to be sold in the USA, or even worldwide, because the market size of this sector, although not publicly available, is exponentially expanding, considering that these devices can be used both by public and private law enforcement organizations. Moreover, a further lowering of the price will increase potential users and purchases, and the production approach allows scalability in reaching worldwide dispersed customers.

Table 3. Net present value analysis for the commercialization of *CellIntel*, in the hypothesis of waged employees (reported is the break-even condition).

Units	68			
Cost of capital	7.64%			
Taxes	40%			
Price	$999			
Cost	$200			
Year	0	1st	2nd	3rd
Revenues		$67,932	$6,7932	$67,932
Cost of unit sold		$(13,600)	$(13,600)	$(13,600)
Salary costs		$(50,000)	$(50,000)	$(50,000)
Depreciation		$(3,333.33)	$(3,333.33)	$(3,333.33)
Earnings Before taxes		$998.66	$998.66	$998.66
Taxes		$(399.33)	$(399.33)	$(399.33)
Depreciation added back		$3,333.33	$3,333.33	$3,333.33
Initial capital expenditure	($10,000)			
Free cash flow to operations	($10,000)	$3,932.53	$3,932.53	$3,932.53
Net Present Value	$200.71			

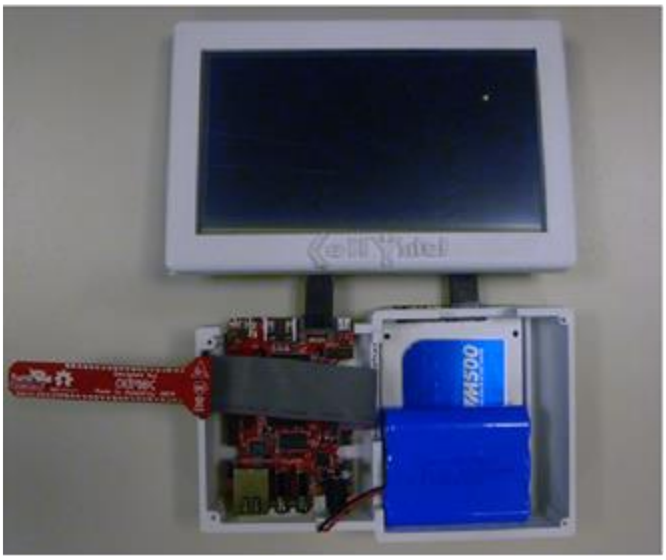
5. Empirical testing

The experimental testing performed was successful in producing the prototype with the above mentioned techniques, in terms of lower cost, same functionalities and improved usability. After a detailed design of the imaging device, developed by people collaborating worldwide, the *CellIntel* prototype was produced with a Stratatsys 3D printer and was manually assembled. The user interface was developed and installed on the mobile forensics imager (Figure 2), and the final product prototype was successfully tested in the field.

Figure 2. *CellIntel* prototype user interface during data extraction of a Samsung Galaxy S1 smartphone.

The assembled prototype reported in Figure 3, consisting of an in-house produced 3D printed case and commercially available components was manually assembled and was tested in the field.

Figure 3. *CellIntel* prototype's components during the manual assembly: LCD screen, 3D printed screen case, battery, SSD hard disk drive, printed circuit board, cables for connections among components and 3D printed base case.



Finally, data extractions performed with the prototype were successful on both Android and iOS devices for forensics investigations use (Figure 4).

Figure 4. *CellIntel* assembled prototype in function: touch screen user interface during the choice of the device to be imaged.

6. Limitations

With the above described integrated approach, we evaluated the economic and practical feasibility of a low cost mobile forensics device, which is able to enter successfully the market for general consumption. However, some limitations affect the here described prototype. Actually, the *CellIntel* prototype produced for this research cannot support all the cheaper phones, running niches and

obsolete mobile OS; this is a limitation that also characterizes other well-known mobile device imagers. Additionally, there is still no support for BlackBerry, Blackphones, , and Windows smartphones, which cannot be imaged using traditional methods (Willassen 2005; Chun and Park 2012; Grispos, Storer, and Glisson 2011).
Moreover, the community of researchers and students working on this project were appointed to maintain the device extraction capabilities with new software releases and to improve product's design. This must be tested to check if it proves to be a reliable solution in the long run.
Finally, as this study represents the first empirical evidence of the successful application of this integrated approach for marketable products, the effective implementation in other sectors is needed to increase the generalizability of the outcomes.

7. Conclusions

The results of this paper provide empirical evidence of the technical viability and economic feasibility of a product developed and produced for an integrated sustainable approach based on open innovation and peer production aided by 3D printing.
The open approach is applied to the design of hardware and software components, so that volunteers and entities on the Web can assist in the development and subsequent enhancements of the product. The prototype produced contributes to the literature postulating the benefits for companies brought about by OI (Chesbrough 2003; Dahlander and Piezunka 2014; Enkel, Gassmann, and Chesbrough 2009; Huizingh 2011; Garcia Martinez and Walton 2014; Raasch, Herstatt, and Balka 2009; West et al. 2014). Moreover, the economic feasibility of a new company operating in existing markets, using this approach, has been measured through the NPV methodology. In particular, we identified the units required to be sold annually to reach the break-even point. That number is very manageable considering the depth of this market, and thereby supports the competitiveness of the aforementioned approach described. In addition, the use of a 3D printer implies that the product could easily be reproduced domestically, with a peer production system. In this way, transportation and inventory costs are reduced, and subsequently prompting lower prices for customers and a decline in pollutant emissions (Nozick and Turnquist 2001). Our empirical results detailed in this paper demonstrates how a sustainable approach and an entrepreneurial opportunity can be accomplished, for a greener business (Seebode, Jeanrenaud, and Bessant 2012) towards the OSI paradigm (Arcese et al. 2014). The adoption of OSI allows firms to realize their economic objectives and sustainability goals, thereby benefiting all the stakeholders (Arcese, Lucchetti, and Merli 2013).
The prototype described in this paper is tested in the growing field of mobile forensics, in an effort to provide cheaper products for smaller law enforcement agencies, who are in need of a cost-effective, portable solution. We were able to offer a product, with the same features as competitors, but for a significantly lower price. Our formula allows a wider range of additional possible buyers and users, and represents a business opportunity that can be exploited successfully. Devices with similar features already exist, therefore, the contribution of this study is the implementation of a new approach, as methodology and motivation are original and innovative. The objective is not only to reply to the growing need of cheaper mobile forensics imaging devices, especially for smaller law enforcement

agencies and private investigators, but also to represent a test bed for the validation of this new integrated approach for new ventures that could represent a game-changing concept.

Further research will be focused on small batch production of devices and field-testing by practitioners in everyday life, to improve the design, the software and the hardware and to verify the robustness and the reliability of the forensics imager. Moreover, the benefits and startup possibilities described in this case study could be applied and tested in other existing sectors, as a new standard to deliver cheaper products in a more sustainable way, able to surpass the market incumbents.

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