Association for Information Systems

AIS Electronic Library (AISeL)

AMCIS 2020 Proceedings

Americas Conference on Information Systems (AMCIS)

August 2020

Bringing Life to Inanimate Objects: From Millenary Material to a Smart Product-Service System

João Barata
University of Coimbra, Centre for Informatics and Systems of the University of Coimbra, Department of Informatics Engineering, barata@dei.uc.pt

Paulo Rupino da Cunha
University of Coimbra, Centre for Informatics and Systems of the University of Coimbra, Department of Informatics Engineering, rupino@dei.uc.pt

Follow this and additional works at: https://aisel.aisnet.org/amcis2020

Recommended Citation

Barata, João and da Cunha, Paulo Rupino, "Bringing Life to Inanimate Objects: From Millenary Material to a Smart Product-Service System" (2020). *AMCIS 2020 Proceedings*. 9.
https://aisel.aisnet.org/amcis2020/org_transformation_is/org_transformation_is/9

This material is brought to you by the Americas Conference on Information Systems (AMCIS) at AIS Electronic Library (AISeL). It has been accepted for inclusion in AMCIS 2020 Proceedings by an authorized administrator of AIS Electronic Library (AISeL). For more information, please contact elibrary@aisnet.org.

Bringing Life to Inanimate Objects: From Millenary Material to a Smart Product-Service System

Completed Research

João Barata
University of Coimbra, Centre for Informatics and Systems of the University of Coimbra, Department of Informatics Engineering, Portugal
barata@dei.uc.pt

Paulo Rupino da Cunha
University of Coimbra, Centre for Informatics and Systems of the University of Coimbra, Department of Informatics Engineering, Portugal
rupino@dei.uc.pt

Abstract

Even the most unforeseen objects can be digitally transformed, requiring a tailored approach to each sector of the economy. This paper presents a year-long design science research to create a smart product-service system (SPSS) in the traditional industry of ceramic roof tiles. Our study describes the challenges of incorporating interactivity and data processing e-services into traditional materials for construction. This case also reveals the importance of multifaceted SPSS strategies to address the concerns of: (1) the end users; (2) the supply chain of the smart ecosystem; and (3) the producer, including the option to implement SPSS(aaS) as a service. To remain competitive, traditional industries must develop innovative strategies to gradually incorporate SPSS in their market offer. Nevertheless, the level of disruptiveness of the SPSS proposal depends on the synergies produced by the joint redesign of physical and digital materialities.

Keywords

Smart product-service system, smart home, product-service system, digital transformation, ceramics.

Introduction

A groundbreaking portfolio of symbiotic products and services is emerging with the integration of information technologies (Zheng et al. 2018). These "smarter" solutions open significant opportunities for agile startup companies but are also accessible to incumbents that need to integrate them into existing capabilities to remain leaders in their sectors or as a competitive weapon to reverse their decline (Bergek et al. 2013). A smart product-service system (SPSS) can be defined as an integrated offer of product and service "*that delivers value for the customers and product manufacturers*" (Chowdhury et al. 2018), "[carrying] *some of the characteristics of smart products, such as the capacity to transform data into knowledge*" (Valencia et al. 2015). SPSSs are gaining popularity with the advent of industry 4.0.

Shifting to a portfolio of smart product-service systems is challenging for traditional companies. For example, the small and medium-sized enterprises (SME) that produce ceramic roof tiles, that we address in this paper, are pressured by the emergence of alternative materials and value-added functionalities in building home covers such as solar panels and green roofs (partially or totally) covered with vegetation (Parizotto and Lamberts 2011). Disruptive innovations are critical in sectors of the economy that are threatened by competition and climate changes. Transformations, on the other hand, are complex and require adjustments at different levels of the organization, including the business model, market strategy, or supply chain integration (Pan et al. 2019). Several authors claimed for additional empirical studies that evaluate this complex transformation and adoption of technologies, for example, in the context of smart homes (Marikyan et al. 2019) and in the integrated digital-physical development (Hendler 2018).

Our work contributes to "smarter," digitalized, and integrated product-service systems in the fast-changing sector of building construction. The overall research objective is to design a smart ceramic roof tile, able to compete in the market of multifunctional roofing materials. Moreover, we discuss the implications of transforming a millenary ceramic product into "*an IT-driven value co-creation business strategy consisting of various stakeholders as the players, intelligent systems as the infrastructure, smart, connected products as the media and tools, and their generated e-services as the key values delivered that continuously strives to meet individual customer needs in a sustainable manner*" (Zheng et al. 2018).

This paper follows the structure suggested by Gregor and Hevner (2013). Hence, the next section revises important concepts for our case company, focusing on the smartness of products and services in construction. The description of the use of design science research follows. Subsequently, the design, development, and evaluation phases are presented. The discussion includes the lessons learned in the SPSS design and in the strategic assessment of the results in the wider context of smart building supply chains. Our paper closes by stating the study limitations, implications, and avenues for future research.

Literature Review

Smart products are "boundary objects" that enable smart services and smart service systems, providing added value to its consumers and providers (Beverungen et al. 2019). When both, the "object" and the service are integrated into a single solution in the market, the smart product-service systems appear (Valencia et al. 2015). The three following sections portray the "*transformation from the product dominant logic of business to product-service bundles constituted by machines and related services*" (Chowdhury et al. 2018). The fourth subsection provides the background for the ceramic roof tile sector.

Products are Getting Smarter

A smart product has three main interacting parts that current organizations must master: physical, smart (e.g., sensors and software), and connectivity (e.g., antennae and protocols), enabling the communication between the product and its cloud (Porter and Heppelmann 2015). The work presented by Novales et al. (2016) extends this vision by introducing the concept of "*'hybridity' (i.e., the combination of digital and physical components),* (…) *digitized product-service bundles (servitization of digitized products), and digitized product ecosystems* [i.e., networks of actors that need to interact]", each one posing particular challenges to managers. Companies have started to incorporate sensors and use cloud infrastructures to improve product biographies (Spring and Araujo 2017), and the Internet-of-Things (IoT) is one of the main responsible for the phenomena, affecting many industries worldwide (Shim et al. 2019). Buildings, cars, airplanes, watches, or washing machines are just a few examples of products that are becoming smarter. The range of parameters that can be "sensed" in the more advanced products is vast, including location, state (e.g., on/off), temperature, motion, faults, and various other operating-related information.

Products are not only becoming smarter and interconnected but are also transforming companies in their business processes and market offers (Porter and Heppelmann 2015). The innovations enabled by smart products are essential to compete, and can assist with many societal concerns, for example, human health and safety (e.g., collecting biosignals), or sustainability (Shim et al. 2019). Moreover, the incorporation of new elements, such as sensors in physical objects can leverage added-value services.

Smart Services are Producing New Interactions

A service becomes smart when it is delivered via an intelligent object capable of sensing its conditions and its environment, enabling companies to improve it and provide personalized features to the customer (Beverungen et al. 2019; Wuenderlich et al. 2015). According to Beverungen et al. (2019), the consumers of the service "*use, network, monitor, and autonomously adapt smart products in the service system's front stage, while service providers aggregate and analyze longitudinal data to optimize and control remotely* [the smart products]". These authors present examples of smart services enacted by smart products, for example, predictive maintenance, optimization of energy consumption, car sharing, or quality assurance.

The level of service smartness can vary, for example, Boukhris and Fritzsche (2019) identify five dimensions: (1) richness of the data, (2) knowledge intensiveness of the engine for decision support, (3) level of sophistication of the outcome delivered to the service users, (4) architecture of the stakeholders, and (5) automation level of the service processes. The first dimension (richness) depends on the type of data collected (e.g., status, use, or environmental data), while knowledge intensiveness can vary from mere monitoring to system optimization. The third dimension classifies the value propositions, while the last two are of a social nature – interactions in the network and human intervention. Tuning the level of service smartness is a difficult task, requiring additional research, for example, aiming at "*simple appliances to provide smart service for smart living or smart healthcare*" (Beverungen et al. 2019).

Finding More than the Sum of the Parts: Smart Product-Service Systems

The combination of sensing technologies, smart systems, and sustainability is at the top of industry priorities to create a new generation of products (Miranda et al. 2017). There are particular aspects that deserve attention in their increasingly complex design, namely, the interaction with other products or humans, the multidisciplinary nature of their development, and the need to consider the opportunities to innovate in the entire product lifecycle (Miranda et al. 2017; Zheng, Chen, et al. 2019). The new layered architecture required by smart products demands new organizational strategies and structures to deal with innovation (Yoo 2010). Moreover, the design of integrated smart product-service systems requires new design approaches that take advantage of digital twins to connect the physical and the cyberspace (Zheng et al. 2018). The sequence of steps usually starts with the project preparation and customer analysis, idea generation and selection, design, prototyping, implementation, and evaluation (Clayton et al. 2012).

It is not easy to convert traditional industries into product-service providers (Claes and Martinez 2010). New competencies, strategic alignment between the product and the service offering, supplier relations, or internal process capabilities are examples of challenges faced by managers in these cases. The challenges are particularly relevant for SMEs, but this type of organizations play an essential role in the development of new products or in the "*smartification of an already existing product*," as stated by Hicking et al. (2018), who identified the possibility of offering a smart product as a service. The integration of smart products in service systems "*leads to technology-mediated interactions, continuous interactions, and routinized interactions*" (Beverungen et al. 2019) between customers and providers.

Smart Buildings Using Millenarian Materials: Myth or Reality?

The main functionality for traditional roof tiles is straightforward: to protect the construction from natural elements, such as rain or snow. Local materials such as ceramics and slate have been used for millennia with the purpose of covering buildings. More recently, two main trends have emerged in this sector, with impact in the ceramic roof tile industry, namely, green roofs and photovoltaic shingles (Parizotto and Lamberts 2011). In both cases, the impact on the ceramic sector is the same: a gradual replacement of traditional roof tiles by other materials and accessories (Parizotto and Lamberts 2011) with added value or innovative functionalities that address the current needs of consumers. Green concerns can be found in the increasing popularity of vertical farms, growing vegetation indoor with vertical stacked layers (Despommier 2013), or in the emergence of farmscrapers where the vegetation becomes the coating of the building.

The entire construction sector is being affected by sustainability, construction 4.0, and the holistic concept of smart homes. Examples of the latter are vast, combining smart products (e.g., for energy management, as presented by Han and Lim (2010)) and smart services (e.g., to support aging, or improve comfort by adjusting temperature) (Marikyan et al. 2019). Some authors also point to the "*high possibility that companies across different industries might enter the smart home technology market,*" but research in smart home ecosystems is still scarce (Marikyan et al. 2019).

Remote home monitoring and control is a classic example that can take advantage of smartphones for interaction and sensors and actuators to control different systems in smart buildings, for example, for water control (Allmendinger and Lombreglia 2005; Boukhris and Fritzsche 2019). However, the typical use of digital services to "make something act," as happens in the control of water valves, is difficult to replicate in the case of objects that were not made to "do something". In fact, different parts of the building made with stone or bricks are an intrinsic part of the structure that usually do not need to move or "be activated".

In some companies, offering smarter systems that integrate physical and digital materialities is a matter of survival, for example, to compete with substitute products or startups with disruptive solutions. However, despite the significant research in smart products (Porter and Heppelmann 2015), smart services (Beverungen et al. 2019; Boukhris and Fritzsche 2019), and smart product-service systems (Novales et al. 2016; Valencia et al. 2015), we could not find cases of "smart" transformations applied to traditional products like ceramic roof tiles. Moreover, SPSS is a recent paradigm that still needs additional research for "*self-adaptiveness with sustainability, advanced IT infrastructure, human-centric perspectives, and circular lifecycle management*" (Zheng, Wang, et al. 2019).

Research Approach

Design science aims to create new artifacts and/or produce relevant design theory (Baskerville et al. 2018) to solve particular organizational problems (Hevner et al. 2004). Our study adopts the variant proposed by Peffers et al. (2007), which starts with the problem identification and motivation, the definition of the objectives, design and development, demonstration, evaluation, and communication of the research outcomes. We initiated the work presented in this paper in February 2019 in collaboration with a traditional ceramic roof tile producer founded in 1970. The case company has been seeing shrinking profits for several years, and they face intense competition from other construction solutions such as sandwich panels or rooftop gardens. Therefore, upgrading a traditional product offer with new technologies was crucial.

Their goal was to develop a "smart" ceramic roof tile to support indoor/outdoor vertical farms, aiming to address the need for modern buildings. On the one hand, they want to be prepared for near-future competition, with startup companies operating in green roofs and vertical farms. On the other hand, they also need to face current ceramic competitors and alternative materials for roofing. Interestingly, their present and expected competition are not driven by the integration of information technologies in the product, offering the captivating case of an incumbent disruptive transformation. Figure 1 presents an example of roof tile model (on the left) and a segment of the company production line (on the right).

Figure 1. Ceramic Roof Tile and Production Process

Ceramic tiles are appealing for consumers with environmental concerns that prefer natural raw materials.

The project started with an evaluation of recent advances in ceramics, innovative solutions in building covers, and a review of the literature about smart products/services/product-service systems. The top manager of the case organization presented three main restrictions to the research team: "*make the product smart, but do not change its identity* [e.g., shape, ceramic core]", "*take advantage of the installed production lines*", and "*make something unique, but economically feasible to introduce in the market*". The next section details how we proceeded.

Uncovering the Intelligence of Ceramic Roof Tiles

Design

According to the experts that cooperated with this project, ceramics have significant advantages when compared to other materials (e.g., synthetic), for example. It is a natural product, it is fire-resistant, it allows air renewal in the building, and it is price-competitive. If a single tile is damaged, it is not necessary to replace large parts of the roof. However, the functionality is restricted to the protection that it offers to the habitat (e.g., rain, wind). A smart roof tile should be able to extend its functionalities and provide added value services to different stakeholders. Yet, digital affordances of a ceramic roof tile are far from obvious.

A joint reflection was made by researchers and practitioners to evaluate the potential benefits of data processing and interaction in roof tiles. We considered the perspectives of three main stakeholders: producer, partners, and end-users. According to the producer's interest, a smart roof tile could collect data to evaluate potential problems in the roof. They provided an example: "*we have complaints about roof tile fractures, color change, water infiltrations or isolation and it is necessary to find the causes* (...) *a smart roof tile could collect data about the environment and the interior of the building, for example, the gap between internal and external temperature*". Architects interested in vertical farms and technology providers for smart home are potential partners for our case company. An advantage of making a ceramic roof tile "smart" when contrasting to other parts of the building is the location on top of the construction, which could allow for exploration of solar energy (e.g., to supply power to the smart roof tile) and for water sensing and capture. For architects, the visual impact of sensing equipment on the roof would be lower. For example, we could discretely incorporate in the roof tile a weather station that collects data for home use (e.g., incoming rain – "close your windows"; incoming sun and wind - "good conditions for drying clothes"). Curiously, the interest of the roof tile owners – end-users that typically drive the development of smart products to the market (Valencia et al. 2015) was not so obvious. The marketing experts said that end-customers had virtually no expectations about innovation in ceramic roof tiles. We concluded that the surprise could be a differentiation aspect in the market, including an interaction between the end-user and the data collected via smartphones (e.g., weather report).

The concept of green roof was a priority for this project, so smart roof tiles seemed promising. Eventually, a new solution based in ceramics could discourage the complete replacement by roof gardens (which is very appealing to architects): the smart roof tile should be able to assist external or internal gardens in walls or balconies. This type of structure needs water (that could be collected in the roof), automatic protection according to the characteristics of the plants (e.g., some of them need more sun or wind). The smart roof tile could benefit from temperature and humidity sensors, as well as water and luminosity. Moreover, the smart roof tile could be able to collect water and make it available to automatic watering systems.

Development

The prototype had physical and digital challenges. First, it was necessary to prepare the roof tile to incorporate the different IoT layers for sensing, processing, transmitting (e.g., Wi-Fi and GPRS module), and the power supply. The code implemented in Arduino Mega® is responsible for processing sensors data and alerts based on specific rules (e.g., gas detection). Communication is possible via GPRS or Wi-Fi connection and an SD card is also incorporated (to improve resilience in case of communication failure). Power can be supplied by batteries, solar panels, or direct access to the building power supply. At this stage of the project, we made no additional changes to the physical product, but there are plans to include a water storage and circulation system to supply vertical farms (in the external building walls) and roof vegetation supported by ceramic layers. We considered various use case scenarios for the smart roof tile:

- *Building owner (end-customer):* Combination of physical affordances for protection and e-services via messaging system, for example, weather report, noise profile during the day in the building surroundings. Monitoring remote or isolated buildings. Insurance negotiation, considering the added value information for building maintenance. Using the smart roof tile to automatically manage green roof vegetation, for example, smart distribution of water captured from rain (e.g., according to the level of the water deposit, the soil humidity, and the water needs of each type of vegetation), and for the activation of artificial light when natural light is below the threshold required by the plants. SPSS variant for elder care that detects fire/smoke or gas (e.g., carbon monoxide from traditional heating systems that, unfortunately, is still a cause of many fatalities);
- *Business Partner (smart home supplier or building contractor):* Support for smart equipment operation (e.g., regulation of air conditioning based on internal and external temperature; opening and closing windows based on rain, noise, and light sensors; vertical farm actuators, for example, opening and closing protections for sunlight or rain, depending on the vegetation, monitoring water supply depending on humidity, and providing rainwater captured by the cover systems). Open access to the smart roof tile data may capture the interest of more partners in the supply chain of smart homes;

- *Producer:* Competitive advantage with a new market offer, strengthening the incumbent position, in use cases such as the resolution of complaints, by installing the smart roof tile after a problem is detected to evaluate the cover over for few months; or data collection (if approved by the owner) for future product improvements. New digital twin interface that is useful to the marketing team (e.g., for product presentation), and to quality managers (e.g., for quality control of the product under operation and complaints management, by providing evidence of quality checking and improvement in quality audits). Incorporating green roof solutions in the portfolio is an opportunity for future work.

Figure 2 presents a variant of the main module and an example of on-demand message.

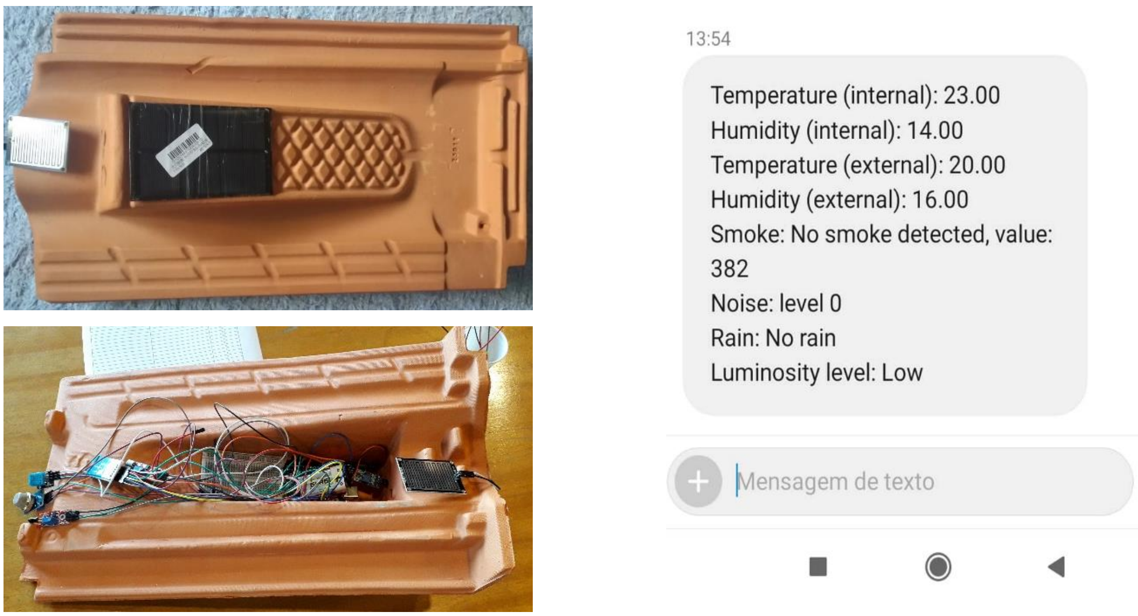

Figure 2. Smart Roof Tile Prototype and Interaction Example (SMS)

Figure 2 shows the interior of the product model and the technology adopted in this project (on the left). The external part of the roof tile (seen on the top-left) incorporates the solar panels and rain sensors. This prototype supports sensing internal and external temperature and humidity, gas (e.g., carbon monoxide on the interior), smoke (internal), and noise (internal and external). On the right, we show an example of short message to the user (e.g., light, rain, temperature, alarm status).

Two smart roof tile implementations are possible, namely, (1) permanently incorporated in the roof system or (2) as a service, when needed (for a specific period if the roof producer needs to evaluate specific conditions at the site). Having obtained the conceptual model of the smart roof tile and the initial prototype to deal with the different situations, understanding its strengths and weaknesses was required.

Evaluation

This section follows the recommendations of the FEDS framework (Venable et al. 2016) with a sequence of steps to "*(1) explicate the goals of the evaluation, (2) choose the evaluation strategy or strategies, (3) determine the properties to evaluate, and (4) design the individual evaluation episode(s)*".

The SPSS novelty and effectiveness are the two most relevant goals to evaluate by the company experts. It includes an object instantiation and is not a purely technical artifact because other social variables are present (e.g., partnerships, competition with alternative products, societal challenges). The selected evaluation strategies are (1) Human Risk and Effectiveness, and (2) Technical Risk & Effectiveness (Venable et al. 2016). It is a complex design, and there are uncertainties involved in this market, justifying the strategy selection. Moreover, the long period of the project enabled cooperation with different experts in ceramic production, promoting a deep reflection about the findings. The main properties of the artifact were the sensing parameters that could potentiate the added value to different stakeholders, the communication possibilities (local, wi-fi, smartphone, and SMS), the power supply, and the impact in the competitive scenario of this traditional organization.

According to the case company experts, it is not feasible to market the prototype with the full range of sensing capabilities, since the total cost would be 100x more that of a traditional ceramic roof tile. Therefore, variants were considered for (1) vertical farms (uses a less expensive electronics board that will need the temperature, humidity, light, and water-related data), (2) people safety (gas and smoke, fire, noise), and (3) smart home cooperation (most relevant sensors to cooperate with other parts of the building such as windows and air-conditioning). The parameters selected for our prototype instantiation were considered the most appropriate. Nevertheless, the adoption of higher quality (and reliable) components for fire detection, noise, or wind (complete weather station) will increase the final price of the system.

The company aims to adapt the marketing for each smart roof tile variant and then evaluate the need of other combinations. The complete version with all the functionalities will be available exclusively for the producer at this stage, aiming at (1) demonstration (e.g., the justification of renovating roof tiles in remote locations that could benefit from specific sensing capabilities to protect the building in case of disasters), (2) resolution of complaints, and (3) evaluation of the roof tile performance in specific climate conditions. Interestingly, the added-value services outweigh the extra cost of the physical product. In fact, the total cost of designing the SPSS was not so different from that of creating a new design for a traditional ceramic roof tile model. Although the process required the involvement of diverse experts and the development of equipment and software, it did not require certification nor expensive laboratorial tests. Moreover, several SPSS insights gathered during the research can be used in different designs of the product mix.

Increasing the “smartness” of this traditional product opened exciting opportunities to collaborate in the smart homes supply chain. For example, the development of a new model of roof tile that vertical farm producers can use in association with the green covers, thus making ceramics an integrated part of the Green Roof movement.

Discussion

It is possible to incorporate sensing, interaction, and sustainability functionalities in traditional ceramic products such as ceramic roof tiles. However, digital capabilities must be evaluated according to the current and (even more difficult) future needs of the supply chain. The most promising opportunities for business development in our case company are (1) the partnership with smart home providers (e.g., smart equipment, automatic energy control, window automation, mobile cover automation), and (2) taking advantage of the strategic location of the physical product (e.g., to evaluate environmental conditions, capture water, and control vertical farm structures – adjusting light and water exposure depending on the vegetation). The end-user will probably not select the smart roof tile if the benefit is merely to monitor some environmental parameters and provide SMS alerts. Therefore, SPSS variants and the “as a service” option may improve the success of SPPS in SMEs of traditional construction sectors.

The cost of the smart roof tile prototype was low, at around 70€. Since a typical roof tile will need two to four of these parts (expected to use one in each cover front), the cost of implementing the variants with a similar average cost seems reasonable for the target market niches. A specific electronics board for each SPSS variant instantiation (in our prototype, the microcontroller and sensors are not currently integrated into a single board) is also expected to improve the system reliability, reduce the size of the sensing and communication layer, and cut total cost. However, the price can still be too high when compared with the average cost for m^2 (10-20 USD, including 12/13 ceramic roof tiles). Therefore, an effective marketing strategy is necessary, involving smart home providers, architects, and building contractors.

The smartness of product-service systems has been studied with a focus on sustainability (Miranda et al. 2017; Zheng et al. 2018). Nevertheless, as we confirmed in this case, sustainable development functionalities can be strengthened if the SPSS provides a competitive advantage to the producer and generates new opportunities for partners of the smart ecosystem (Novales et al. 2016).

Below, we present a brief analysis, according to Porter (2008)'s five forces:

- *Rivalry Among Existing Competitors*: The smart roof tile is not comparable to any product existing in the local and international markets. The product can differentiate the company offer with an integrated system. The case company is a first-mover able to (1) create stronger partnerships, and (2) prepare their processes for the new product lines, slowing the followers' pace. Remarkably, the new smart roof tile can be exported at a larger scale when compared to the current situation: low unit price and high transport cost of ceramics poses severe limitations to export strategies;
- *Threat of New Entrants*: The smart product-service system requires partnerships with leading smart home producers to maximize the success of the approach. New entrants must compete with both natural materials (ceramic) and e-services. Moreover, contracts with architect offices and tech-companies operating in smart homes will be key to protect the incumbent investment. However, a first-mover can also change the spectrum of competitors. For example, the suppliers of green roof tiles and vertical farms may promote partnerships with local IT companies and ceramics producers, which is new to our case company and need to be followed closely;
- *Bargaining Power of Buyers*: The smart roof tile can improve brand image and increase the pressure made by end-users on building contractors (end-customers of our case company). Reducing the power of buyers is an advantage for first movers in SPSS for smart building;
- *Bargaining Power of Suppliers*: The smart solution requires new partnerships, increasing the power of suppliers. The company currently owns its sources of clay; therefore, the smartness of its products can raise new risks. Nevertheless, the companies with skills to produce electronics boards and the required technological layer are increasing. Moreover, the company has the possibility of creating a spinoff to explore smart solutions, integrating the system supply chain;
- *Threat of Substitute Products or Services*: Entering the green roof solutions is vital to address the trends in architecture and sustainable development. The smart roof tile can add value to vertical farms instead of being seen as an old-fashioned cover option. The cost of change will increase with an integrated solution that communicates with other smart objects in the building.

Digital transformation can revive traditional products based on physical affordances. Incumbents such as ceramic roof tile producers can explore the synergies of product-service systems with smart capabilities that simultaneously expand physical affordances while creating new digital ones. However, each sector of the economy has particularities that must be studied.

There are several factors that SMEs must be aware of in their SPSS transition. First, they should find an independent technological partner (e.g., university) to assist them in the internal development of SPSS competencies. Second, they must be prepared for delayed returns. SPSS may require multiple versions and configurations, and short term pilot projects may be difficult to evaluate due to lack of data to understand the benefits over time. Third, they should take inspiration from other sectors, but keeping an open mind about disruptive innovations is also advised. For example, vehicles can become smarter by adding new elements (e.g., sensors and computation) but do not require a drastic transformation in their structure. Similarly, only a few ceramic roof tiles need to be changed in an entire roof, but, unlike vehicle sensors, the "smarter ceramic roof tile" can be moved when necessary (e.g., for temporary evaluation of a specific roof). In our case, merely mirroring how vehicles are made smart would lead to missed opportunities with smart houses and green rooftiles. Companies must evaluate the possibility of creating surprising new needs. The most improbable product can use digital transformation to turn around a scenario of decline.

Conclusion

The technologies of the fourth industrial revolution have a significant impact on the product portfolio. This era can deliver an integrated offer of smarter products and services. However, sensing, smarter, interconnected, and sustainable systems (Miranda et al. 2017) must come with a strategic plan to explore the full potential of sociomaterial changes. Smart product-service systems are at the core of end-to-end digital integration promoted by industry 4.0.

This paper presents the results of a design science research project (Peffers et al. 2007; Venable et al. 2016) in a traditional ceramics roof tile producer, struggling to compete with a millenary product in an increasingly digitized world. They aimed to create a blend of physical and digital elements (Yoo 2010) to improve their market presence with a smart roof tile. The design of an innovative prototype made visible the value of data and configurable services for vertical farms, elderly protection, smart homes supply chain, and product quality and improvement.

For theory, our research contributes to the understanding of smart product-service systems in traditional sectors of the economy. This paper provides an example of designing smarter offers for the market that include social and dual materiality challenges (Novales et al. 2016; Yoo 2010). While most of the research in smart product-service systems focuses on the technical aspects of transformation (Zheng et al. 2018), our study shed light on the strategic and competitive forces, and in the societal challenges that can be addressed with smarter systems in buildings. For practice, this paper presents the design of a smart roof tile that explores multiple stakeholders' interests while preserving its physical identity. The deployment of smart service systems using boundary smart products (Beverungen et al. 2019) has the potential to produce synergies resulting from the physical characteristics and the digital functionalities in a combined product that may force deep reconfigurations of the market. Moreover, we present an example of a smart product-service system as a service: when the system deployment is useful for a specific timeframe and can be reused in multiple locations as happens in the process of complaint resolution.

There are limitations that must be stated, and there are also starting points to envision future research. First, the case company context and particularities of its product-service system. Although the transferability of the design can be considered for other inorganic-based products (e.g., glass, stone), it is necessary to create additional prototypes and evaluate the competitive forces. The sensing parameters, the need for connectivity, the sustainability concerns, and the added value to distinct stakeholders can vary. Second, although we obtained a new and inspiring version of a smart roof tile, an industrial version needs to be created, meaning a new integrated electronics board for each SPSS variant and eventual modifications in the roof tile structure. It will be necessary to evaluate the artifact in a longitudinal study, for example, the response to warnings in case of hazardous events or related to the usefulness of home-related tasks. Third, there are opportunities to develop new market partnerships and improve the image of this product in the market; however, at this stage of the research, we could not yet get feedback from other stakeholders (e.g., board producers and vertical farms designers in new or existing buildings). It is necessary to shift the focus of the company offer from ceramics materials to added value building covers made with physical and digital elements that cooperate for sustainability and human safety. Moreover, it will be interesting to evaluate how construction stakeholders see the integration of smartness in traditional products. Future work is necessary to ensure the reliability of these implementations that deal with human safety and can influence the performance of the entire building.

Acknowledgements

The authors would like to thank Victor Oliveira, Lina Gomes, and Fábio Rodrigues for their collaboration in this research. Co-funded by the European Regional Development Fund (ERDF).

REFERENCES

Allmendinger, G., and Lombreglia, R. 2005. "Four Strategies for the Age of Smart Services," Harvard Business Review (83:10).

Baskerville, R., Baiyere, A., Gregor, S., Hevner, A., and Rossi, M. 2018. "Design Science Research Contributions: Finding a Balance between Artifact and Theory," Journal of the Association for Information Systems (19:5), pp. 358–376.

Bergek, A., Berggren, C., Magnusson, T., and Hobday, M. 2013. "Technological Discontinuities and the Challenge for Incumbent Firms: Destruction, Disruption or Creative Accumulation?," Research Policy (42:6–7), pp. 1210–1224.

Beverungen, D., Müller, O., Matzner, M., Mendling, J., and vom Brocke, J. 2019. "Conceptualizing Smart Service Systems," Electronic Markets (29:1), pp. 7–18.

Boukhris, A., and Fritzsche, A. 2019. "What Is Smart About Services ? Breaking the Bond Between the Smart Product and the Service," ECIS 2019 Proceedings, pp. 1–16.

Chowdhury, S., Haftor, D., and Pashkevich, N. 2018. "Smart Product-Service Systems (Smart PSS) in Industrial Firms: A Literature Review," in Procedia CIRP, pp. 26–31.

Claes, B., and Martinez, V. 2010. "Challenges in Transforming Manufacturers into Product-Service Providers," Journal of Manufacturing Technology Management (21:4), pp. 449–469.
Clayton, R. J., Backhouse, C. J., and Dani, S. 2012. "Evaluating Existing Approaches to Product-Service System Design: A Comparison with Industrial Practice," Journal of Manufacturing Technology Management (23:3), pp. 272–298.
Despommier, D. 2013. "Farming up the City: The Rise of Urban Vertical Farms," Trends in Biotechnology (31:7), pp. 388–389.
Gregor, S., and Hevner, A. R. 2013. "Positioning and Presenting Design Science Research for Maximum Impact," MIS Quarterly (37:2), pp. 337–355.
Han, D. M., and Lim, J. H. 2010. "Design and Implementation of Smart Home Energy Management Systems Based on ZigBee," IEEE Transactions on Consumer Electronics (56:3), pp. 1417–1425.
Hendler, S. 2018. "Digital-Physical Product Development: A Qualitative Analysis," European Journal of Innovation Management (22:2).
Hevner, A. R., March, S. T., Park, J., and Ram, S. 2004. "Design Science in Information Systems Research," MIS Quarterly (28:1), pp. 75–105.
Hicking, J., Zeller, V., and Schuh, G. 2018. "Goal-Oriented Approach to Enable New Business Models for SME Using Smart Products," in PLM 2018, pp. 147–158.
Marikyan, D., Papagiannidis, S., and Alamanos, E. 2019. "A Systematic Review of the Smart Home Literature: A User Perspective," Technological Forecasting and Social Change (138), pp. 139–154.
Miranda, J., Pérez-Rodríguez, R., Borja, V., Wright, P. K., and Molina, A. 2017. "Sensing, Smart and Sustainable Product Development (S3 Product) Reference Framework," International Journal of Production Research (7543), pp. 1–22.
Novales, A., Mocker, M., and Simonovich, D. 2016. "IT-Enriched 'Digitized' Products: Building Blocks and Challenges," AMCIS Proceedings.
Pan, S., Zhong, R. Y., and Qu, T. 2019. "Smart Product-Service Systems in Interoperable Logistics: Design and Implementation Prospects," Advanced Engineering Informatics (42:April), pp. 1–9.
Parizotto, S., and Lamberts, R. 2011. "Investigation of Green Roof Thermal Performance in Temperate Climate: A Case Study of an Experimental Building in Florianópolis City, Southern Brazil," Energy and Buildings (43:7), pp. 1712–1722.
Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. 2007. "A Design Science Research Methodology for Information Systems Research," Journal of Management Information Systems (24:3), pp. 45–78.
Porter, M. E. 2008. "The Five Competitive Forces That Shape Strategy," Harvard Business Review (86:1), pp. 25–40.
Porter, M. E., and Heppelmann, J. E. 2015. "How Smart, Connected Products Are Transforming Companies," Harvard Business Review (2015:October).
Shim, J. P., Avital, M., Dennis, A. R., Rossi, M., Sørensen, C., and French, A. 2019. "The Transformative Effect of the Internet of Things on Business and Society," Communications of the Association for Information Systems (44:1), pp. 129–140.
Spring, M., and Araujo, L. 2017. "Product Biographies in Servitization and the Circular Economy," Industrial Marketing Management (60), pp. 126–137.
Valencia, A., Mugge, R., Schoormans, J., and Schifferstein, R. 2015. "The Design of Smart Product-Service Systems (PSSs): An Exploration of Design Characteristics," International Journal of Design (9:1).
Venable, J., Pries-Heje, J., and Baskerville, R. 2016. "FEDS: A Framework for Evaluation in Design Science Research," European Journal of Information Systems (25:1), pp. 77–89.
Wuenderlich, N. V., Heinonen, K., Ostrom, A. L., Patricio, L., Sousa, R., Voss, C., and Lemmink, J. G. A. M. 2015. "'Futurizing' Smart Service: Implications for Service Researchers and Managers," Journal of Services Marketing (29:6–7), pp. 442–447.
Yoo, Y. 2010. "Digitalization and Innovation (IIR Working Papers)," Hitotsubashi University Repository.
Zheng, P., Chen, C. H., and Shang, S. 2019. "Towards an Automatic Engineering Change Management in Smart Product-Service Systems – A DSM-Based Learning Approach," Advanced Engineering Informatics (39:August 2018), pp. 203–213.
Zheng, P., Lin, T. J., Chen, C. H., and Xu, X. 2018. "A Systematic Design Approach for Service Innovation of Smart Product-Service Systems," Journal of Cleaner Production (201), pp. 657–667.
Zheng, P., Wang, Z., Chen, C. H., and Pheng Khoo, L. 2019. "A Survey of Smart Product-Service Systems: Key Aspects, Challenges and Future Perspectives," Advanced Engineering Informatics (42:July), pp. 1–19.