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A role for physical prototyping in Product-Service System design: Case study in construction equipment

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Abstract

Using a case study methodology to exploring an ambitious experimental combination of a construction equipment manufacturer's products tailored to provide exponential increases in efficiency and reductions in CO2. The products and system represent a relevant example of new technology being the foundation upon which a functional offering IPSS can be designed. The researcher constructed a scaled down functional experiential prototype reflecting a full scale experimental all electric quarry site in under operation outside of Goteborg, Sweden. The prototype site represented the primary equipment and system functionality, to act as a boundary object around which relevant stakeholders both internal and external could share the vision of an electric autonomous future. This was confirmed via observation at an event where the scale site was used for this purpose and verified with follow up interviews to dig deeper into the impact this tangible representation could have in increasing the perceived viability of the full scale technology's potential on display thousands of miles from the event.

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Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Globalization and the high pace technology innovation, have radically changed the industrial strategies pursued to create value [8]. Companies have shifted from a product-centric thinking to the increasing provision of services. The results of the "servitization" process are commonly referred to by the term "Product-Service systems" (PSS) [1]. Large and established product manufacturer shifting toward PSS-provision, need to rethink the way in which complex products are designed and developed since the early stages of development [11] the creation of robust design solutions while encompassing, at the same time, radical changes in the product operating system and unprecedented technological innovations [2]. In the case of traditional industries such as construction machinery and mining, the advent of new technologies and industry 4.0 capabilities enable more tailored and efficient solution offerings. However, the concentration of knowledge needed to operate the transition toward PSS also lie with the capability to generate innovation and effectively communicate it to relevant stakeholders.

The research presented in this paper focuses on the conceptual design stage of PSS, where cognitive, social and technical challenges abound [9], and explore how the creation of innovative systems solutions can be supported in a complex industrial context dominated by established product development and systems engineering practices. Authors have largely explored the application of methods to exploit the creativity and innovation in product development, building a consistent research stream dealing with the so-called Design Thinking approach [4]. However, only in recent years authors have started to explore the potential to apply Design Thinking method to engineering new complex systems [9], not directly addressing the context of PSS development.

This paper focuses on one of the aspects of Design Thinking, which is the use of early prototypes to convey information and raise discussion and understanding of new concepts in the very early design stages. Modern innovative product development

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processes stress the importance of creating tangible prototypes for their ability to communicate complexity, enable rapid feedback and provide guidance on design changes in the early stages of the process. The research presented in this paper is based on the hypothesis that in the context of PSS design, physical prototyping (from small scale systems to full scale individual equipment) can create boundary objects which act as effective tools for engaging relevant stakeholders in meaningful dialog around small details or the entire physical system. Tools like this could enable design teams and companies to better tailor a PSS to add the more value and be more easily accepted as potential alternative to traditional offerings.

The aim of the paper is to raise the discussion about how physical prototyping can create boundary objects for engaging customer stakeholders in early phase PSS design discussions. This is achieved by presenting the findings of a case study run in the construction equipment industry, where the use of a small-scale prototype of a construction site as a boundary objects for multi-stakeholder discussions has been tested.

2. Context of the Case Study

The case study was run in collaboration with a construction equipment manufacturer aiming to develop the world's first 'emission-free' quarry. Drawing on the electromobility and automation expertise, the research project, dubbed Electric Site, aims to electrify each transport stage in a quarry from excavation to primary crushing, and transport to secondary crushing. The system's efficiency, safety and environmental benefits are set to impact both customers and society at large.

Such new solutions with machines, technologies and operations consisting of complex products and systems are functionally different compared to traditional equipment manufacturer offerings. This raises the potential to obfuscate the advantages of these new solutions from the internal and external stakeholders. In any product-service system development process it is necessary to garner feedback to inform the design as early as possible. A challenge arrises here due to PSS design methods relying solely or heavily on two-dimensional service blueprinting techniques as the medium for conveying complete solutions until fully functional products and systems take a physical form towards the end of the design phase.

It was the intention of VCE to create a functional physical instantiation of the electric site in a small scale prototype form to provide tangibility to their feasibility claims about the full scale operation before it was constructed. The corporate interest was to reduce the need for transporting stakeholders to Sweden to observe the testing of the machines, by creating an interactive display that could, in essence, bring the site to them. From a research perspective, the intent was to demonstrate and test how the physical prototyping of functional system components in a small scale construction environment could act as an effective boundary object to drive a deeper dialog with all interested parties whom are vital to the full scale successful implementation in the early design phases.

3. Prototypes as Boundary Objects

Overall, the venture of prototyping is to gather information to help in the decision-making process of design. The designers at IDEO have a saying, "if a picture is worth a thousand words, a prototype is worth a thousand meetings". They provide opportunities for fast feedback, new inputs and a hands-on user experience readily available. Furr and Dyer assert that rapid prototypes have a fundamental role in hypotheses validation[7]. They also discovered that in some cases it can be beneficial to fake the capability of a product if the experience is your key point of investigation [7]. Experiential Prototyping techniques endeavor to accomplish three goals towards addressing the problem: Understanding existing user experiences and context, Exploring and evaluating design ideas, and Communicating ideas to an audience [4].

In innovative development, actors often come from different practices, functions, or organizational worlds [6] and must collaborate to solve problems and develop solutions [12] together across the boundary or shared area (a boundary is not at the periphery, but rather dead-center between the collaborators) that separates them. To effectively cross that boundary, they need to facilitate this collaboration, share knowledge and information and solve problems together even though they are not automatically equipped with the same language, understanding of the vocabulary employed, or understanding of what is described [6]. A remedy to this is to utilize a boundary object [12] as a mediating artefact between the social worlds. The boundary object is defined by Star and Griesemer as "...objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them." (p.393)[12].

According to Star there are three fundamental aspects to the class description of the boundary object; interpretive flexibility, material structure, and granularity, which corresponds to the information and work requirements of the groups utilizing the object, that is what is needed to represent and take the knowledge base from as-is to to-be (i.e. the work) [14].

A boundary object is not about achieving consensus among the actors [13], and the boundary object as such may mean different things to different people. Important is that it facilitates users to employ a shared syntax, learn about differences across the boundary, and transform their knowledge together [6]. Derivatives of the original definition have stressed on additional aspects that are important for practice, and which could be supported by the mediating object. Boujut and Blanco [3] use the term intermediary objects as a way of depicting these objects as representations of intermediate states of the future product, acting as mediators as a prescription from one actor to the next, transformations of the product from one state to the next, and as a representation of the future product. The intermediary objects can provide a frame for collaboration along the development process. Essentially, as more information and knowledge are created the intermediary object evolves[3].

Lee [10] introduce the concept of the boundary negotiating artefact as having the role of not only traverse boundaries, but also to renegotiate these boundaries to establish new ones. By doing so the focus is on synthesis and innovation across different practices. In a similar vein, Subrahmanian et al. [15] frame the prototype as a boundary object, to stress the constant dynamic (i.e., "prototypical understanding") that goes on at the interfaces between developers. Design is seen as a theory-building activity where designers create prototypes as representations of their current understanding of the product [15].

4. Results

The setting for the demonstration of the prototype site took place over a 3-day event around emerging technology and products from Volvo CE (VCE), Volvo Cars and Volvo Trucks. Attending audience included members of Volvo management, key customers and the press. 3 different groups representing each of these were guided through multiple stations with presentations at each station. The station including the prototype site was focused on communicating VCE's work on the semi-autonomous electric site aimed at a 10x improvement in efficiency of quarry operations while reducing on-site emissions by nearly 100%.

As seen in figure 1 the research team constructed a 1:14 scale prototype of the new autonomous electrified machines working on a 5m x 5m model of a generalized quarry site, consisting of two loading/dumping scenarios. The loading machines were manually operated, and the electric haulers were autonomously controlled.


Figure 1. Scale Site at The Volvo Event

This scale site was operated by the research team during the culmination of a presentation by the project leaders from both Volvo CE and Skanska, responsible for the full-scale experiment site operation taking place in Sweden. They discuss the need to redefine how the operational dynamics of site functionality must be redesigned in tandem to take full advantage of the electric and autonomous equipment on display. This translates to a move away from equipment designed to be broadly capable of many tasks and more towards product service system solutions consisting of equipment that can perform purpose-built tasks exponentially better.

4.1. Observations

During the demonstration of the site the project leaders fielded questions from the audience while a member of the research team recorded the questions asked by each group observers. Each group asked distinctly different types of questions illustrating their unique areas of interest. The observers posed numerous questions, but for display purposes they are organized by group and category with embodying samples (as seen in table 1) to avoid the irrelevant and non-unique questions.

Table 1. Observations divided by stakeholder group

Group	Question Category	Question Examples
Volvo Management Personnel	Technology Readiness	Is it reliable and safe enough to match our brand?
	Technology Bleed	What other areas of the company can benefit?
	Manufacturability	How and where can we cost effectively make this equipment?
Customer Representatives	Operational Changes	How many to equal my current operation's production?
	Availability	When will these machines be publicly available?
	Feasibility/Flexibility	How can this be adapted to fit my industrial operation?
Media	Functionality	How do they work? (small and full scale)
	Delivery	When will these go into production?
	Future Vision	What is next in the innovation pipeline?

A more detailed analysis of the content of the questions is found in the discussion section, but briefly we can highlight how these examples demonstrate an ability for the prototype site to act as an effective boundary object. Highlighting the amount of questions that had to do with more than the functionality of the scale site versus how much focus was translated into inquires relating to the full scale site demonstrates the ability for people to see demonstration for more than a collection of toys and more like a representation of a real situation. The categorical differences in question substance also bodes well for the perspective that each group was able to see it through their own lens without having to change anything about the site itself, the elasticity of their viewpoints was entirely related to the observer further reinforcing the scale site's classification as an effective boundary object.

4.2. Interviews

The results from the observations were complemented with open-ended interviews with experts, two of whom were part of the customer observation group and two were with the project leaders for the Electric Site (representing Skanska and VCE). Due to the low number of interviews conducted, the results here are used for the triangulation of the data collected to derive more solid and reinforce reliable conclusions. The questions are stated with the most relevant quotes from the respondents displayed below.

Interviews held as semi-structured discussions around two main questions:

a) *How observing the scale prototype in action impacted their perception of the Autonomous/Electric site solution's feasibility within their industrial context?*

"Scale prototypes like the site enable visualization of the operations and systems of machines where the true gains in efficiency are realized. Expands the conversation beyond individual machines questions to more operational level questions about manpower changes and machine-to-machine interactions."

"Site serves as an excellent communication initiation tool. Provides a way to more tangibly visualize the new products and their interactions."

"As I see this just as another media to explain our future plans next to already existing posters, ppts and videos I think there is no drawback and only positive additional impact. As it is something three-dimensional and for real (people can see, hear and feel) it is just a very good illustration of what will happen and with the automation it triggers process questions and helps explaining. As also on batteries it is also a nice catch to always refer easily to the real solution so from a communication standpoint it is easy to fit into a presentation and talk around it."

b) *What kind of opportunities do you see with new technology within your operations?*

"Creating solutions for a demand and that demand is efficiency and safety. Contrary to generalized very capable machines that are inherently less efficient at conducting specialized tasks. The future is focusing on combinations of machines to satisfy the operational needs. Means a need to look at operation more abstractly in order to broaden the potential solution space of combinations. Automation allows for more structured workflows as opposed to individual workers being real time decision makers. This enables a better modeling of the operational and safety risk."

"Biggest wish from a customer perspective is to have some sort of standardization of traffic/production control to allow for pairing of different manufacturers machines in the same system. Don't want to be locked in like apple but more like android with ability to put different machines on the same network. Or more like telecoms in general where the network is built by everyone and allows all devices to connect."

"At Waste Management we are interested in autonomy and remote operation for different reasons that normal. They have trouble both hiring people and maintaining them as employees due to the environment. Interested in creating remote operation stations for millennials to run multiple machines from."

5. Discussion

Scale experiential and non-functional prototypes served as effective Boundary Objects allowing customers (and internal stakeholders) to envision how these new products as a system solution can be implemented across a range of industries. Design thinking and by extension the act of prototyping is an approach for addressing design complexity and as products are phased into PSS solutions they continue to increase in technological complexity and interdependency between other system components. Long [11] connects engineering systems thinking as a necessary skill for design thinking which carries over to how to use of tangible and experiential prototypes as boundary objects to convey system concepts as well as the new products enabling the new design.

The statements captured during the showing of the prototypes made evident an attitude of not caring what the machines look like if they can accomplish a specific task better than those currently available. However, skepticism exists around the feasibility of the components adding up to be more capable than their current operations in place now. The scale prototype was able to bring this front and center with questions while also enabling the hosts to explain in more detail how this is actually possible by pointing at the artifact interactions and extrapolating how the components could be customized to best suit the a target customer's operations.

A key feature of prototypes is to allow to identify gaps otherwise difficult to observe. Some of the gaps can be caused from observers not grasping the level of fidelity on display is not a 1:1 of what happens in real life and other gaps are legitimate concerns that without the "realness" of the boundary object might not be brought into the design discussion until it is too late or much more expensive.

6. Conclusion

PSS solutions that lean closer to function and result oriented category must offer significant advantages whether it be in safety or sustainability the advantages need to match the values of the manufacturer and their customers. The paper has discussed the role of Experiential prototypes and functional prototypes as boundary objects creating shared visions between customers and manufacturers garnering valuable feedback data to guide design decisions. The case study of a construction equipment company investigating the transition toward PSS by means of early prototypes has been presented framing the findings in the field of design thinking and complex systems design.

Future work will focus into formalizing a functional requirement guided and innovative product centered PSS design methodology that includes early phase physical prototyping enabling data-driven design. Through the development of an established methodology it would be possible to run multiple case studies validation in different industrial context, to verify the presence of similar benefits in different context. This would contribute to the generalization of a PSS design approach including early stage experiential and functional prototypes.

7. Future Work

In the interviews the customers want interoperability between different manufacturers and not to be locked into using only Volvo Equipment for everything to function properly. These concerns are coming into the forefront while the maturity of new technologies such as AI, Autonomy and Electrification is increasing to a point where it may be deployed in previously unrefined industries. Handling such compatibility issues will potentially become service offering requiring manufacturers to play together if they expect to meet customer requirements of the future. Again, the use of tangible and experiential prototypes to enable immersive design discussions across trans-disciplinary and trans-corporate partnerships may a potent tool to drive this level of collaboration by allowing shared vision of the system and catching valuable feedback from customer stakeholders in the earliest phases of design.

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