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Design for Sustainability in PSS: Evidences of QFD-Based Method Application

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Abstract. Nowadays companies are pushed to offer solutions with new functionalities, higher performances, lower environmental impact, lower cost, and high usability for final users. In this context, the concept of Product-Service System (PSS) represents a valid way from manufacturing firms to evolve their market proposition, reduce impacts of their processes, and satisfy the customers' needs. However, the design of PSS is still difficult, due to the lack of structured methodologies and evidences of the benefits connected with their adoption. The research adopts a systematic QFD-based methodology and demonstrates its validity to develop high sustainability PSS solutions. The case study focuses on the definition of a new PSS for green roofs: two groups of students, using respectively traditional methods and the proposed QFD-based methodology, were involved. The two PSSs conceived were evaluated in terms of outputs supporting the design phases and sustainability impacts. The case study results demonstrated how the adoption of a systematic method allows developing more business-oriented and more sustainable PSS in respect to traditional methods.

Keywords. Design for Sustainability (D4S), Design Methods, Product-Service Systems (PSS), Systematic Design, Quality Functional Deployment (QFD).

Introduction

Design for Sustainability (D4S) is an important and emerging trend for modern companies, and aims at developing products and systems able to minimize the impact about environmental, economic and human-related issues [1]. It is "important" since only a sustainability approach can preserve the available resources and permit future developments also for the next generations; it is "emerging" since companies are becoming more aware about the impacts of their processes on planet, profit, and people [2]. Moreover, such trend is pushed also by the spread of Information and Communication Technologies (ICT) in modern products, which are capable to share information, interact with other connected devices and store data in order to satisfy the user needs, offering the possibility to develop product-related services. The so-called Product-Service Systems (PSSs) represent the combination of physical products and tangible services, and can be applied also to increase both consumer satisfaction and sustainability [3]. However, PSS design is still difficult for companies, especially for the product-oriented ones: usually products and services are developed in a separated

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way and integrated only at the end, with low technical performances (mainly due to interfacing problems, low user acceptance, and data collection and storage), high costs (due to infrastructure issues and difficulties in business model definition) and low sustainability (due to not optimized assets and not necessary functionalities). In this context, the research considers a recently defined QFD-based methodology to support PSS design [4], and tests its application to a case study in sustainable building sector, focused on the definition of a new PSS for green roofs. Such a method starts from the analysis of the market needs and adopts a set of correlation matrices to find out the PSS functionalities, assets to be included, and partners to be involved in a systematic way. As a result, cost and resources are optimized in respect with the specific needs to be satisfied. Such a method is also compared with the traditional design methodology, based on focus groups and brainstorming, applied for the same case study. Results demonstrate how a rigorous design methodology can promote D4S and business modeling better than traditional methods.

1. Related works

Different classifications of PSSs have been provided in literature, but the Tukker's model is probably the most widely accepted [3]. It presents a PSS as an offer in a "product-service continuum", where three main models of PSS can be recognized: A) *product-oriented*, where the physical product is sold in a combination with services such as maintenance, recycling and customer trainings, which guarantee the functionality and a long use cycle; B) *use-oriented*, where the product is not owned by the customer anymore, but is made available for customer usage by the producer (e.g. through leasing); and C) *result-oriented*, where a "solution" required by the customers is provided in place of a product (e.g. offering travels instead of cars). In this context, firms can move from one type of PSS offering to another by changing the relative share of product and service components according to user requirements. Moving from the traditional products to one kind of PSS is called Servitization [5].

As far as PSS design is concerned, the literature review highlights that many methods and evaluation tools for PSSs have been proposed in recent years, and also the role of PSS in improving sustainability issues has been pointed out. However, there is still a lack of concrete and validated guidelines for PSS design in industry and its direct correlation to sustainability purposes. In this context, Ota [6] proposed a method for requirement analysis considering environmental factors, Favi et al. [7] offered a PSS lifecycle approach, Kimita and Shimomura [8] proposed a review of such approaches from different viewpoints (from value to cost, functions, qualities, or performances), and Peruzzini and Germani [9] used a structured approach to design sustainable PSSs. Recently, a combined methodology to support PSS design has been proposed to overcome the main limitations emerged from the literature review and achieve a successful PSS design process, focused on the satisfaction of the customer needs [4]. It is based on a set of correlation matrices to map the relationships between input and output data that are faced at each stage according to the Quality Functional Deployment (QFD) technique. It allows to progressively defined the customers' needs, the system requirements, and functions to be realized, until the partners' selection. Thanks to its systematic approach, such a method can promote also D4S, due to the control of resources involved step-by-step.

2. Case study

2.1. Motivation and PSS focus

The case study focuses on the ideation of a new PSS for the so-called "green roofs". Green roofs are typical elements for sustainable buildings and innovative urban architecture, that serve several purposes such as absorbing rainwater, providing insulation, creating a habitat for wildlife, providing a more aesthetically pleasing landscape, and helping to lower urban air temperatures and mitigate the heat island effect [10]. Green roofs are mainly adopted to optimize the roof surface, by creating new space with several usages, avoiding high costs to buy new land and improving the economic value of the property; to improve the microclimate, by the evaporation process on the roofs makes air more damp and cool in the surrounding areas; to decrease the water leakage, by evaporating more than half of the annual rainfall; to reduce the pollution by increasing the green surfaces, reducing sound reflection, and insulating by heat both in summer and in winter. Due to the numerous advantages, the market for green roofs is growing fast.

The company involved in the case study is a global firm that produces and sells green roofs since 1989. Its current offer consists of a set of modules (for any specific kind of plants or vegetation), including also installation costs, and a tailored irrigation system, according to the specific building project. The business model is a traditional B2C and the product ownership is totally transferred from the company to the customer. After product selling, additional services are usually offered to the customers, such as roof maintenance, which is fundamental to achieve the expected benefits and guarantee the roof long life. In the current offer, the product lifecycle is made up of four main phases: 1) Production, when the green roof modules and the irrigation system are built and prepared to be sold; 2) Use, that starts after the green roof installation and involves the exploitation and usage of the green roof for many years (according to the building lifecycle); 3) Maintenance, as an after sale service by the producing company, which provides all actions required to guarantee the roof wellbeing (e.g. change of a defective module due to died or dried vegetable), replacement or modification of the irrigation system, etc.); and 4) Disposal, that is required after the roof end-of-life, where all the plants are disposed of different manners, usually never reused. Actually, the producing company doesn't care about this phase.

The current offer presents several strengths and weakness. The strengths are: the modular architecture, the easy built and replace, the quick and easy installation, and the low risks for the company during the lifecycle use phase. About weakness, there are some main issues limiting the spread of green roofs usage:

- high costs for buying and installing for the customer,
- low level of customer relationship,
- lack of information about product use and disposal,
- high cost and effort for maintaining the roof in optimal conditions to have the expected benefits.

In order to overcome the current weaknesses, the producing company was interested in creating a PSS value proposition. Indeed, the company would offer a new value proposition to its customers in order to sell the green roof as a PSS, in order to expand its market. A new PSS value proposition will have to:

- reduce the purchase costs for customers, by spreading the system costs along the entire PSS lifecycle,
- guarantee installation and maintenance services in a unique offer, to simplify both installation and maintenance for the customers,
- improve the roof sustainable performances, thanks to a more accurate use and maintenance of the roof itself.

Unlike the traditional product offer, maintenance should be provided in a new way in order to monitor the roof behavior through a set of sensors able to collect information about irrigation storage system and from the surrounding ecosystem. This monitoring allows a continuous data collection and analysis, which enable automatic problem detection and preventive reaction, to avoid or at least limit dehydration and death of the roof plants. Furthermore, the new PSS solution could create a close loop lifecycle, where the defective modules (e.g. dried plants) can be suddenly replaced and regenerated to be used again (as a recycling service) in order to realize a more sustainable solution in terms of environmental benefits, economical expenses and human efforts necessary to care and handle with it.

Figure 1 compares the business models for the current product offer (A), and the PSS value proposition (B). The latter (PSS) aims to realize a more sustainable solution in terms of environmental impact, human efforts and economic impacts for the final customers; moreover, the producing company becomes the owner of the system, and the customers can have a improved and steady maintenance service along the entire PSS lifecycle, with a positive effect on the global green roof performance.

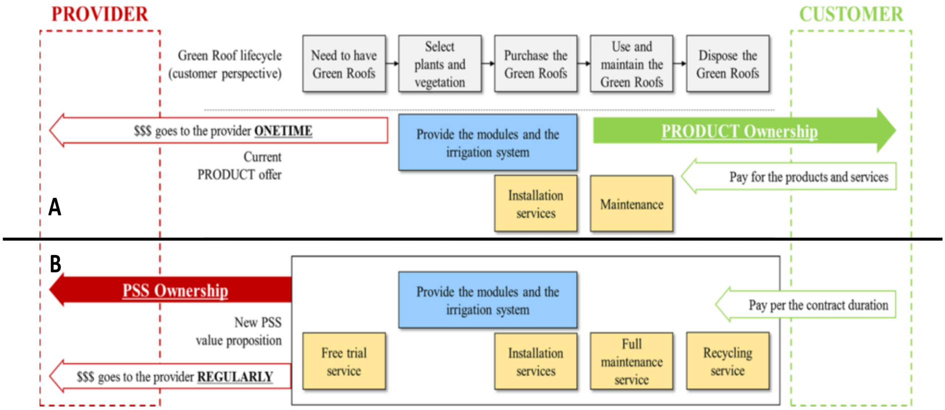

Figure 1. Business model comparison between the current product (A) and the new PSS proposition (B).

3. PSS design: traditional vs QFD-based method

The case study focuses on the definition of a new PSS for green roofs to overcome the main limitations of the current product solution. Two design processes are compared: a traditional process, driven by traditional design method adopted to PSS, based on brainstorming and focus groups, and an structured process, based on a recently defined QFD methodology, which starts from the analysis of the target market and user needs, and goes through the definition of requirements, PSS functions, ecosystem and business model in a systematic way [4]. The PSS design process was carried out by two groups of students, graduating in mechanical engineering and engineering management courses. One group adopted traditional approaches and the other one the QFD-based method, after a brief presentation of them to the students. The two design teams worked in parallel and were supported by people belonging to the producing company of the green roof, especially from the Marketing, Technical and Service Departments.

3.1. Traditional PSS design

The former group developed the new PSS idea by traditional design approaches, according to the following steps:

- Study of market analysis, carried out by the marketing company staff;
- Focus groups and brainstorming sessions, in order to investigate the main limitations of the current product and identify the context in which the new PSS will be introduced;
- Analysis of the new PSS characteristics and investigation of the scenarios where PSS will be used;
- Simulation of how the new PSS will be created provided and maintained, mainly by Business Use Case (BUC) analysis [11].

During the focus groups, the main strengths and weaknesses of the current product offer were assessed in order to identify the new PSS value proposition. By one-day brainstorming, students identified the most promising ideas about the functionalities of the new PSS solution. Subsequently, the main PSS characteristics were identified in order to understand whether and how the new PSS could validly substitute the current product offer. The results from the design activity brought to the definition of the main PSS features. Finally, the new PSS idea was simulated adopting the BUC approach to define its impact on the customer' satisfaction and the hypothetical PSS use scenario.

3.2. QFD-based PSS design

The design of the new PSS, as presented in section 2.1, was faced through the application of a QFD-based methodology as proposed by Marilungo and Peruzzini [4]. Such a methodology integrates several techniques, and basically focuses on the analysis of the market needs and their correlation to the technical requirements, through the application of a set of QFD matrices. The main design steps were:

- Identification of the customer requirements and main PSS functions on the basis of the market analysis, carried out by the marketing company staff;
- Correlation between customer requirements and PSS tasks by ethnography and participatory design techniques (based on personas) [4], according to the specific PSS focus and customers' objectives. Requirements are defined according to [12];
- Technical analysis where the PSS assets required are identified through the analysis of the main tasks to execute, and correlation between assets and PSS functionalities according to the PSS application scenarios, to define the most affected assets, which then are correlated with the partners' resources needed to involve;
- Simulation of how the new PSS will be created provided and maintained, mainly by BUC analysis [11].

Table 1 shows the correlation between the identified user requirements and the technical tasks. User requirements were collected by the design team in the basis of a preliminary market analysis, thanks to the application of requirements elicitation techniques, while PSS tasks were defined coherently to the PSS value proposition. Table 2 shows the correlation between assets and functionalities. The assets are the tangible or intangible recourses needed to realize the tasks; the functionalities are what can be delivered to satisfy customers. For the specific use case, Table 2 shows the assets and their correlation to the tasks presented in Table 1. As a result, the PSS functionalities were defined. They are:

1. *Green place*, which consists of simply offering an urban green area;
2. *Comfort place*, which offers to change house roofs in more sustainable and confortable spaces;
3. *Insulator house*, which provides a thermal and acoustic insulation of the building;
4. *Economic saving*, which can be achieved thanks to both the water storage system, allowing to avoid water waste, and the heating / cooling features that allow saving money for house heating or cooling;
5. *Ever green and maintenance*, which consists of regeneration of expired vegetation, provided as a service.

Finally, Table 3 shows the correlation between the PSS assets, as identified in Table 2, and the partners' resources required to provide such the assets. About resources, Table 3 shows only the main partners involved in the company supply chain (due to space limit). Correlations are expressed according to 0-1-3-9 scale.

Table 1. Correlation between PSS tasks and user requirements by QFD method.

GR = Green Roof	USER REQUIREMENTS											
TASK	Have an urban area at zero	Emphasis on environmental	Improve the live quality	Turn the city into an island green	Improve the thermal	Increase the buildings energy	Easy to installation and	Improve acoustic insulation	Make a green building	Reduce risks due to weather	Have vegetation always green	**TASK IMPORTANCE**
Furnish the GR	9	9	9	9	1	9	0	9	9	1	3	**68**
Make a modular space	0	1	9	0	0	0	9	0	1	1	0	**21**
Greening of the GR	9	9	9	9	3	9	0	0	9	9	9	**75**
Installation of GR waterproof layer	1	1	1	1	9	9	3	0	1	0	3	**29**
Maintenance actions on the GR	3	3	3	9	0	1	9	0	3	3	9	**43**
Feasibility analysis	3	0	0	0	1	0	0	0	1	0	0	**5**
Installation of drainage ditch	0	1	3	1	1	3	3	0	1	0	3	**16**
Realization of GR modules	3	1	3	1	9	9	3	9	9	9	3	**59**
Creation of water storage system	1	1	1	1	3	3	3	0	1	0	3	**17**
Creation of irrigation system	3	1	3	1	0	1	3	0	1	0	9	**22**
Design and creation of sensors system	0	3	0	0	0	0	0	0	1	9	9	**22**
REQUIREMENTS IMPORTANCE	**32**	**30**	**41**	**32**	**27**	**44**	**33**	**18**	**37**	**32**	**51**	

Table 2. Correlation between PSS assets and functionalities by QFD method.

	PSS FUNCTIONALITIES					
ASSETS	Green place	Comfort place	Insulator house	Economic saving	Ever green & maintenance	**ASSETS IMPORTANCE**
Modular structure	3	9	3	0	9	**24**
Plants and vegetation	9	3	9	9	9	**39**
Substratum and drainage material	3	1	9	3	3	**19**
Drainage ditches	3	1	3	9	3	**19**
Components for water storage	1	1	3	9	3	**17**
Other accessories	0	9	0	0	1	**10**
Filter layer	1	1	3	0	3	**8**
Waterproof coat	1	1	3	9	3	**17**
Irrigation system	9	1	1	3	9	**23**
Sensors system for monitoring	9	3	0	3	9	**24**
DB to data collecting	9	1	0	3	9	**22**
FUNCTIONALITIES IMPORTANCE	**48**	**31**	**34**	**48**	**61**	

Table 3. Correlation between PSS assets and partners' resources by QFD method.

	ASSETS											
PARTNERS' RESOURCES	Modular structure	Plants and vegetation	Substratum and drainage material	Drainage ditches	Components for water storage	Other accessories	Filter layer	Waterproof coat	Irrigation system	Sensors system for monitoring	System DB	**PARTNERS IMPORTANCE**
GR builders	9	0	0	3	3	3	3	3	3	1	1	**29**
Vegetation providers	3	9	1	0	0	0	0	0	1	1	0	**15**
Designers for GR furnishing	0	0	0	0	0	9	0	0	1	0	0	**10**
Gardeners	3	3	3	1	1	1	3	1	3	0	0	**19**
Substratum providers	3	3	9	0	0	0	0	0	0	0	0	**15**
Engineers and technicians	3	1	1	9	9	3	9	9	9	1	1	**55**
GR engineers	0	0	0	9	9	1	3	3	3	3	3	**34**
HW provider for sensors system	0	0	0	9	9	0	1	1	9	9	3	**41**
SW provider for sensors system	0	0	0	0	0	0	0	0	3	9	9	**21**
Data manager	0	0	0	0	0	0	0	0	9	9	9	**27**

3.3. Results and discussion

In order to compare the two PSS value propositions as designed by the two approaches (i.e. traditional and QFD-based), the main results coming from the two design teams are presented and discussed. The traditional approach allowed the current product offer to be analyzed in order to identify the more profitable PSS and to highlight the main drawbacks, mainly referred to service potential, product design, innovation, adaptability, client contact, and operational performance. Such an analysis highlighted the main points to improve by a proper PSS. Indeed, the design team defined a new PSS scenario, even if a low level of detail. Different ways to implement the maintenance service into the product offering and some solutions to have a more profitable customer relationship were proposed. However, it was long and difficult to achieve a complete PSS solution. The main outputs of the preliminary design phases were a set of diagrams as indicated in Figure 2 (arrows highlight the main areas of improvement identified during the focus group).

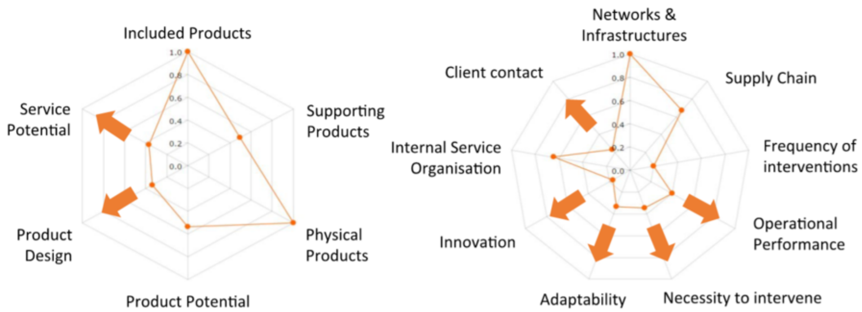

Figure 2. Outputs from traditional design approach: areas of improvements for the PSS development.

Instead, the QFD-based methodology supported not only the definition of the main PSS features, but also the identification of the PSS functions and assets (i.e. tangible and intangible assets, resources required to implement the service over the product, key partners to involve). Furthermore, it supported a preliminary business modeling for the new PSS by the application of the matrices. The preliminary business model is shown in Figure 3: such model proposed a low installation cost and an annual fee for maintenance actions, in order to give a reasonable return of the investment for the company provider and a good "value for money" for the customers.

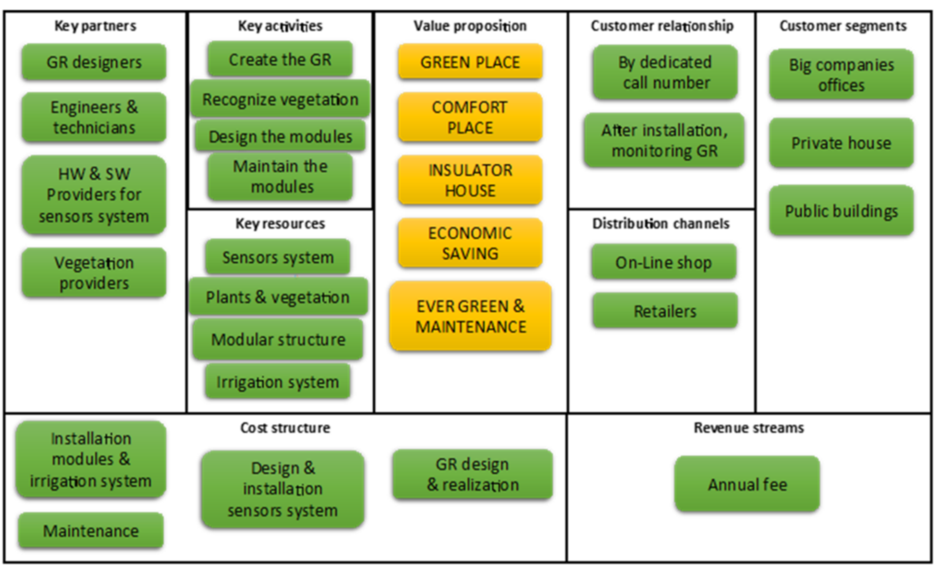

Figure 3. Outputs from the QFD-based design approach: preliminary PSS business model.

Furthermore, the adoption of a structured methodology for PSS design allowed the new PSS lifecycle to be detailed in advance and the impacts on sustainability analyzed during the design phase, to be compared with the traditional product lifecycle. As a result, the positive contribution of the new PSS solution with respect to traditional product lifecycle as presented in Figure 4. Indeed, the traditional model implies waste of material and product in the disposal phase, which brings to higher cost and resource leftover. Contrarily, the PSS solution allows recovering products and materials thanks to same ownership according to a close-loop model, saving resources and money. Such results demonstrated how the adoption of a structured methodology, as the QFD-based one, can simplify the design and the implementation of service-oriented PSS with better performances and higher sustainability (i.e. reduced costs, lower environmental impacts, less human intervention). Further developments can refer to the definition of a PSS workflow in a more structured way, as recently presented by Viriyasitavat [13].

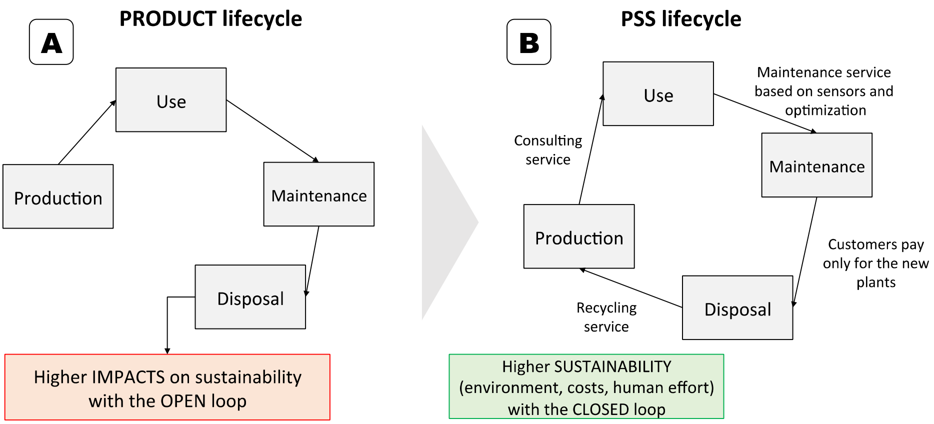

Figure 4. Impacts on sustainability due to traditional product lifecycle (A) and new PSS lifecycle (B).

4. Conclusions

The research proposed to apply a QFD-based methodology to design sustainable PSS in order to promote Design for Sustainability (D4S) also among PSS and presented a case study where non-expert designers will develop a PSS in the green roof sector, starting from the main limitations of the current product offer. Two groups were involved, supported by the producing company of green roofs: the first group adopted traditional approaches based on focus groups and brainstorming, while the second group adopted the proposed QFD method. The second design team was able to study consumer needs more deeply, to consider technical aspects more consciously, and to evaluate also business aspects. As a result, the level of servitization and the global PSS quality achieved by the second PSS was higher in respect with traditional methods. Such a result suggests how D4S can be achieved easily by means of structured methodologies, like the proposed one. Future works will be focused on testing the expected benefits in terms of reduced environmental, economical and human-related impacts also on real PSS prototypes by proper simulation tools.

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