Data Mining through Early Experience Prototyping

A step towards Data Driven Product Service System Design

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Abstract: The construction industry is ripe for disruption through innovative solutions that provide added productivity. Equipment manufacturers are attempting to disrupt their industry with investments in autonomy, electrification and product-service system business models. Designing solutions that will operate in completely new systems or modify an existing complex system require new approaches to address the uncertainty of system impacts. An iterative approach can help tackle ambiguity through cyclical validation of design decisions. Data mining in each cycle adds a quantitative dimension to the rationale of decision making, but data is sparse and difficult to collect in parallel with design of theoretical product-service systems operating in future scenarios. This can be combated using experiential prototyping techniques to design flexible infrastructure that supports contextualized data gathering in a variety of focused design sprints using Design, Build and Test approach. The intricacy of designing innovative solutions to increase productivity in the construction industry can be untangled by framing aspects of the problem in small sprints and testing them in a contextualized setting built to generate functional data to drive design.

Keywords: Product Service System, Data Mining, Experience Prototyping, New Machine Development

1 Introduction:

Over the last 60 years, global increases in productivity for construction based industries have lagged behind similar industries such as agriculture (by a factor of 15) and manufacturing (by a factor of 8) particularly due to a lack of innovation (Barbosa, et al. (2017)). Much of this deficit in innovation can be attributed to construction’s level of operational complexity when compared to agriculture and its constantly changing operational environment in contrast to manufacturing’s static workflows (Abderraham and Balaeur (2008)). Yet, as technological capability continues to increase, opportunities exist to be the best smart construction equipment supplier.

Attempting to expand into a non-existing market reveals a plethora of ambiguity concerning the form and function of new products, services and systems. Compounding the challenges associated with ambiguity is the difficulty of gathering data to drive design when addressing hypothetical future scenarios and environments. For instance, a Swedish Construction Equipment Manufacturer is developing autonomous and full electric machines as part of their committed to a 10x increase in efficiency (Volvo Concept Lab (2017)). But, introducing autonomous construction equipment results in an unknown hybrid interaction of new and original artifacts consisting of complex and dynamic interactions with converging hardware and software, products and services, humans and machines.

By integrating the system components toward the provision of a functional solution rather than individual products, manufacturers can arrive at Product Service System (PSS) solutions (Tukker (2004)). When purposefully designed, PSS’ provide increased customer value, improved long-term return on investment, built-in environmental-friendly aspects and possible, spare part and waste reductions (Tukker (2004)). However, focusing on the functional integration of products and services affects the manufacturer’s development process ie. how development work is organised and which tools and methods are used.

Engineering design thinking provides sets of tools and methods capable of unpacking the ambiguity in PSS development through a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints (Dym et al. (2005)).

Generation and evaluation of concepts can be accelerated through the incorporation of data-mining to drive design decision rationale. This concept is engendered by the emerging field of data driven design (Bertoni and Larsson...
(2017)). Set in the context of PSS development for construction equipment manufacturers, various types of data must be collected ranging from quantitative machine performance factors to qualitative user experience factors (Isaksson, Larsson and Rönnbäck (2009)) . Considering the intangible nature of new machine concepts and future construction operations, efforts must be made to simulate these elements.

Simulations, in this data-gathering context, include all elements necessary to elicit realistic interactions in a theorized future scenario. Utilizing experiential prototyping, designers can engage with users in a contextualized representation of the envisioned PSS solution. Ideally, this serves to create a shared sense of empathy with the ultimate goal of guiding design decision towards the satisfaction of true system needs.

1.1 Objective

The objective of this paper is to explore data driven design for the purpose of guiding product-service system development in the construction industry via flexible experiential prototyping infrastructure.

1.2 Methodology:

This work was based on a case study (Yin, 2004) focusing on the development of Human-Robot Interactions between construction workers and prototype autonomous vehicles. More specifically, how the elements of an augmented reality interface can facilitate a building of trust between human and autonomous machine. Testing of the interface was conducted via Microsoft Hololens paired with scaled down functional model machines on a scaled down construction site with digging, loading and dumping operations.

Data was gathered in the form of user feedback via questionnaires and qualitative data from researcher conducted observations and interviews. Analysis of the data was done by identifying trends and converging opinion statements from the collective body of feedback.

2. Scientific Background:

2.1 PSS Design

Complexity in product development is emphasized when hardware, software and services are packaged into a single ‘total offer’ (Alonso-Rasgado et al. 2004). Product-Service Systems (Mont, 2002) is one of the industrial trends representing the shift in manufacturers’ strategic focus from selling a physical product to providing performance and availability, as a way to satisfy more sophisticated needs and expectations (Baines et al. 2007; Williams, 2007). Eight types of PSS are proposed by Tukker (2006), which have been are further synthesized by Cook et al. (2006) in:

- Product-oriented PSS: the ownership of the physical artifact is transferred to the customer and services are offered to ensure the “utility of the product”, such as warranties and maintenance.
- Use-oriented PSS: the service provider retains the ownership of the physical artifact and the customer pays for its use over a period of time or units of service.
- Result-oriented PSS: the service provider, as in use-oriented PSS, retains the ownership rights of the physical artifact, and the customer pays a fee proportional to the expected outcome rather than for the mere usage of the product. For instance, instead of leasing or buying a haul truck the customer can sign an agreement for material transport by mass with an full service provider.

Compared to the traditional one-sale model, designing these PSS types challenges engineers to raise their awareness on customer and stakeholders needs along the entire product lifecycle, so to realize solutions that are value adding for all the actors involved (Isaksson et al. 2009). Furthermore, PSS development is known as functional product development, where the solution of any combination of hardware, software and services is developed in a coordinated development effort.

2.2 Data Mining:

Data mining is defined as the discovery of non-trivial, implicit, previously unknown, and potentially useful and understandable patterns from large datasets (Anand and Buchner, 1998). When it comes to application of data mining in industrial environments, the term is often associated with the concept of machine learning, i.e. the study of computer algorithms that improve automatically through experience (Mitchell, 1997) Data mining and machine learning are used in engineering both with the predictive goal of forecasting the value of a variable and with the descriptive goal of understanding and discovering patterns in the available data (Anand and Buchner, 1998). Data mining can thus be used to support data driven rationale during a design process.

2.3 Experiential Prototyping

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 (2014) assert that rapid prototypes have a fundamental role in hypotheses validation. 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 (Furr and Dyer (2014)).

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 Buchenau and Suri (2000).
2.4 HRI

Vaussard et al. (2014) had been able to split the direct and indirect interaction between human and robot into three main parts:

1. how users operate and give commands to the robot,
2. how the systems gives feedback to the user and
3. indirect interaction with the users and robots shred environment.

It has been stated that users wish to understand how the robot is working, what could be described as transparency. The study also revealed, that an inadequate information sharing is decreasing the long-term acceptance of the robotic system, what was also stated by Lynas and Horberry (2011). It has been indicated, that a user-centered design approach is likely to overcome collaboration issues with a parallel focus on system automation rather than component automation by Lynas and Horberry (2011).

Brezeal et al. (2013) as well as Jung et al. (2013) highlight the importance of the human-robot interface, and especially its design, as key success factor for the human-robot teamwork. In their study about resilient autonomous systems, Matthews et al. (2016) pinpoint the challenges for the teaming between human operators and autonomous systems. The study suggest to design an interface that enables the autonomous system to effectively signal its capabilities and its intent to the human operator.

3. Results:

3.1 Prototype Results

To construct an effective prototype experience flexible enough to test a variety of interface functionalities, generic scenarios from real construction operations were needed. Collaborating with a Swedish construction manufacturing company’s marketing department provided the necessary relevant activities to be included in the prototype.

As large scale organizations (such as: Uber and University of Michigan) heavily invest in autonomous transport they have recognized the importance creating models of cities to test and simulate their specific concept’s operation in realistic context. Most other high fidelity investigations into autonomous vehicle intention communication and pedestrian interaction, create scaled functional machines based on golf carts or smaller vehicles [e.g., Matthews et al. (2017), Florentine et al. (2016), St.Clair et al. (2011)] in order to have an artifact for testing a range of interfaces or interaction techniques. In contrast, an autonomous construction site will involve multiple machines collaborating to complete specific tasks (Ameen and Safawizadeh (2017)), requiring humans to process information from multiple sources simultaneously.

To address this distinct difference, the developed prototype platform consisted of a 5m x 5m scaled down site including two autonomous haulers’ loading and dumping interactions (figure 3.1) typical of a quarry or mine operation.

![Figure 3.1: Hauler and excavator loading operation on scale site.](image1)

The machines were 1:11 scale remote control versions of Volvo CE’s currently available EX01 excavator and LX01 wheel loader concepts, with the addition of the prototype HX02 autonomous hauler. To best reflect the reality of the operation, loading machines (excavator and wheel loader) were left as remotely controlled machines, while the HX02s were fitted with sensors, control boards and communication devices to enable an autonomous experience for the user.

A Microsoft HoloLens was acquired to build a functional prototype of an AR interface resulting in an application transmitting voice commands to haulers and display an information panel with fictional data. (fig 3.2)

![Figure 3.2: Deployed Hololens interface testing layout](image2)

3.2 Data Generation

Experiential Prototyping is not normally found in the construction industry, but it is essential when the goal is generating/gathering feedback data from a large number of diverse users interacting with a limited production prototype designed for a hypothetical construction site. With the scale site constructed as a research platform the stage was set to generate testing data on the HRI prototype’s feasibility to meet the needs of future construction scenarios including manually operated machines, autonomous machines and human laborers.
In testing with the infrastructure, data gathered consisted of quantitative responses to a questionnaire aimed to confirm desired emotional responses to the inclusion of user interface elements. To complement the questionnaire and broaden the scope of potential learnings, qualitative observations and interviews were conducted of users and non-user observers.

The questionnaire were designed to measure emotional responses to the drivers identified in a previous case study Winqvist (2016). The range of available response variables was intentionally narrowed so data gathered indicated a binary presence of the desired emotional components rather than the degree which is less reliable at the designed fidelity.

The response prompts were:
1. HoloLens app made me feel connected to the machines
2. HoloLens app increased my trust of the haulers
3. Voice commands made me feel in control
4. The AR display was more helpful than distracting
5. Overall site experience felt realistic in its operation

The responses of 15 respondents are gathered in the Graph 3.3 below.

Figure 3.3: Questionnaire responses to AR experience

The 15 respondents do not make for statistically significant quantitative data, but basic trends in the response create useful qualitative data. Lowest scores were found in the perceived realism of the scale site. Interview questions confirmed this stemmed from the RC controllers connected to the scale wheel loader and excavator being seen as “toys” more so when combined with low skilled drivers demonstrating “unrealistic operations” that would create “unsafe and inefficient performance”. Responses to questions 1-4 indicated an optimistic attitude towards the HoloLens AR platform as an interface.

Interviews, in the unstructured format they were conducted, more resembled conversations. Not shockingly, most conversations started with the question, “what is it?” The researcher answered this question the same to all who asked, describing it as “A scaled site demonstration platform for autonomous vehicles in construction operations, currently being used to test HMI’s with the autonomous haulers”.

Following this description people either totally disengaged or became curious at the word “currently”. Suddenly, people began to give their own interpretations for its potential function.

One such quote include the concept of aligning the user involvement with collaborative actions between humans and autonomous machines not just other humans, “you should find ways to include more users interchangeably, like an MMO game”. This would allow more people to craft more unique individual experiences with the same equipment. Expansion and immersion of the user experience was addressed by the following two quotes, “okay, well how will people in the machines communicate with those autonomous ones?”, “It would be more interesting to drive the manual machines from that simulator” (referring to a Volvo CE wheel loader operator simulator). While this functionality would create functional training mechanisms they also enrich the context of the user experience. Adding these dimensions to the site could serve as a bridge to acclimate humans to the collaborative nature of future semi-autonomous sites.

Some key quotes revolved around the autonomous demonstration site activities and features. While watching the machines perform tasks, someone logically scanned to see who was controlling them, they asked, “So, nobody’s driving that right now?” in reference to the hauler running its route. The answer was no and to their delight the concept of the site became one of the future, not just a playground with fancy toys. Additionally, while observing HMI testing a spectator was curious about the verbal command over the haulers, they were not aware of how much control or when the connection was active in their question, “Is the machine listening to me?”. These questions reflected the designed features for testing trust derived from the functionality in the HMI features.

Other’s statements captured the observer’s perception of the real operations being simulated. Due to the scaled down nature of the demo site, perspectives were automatically shifted to reflect theorized future collaborative roles captured in this quote, “I feel like a site manager staring down at the operation”. This theme gained traction building off the genuine interest in the future scenarios of construction. Curiosity about the infrastructure requirements came in questions like, “How long can the real ones run for?” and “where and how do they charge up?”. This even expanded to the HMI potential with feedback about its real roll out features in the quote, “If they were real I’d like to see more granular data on the interface”. This kind of comment shows the users immersing themselves in the future usage.

4. Discussion:

Over the last decade, data mining has been recognised for its potential to profoundly shift decision making to be more transparent, informed and autonomous, and with less bias. While this has become a reality for the design of certain artifacts in the construction industry, the same cannot be said
for PSS or functional solution development. The work conducted in this case study aimed to address the issue of creating adequate user context for generating feedback on the human element in future scenarios. In this way, future PSS scenarios can be dissected and tested with minimal effort compared to construction of full scale machines and test sites.

The scale infrastructure in this case study was built to recreate the key interactions identified in foresighting of future autonomous construction sites. Although the data generated from the conducted testing was primarily qualitative in nature, the components of the site (i.e., machines and interface devices) are entirely capable of producing quantitative data similar to that collected by Akhavian and Behzadan (2013) who highlight the importance of factual data for as input for a construction simulation model.

It is claimed, that there is a trend in the simulation of construction fleet activities on estimating input parameters using expert judgments and assumptions. To have a reliable source of simulation input parameters, the authors used a model site and laboratory environment to validate their statement that a construction fleet operation can benefit from knowledge-based data-driven simulation model generation.

By streaming equipment data (such as position, weight and angle) and subsequently applying fusion and reasoning algorithms, Akhavian and Behzadan (2013) show promising trends in simulation quality of site operations. Based on this, equipment manufacturers have begun to take steps to include data gathering capability on active machines, yet this data serves to improve mainly maintenance and use phase services. This can lead to the sub-optimization of system elements when the goal is actually functional solution or PSS.

The application of new technologies in the construction and mining sectors is very much dependent on the productivity of the solution and how well it fits into the existing operation. Isolating the impact of individual changes in a complex system can be difficult which is why in engineering design, prototyping as a verb is an essential philosophy to finding flaws in concepts early when investment is low and design freedom is still broad (Furr and Dyer (2014)).

An overarching principle behind the scaled down site operations rests on the following theorem. Through a tangible experiential prototype platform embodying the idealized PSS concept environment, designers could backcast a series of iterative development missions for the five stages of PSS design: Planning, Idea generation, Sub-System, Detailed Design, Deliver and Use-Phase. With a scale site, more variations of PSS scenarios can be explored at an increased pace leading to more informal early phase decision making.

An important aspect is the flexibility of the prototype platform elements to support investigations into the various interactions engendered by functional system solutions. Furthermore flexibility extending to the customizable fidelity of the elements can focus the data gathering to answer specific design questions avoiding irrelevant feedback on external components. This can benefit the parallel development processes required for successful PSS design by creating a shared foundational vision of the future scenario across all perspectives during inquiry.

5. Conclusions:

Through targeted inquiry, a cyclical approach can be applied to generate/mined data on future scenarios to drive their development. Beginning with designing the future PSS scenarios to explore before applying experiential prototyping techniques to create a holistic interaction exposing users to tangible artifacts set in the desired context. Data is generated from the user engagement with the scenario and its artifactual components, then mined to provide input for design decisions.

Thus, data driven design, as it is defined by the authors, is the deployment of data, generated through data mining activities, during all design process stages of a product or a specific service as well as product service systems. In that context, the data can have different characteristics such as temporal physical machine and / or process data, contextual data, factual data, user feedback etc. but adds to generate a basic knowledge about the nature of the observed system.

7. Future Work:

Taking the next logical step with this research is to add more granular data capturing devices to the site equipment while at the same time finding the conversion factors for translating the scaled down data to full scale operational inputs. Additionally, converging this quantitative data with qualitative user feedback as a holistic way to drive design decisions.

8. References:

Abderrahim M., Balaguer C. (2008). Trends in robotics and automation in construction. University Carlos III of Madrid, Spain.

Akhavian, R., & Behzadan, A. H. (2013). Knowledge-based simulation modeling of construction fleet operations using multimodal-process data mining. Journal of Construction Engineering and Management, 139(11), 04013021.

Alonso-Rasgado, T., Thompson, G., Elström, B-O. (2004). The design of functional (total care) products. Journal of Engineering Design, 16(6), 515–540.

Anand, S. S., & Büchner, A. G. (1998). “Decision support using data mining”. Financial Times Management.

Ameen, N., & Safawizadeh, H. (2017). Visualizing Material on Site for Machines and Humans: A Step toward an Autonomous Construction Site (Master Thesis, Blekinge Institute of Technology). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:bth-14937
Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., 2007. State-of-the-Art in Product-Service Systems. Journal of Engineering Manufacture, 221 (10), 1543–52.

Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M.J., Sridhar, M., Parsons, M., Bertram, N., Brown, S. (2017) Reinventing Construction: A route to higher productivity. Available at: http://www.mckinsey.com/industries (Accessed: 10 October 2017).

Bertoni, A., & Larsson, T. (2017). Data Mining in Product Service Systems Design: Literature Review and Research Questions. Procedia CIRP, 64, 306-311.

Breazeal, C., DePalma, N., Orkin, J., Chernova, S., & Jung, M. (2013). Crowdsourcing human-robot interaction: New methods and system evaluation in a public environment. Journal of Human-Robot Interaction, 2(1), 82-111.

Buchenu, M., & Suri, J. F. (2000, August). Experience prototyping. In Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques (pp. 424-433). ACM.

Cook, M., Bhamra, T.A., Lemon, M., 2006. The transfer and application of Product Service Systems: from academia to UK manufacturing firms. J. Clean. Prod. 14, 1455-1465.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. Journal of Engineering Education, 94(1), 103-120.

Florentine, E., Ang, M. A., Pendleton, S. D., Andersen, H., & Ang Jr, M. H. (2016, October). Pedestrian Notification Methods in Autonomous Vehicles for Multi-Class Mobility-on-Demand Service. In Proceedings of the Fourth International Conference on Human Agent Interaction (pp. 387-392). ACM.

Furr, N. R., & Dyer, J. (2014). The Innovator's Method: Bringing the Lean Startup Into Your Organization. Harvard Business Press.

Isaksson, O., Larsson, T.C., Rönbäck, Å.O. (2009). Development of product-service systems: challenges and opportunities for the manufacturing firm. Journal of Engineering Design, 20(4), 329-348.

Jung, M. F., Lee, J. J., DePalma, N., Adalgeirsson, S. O., Hinds, P. J., & Breazeal, C. (2013, February). Engaging robots: easing complex human-robot teamwork using backchanneling. In Proceedings of the 2013 conference on Computer supported cooperative work (pp. 1555-1566). ACM.

Lynas, D., & Horberry, T. (2011). Human factor issues with automated mining equipment. Ergonomics Open Journal, 4, 74-80.

Matthews G., Barber D. J ., Teo G ., Wohleber R. W. , and Lin J. , (2016) “Resilient Autonomous Systems : Challenges and Solutions,” in Resilience Week (RWS), 2016, 2016, pp. 208–213.

Matthews, M., Chowdhary, G., & Kieson, E. (2017). Intent Communication between Autonomous Vehicles and Pedestrians. arXiv preprint arXiv:1708.07123.

Mitchell TM. Machine learning. 1997. Burr Ridge, IL: McGraw Hill. 1997;45(37):870-7.

Mont, O. K. (2002). Clarifying the concept of product–service system. Journal of cleaner production, 10(3), 237-245.

St.Clair A., Atrash A., Mead R., and Mataric M.J. (2011) Speech, gesture, and space: Investigating explicit and implicit communication in multi-human multirobot collaborations. In AAAI Spring Symposium: Multirobot Systems and Physical Data Structures.

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business strategy and the environment, 13(4), 246-260.

Vaussard, F., Fink, J., Bauwens, V., Rétornaz, P., Hamel, D., Dillenbourg, P., & Mondada, F. (2014). Lessons learned from robotic vacuum cleaners entering the home ecosystem. Robotics and Autonomous Systems, 62(3), 376-391.

*Volvo Concept Lab* 2017, viewed 10 October 2017, <http://www.volvogroup.com/en-en/about-us/r-d-and-innovations/volvo-concept-lab.html>.

Williams, A. (2007). Product service systems in the automobile industry: contribution to system innovation?. Journal of cleaner Production, 15(11), 1093-1103.

Winqvist, D. (2016). Augmenting communication channels toward the evolution of autonomous construction sites (Master Thesis, Blekinge Institute of Technology) Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:bth-12752

Yin, Robert K. (2014). Case study research: design and methods. 5. ed. London: SAGE
