EVALUATING PROTOTYPING SUPPORT IN EARLY TRANSFORMATIVE PSS DESIGN

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ABSTRACT

Prototypes are an established tool for rapidly increasing learning, communication and decision making rationale for design projects. The proven success has spawned a litany of approaches and methods for building and planning the efficient planning and construction of prototypes. Translating these methods into simple usable tools to assist novice designers has generated broadly applicable canvases to support prototyping across the design process. Product Service System design has similarly introduced prototyping methods and tools into the process. Presently there is a lack of support for generating early phase tangible prototypes for functional PSS design aimed at more radically innovative solutions instead of currently dominant traditional products with traditional add-on services. This work explores the viability of utilizing existing prototyping support tools in the context of early PSS design through workshops with student designers and practitioners. The data from these workshops illuminates the alignments and misalignment gaps presented as guidelines to enable better support for early PSS designers.

Keywords: Product-Service Systems (PSS), Prototyping Support, Early design phases, Conceptual design

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1 INTRODUCTION

The early stages of design suffer the most from the designer's paradox where knowledge about the solution and problem are at their lowest, but the design freedom is at the highest (Ullman, 1992). All projects are bounded by a timeline and it is in the designers' favor to conduct as much learning as possible as early as possible in the process. Accelerating the learning helps to retain the early design freedom for producing the most optimal solution before resource constraints limit the amount of change available. A central tool in the designer's toolkit for accomplishing accelerated learning is through prototypes (Leifer and Steinert, 2011).

Modern product complexity demands expanding design teams towards integrating different domains and disciplines (Exner et al., 2015). In these transdisciplinary settings prototypes can be a fundamental tool to enhance communication (Buchenau and Suri, 2000)(Brandt, 2007), learning (Leifer and Steinert, 2011), and decision making (Kriesi et al., 2016) throughout the entire design process (Ulrich and Eppinger, 2000)(Otto and Wood, 2001)(Lauff et al., 2018a). Additionally, prototypes have been shown to boost design performance (Neeley et al., 2013)(Dow et al., 2009), influence stakeholder buy in (Greenberg et al., 2013), supplement designers' mental models (Lin and Seepersad, 2007)(Lemons et al., 2010), and enhance both technical and social skills development (Lauff et al., 2018b). To realize these benefits researchers have presented numerous prototyping methods and strategies which have been extensively reviewed in Menold's dissertation (Menold, 2017).

In the field of Product Service System (PSS) design a substantial body of research is devoted to incorporating prototypes, Exner et al. (2016) identified 14 methods integrating prototypes and Ilg et al. (2018) identified 35 methods with 18 unique PSS prototype types. Ilg et al.(2018) proposed a Prototype Application Chart correlating the prototype types with the phases of PSS design and development where they are most applicable. Exner et al. (2016) culminated their work with a new method emphasizing a focus on 3 progressive objectives and evolving the prototype fidelity throughout the process starting with paper based prototyping, ending with a supportive software solution. Even with this breadth of existing methods, the use of prototypes in the design of PSS solutions as an integrated system is less common. In particular, the use of physical prototypes is only covered in Exner et al.'s method (SHP4PSS) of the previously covered methods (2018).

Lugnet et al. (2020) have identified in PSS design a barrier exists to realizing potentially greater sustainability and circularity gains stemming from the misconception that the combination of products and services in PSSs is at risk of being interpreted in the design and development stages as a traditional product supported by traditional services creating nothing more than a product and add-on services. They continue to recommend the application of systems thinking to develop better approaches for building new shared visions at different system levels in the early stages of design. Here the use of prototypes is a promising measure to master these challenges and in particular physical prototypes in the early phases where the level of radicalness of the final solution is primarily determined (Leifer and Steinert, 2011). What we see in PSS design at large is a lack of simple and clear support for translating the abundance of methods and approaches for the creation of and planning of prototypes into design practice.

Based on these needs, the aim of this paper is to explore if and how the value created for design by simple effective tools like the Prototyping Canvas (Lauff et al., 2019) and the Prototyping Planner (Hansen et al., 2020) can be potentially translated into the support of early PSS design prototyping. The research questions are:

What dimensions or elements of existing canvas support tools directly translate to conceptual PSS prototyping?

What specific support do novice PSS designers need to enable better alignment of early PSS design exploration need and approaches?

2 BACKGROUND

2.1 Design Thinking

Traditional engineering is a relatively convergent process from a set of requirements via design concepts and specifications to realize products in an effective way (Dym et al., 2005). When the challenge is wicked there is a need for an approach that builds in tolerance for ambiguity and uncertainty, allowing for iterative exploration of the design space. Design thinking (DT) as defined by

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Brown (2008) is a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success. DT serves as a framework to explore early design phase ambiguity while building empathy between internal and external stakeholders.

A central concept of DT is that it builds in a perspective of alternating divergent and convergent inquiries and design cycles (Dym et al., 2005). Engineers are traditionally well-trained in solving problems and finding answers, whereas design thinking tends to uncover wicked problems where the investigations result in multiple, ambiguous and competing answers leading to further questions for investigation. DT is also known as a prototype-driven approach meaning problem and solutions spaces are explored iteratively through the creation of prototypes to represent concepts. In this context prototypes are not meant to represent final products, instead they are used to learn about the strengths and weaknesses of the idea and to identify new directions that further prototypes might take (Brown, 2008). Knowledge is created by expanding to and embarking on new generative design questions (Eris, 2004)(Dym, 2005) that leads to developing concepts of potentially different sets of future solutions. Thus, there's an expectancy to work iteratively in alternating divergent and convergent design cycles (Dym, 2005).

2.2 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). PSSs (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). Eight types of PSS are proposed by Tukker and Tischner (2006), which have been 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 a washing machine, the customer can sign an agreement for receiving clean clothes through a washing service.

Compared to the traditional one-sale model, designing these PSS types challenges engineers to raise their awareness of customer and stakeholders' needs along the entire product lifecycle, in order to realize solutions that are value adding for all the actors involved (Isaksson et al., 2009). The need to integrate several domains (i.e. product development, service development, recycling, etc.) means for organizations to move "downstream" knowledge (from the later phases of the lifecycle) into the early phases of the design process and raises the demand for methods and strategies that support collaboration and cross-disciplinary integration in design. A strategy to foster collaboration is to structure this knowledge in models: these shall enable design teams to play with the definition of design concepts, and to sort out the optimal combination of hardware and service that maximize the 'value' trade-off (Isaksson et al., 2015). However, how to build effective 'value models' to support trade-off activities and decision making in the early stages of an intentional PSS design is still an open question in literature (Isaksson et al., 2015)(Bertoni et al., 2016) and in practice.

3 METHOD

This work is part of a larger design research study conducted using Design Research Methodology, DRM (Blessing et al. 1995), thus reflecting a Descriptive Study II towards the evaluation of a prescribed support tool. The support tool in focus for this paper has been generally accepted as successful in the larger field of design and this study evaluates the fit for a more specific area of design (i.e. early phase PSS prototyping). Collaborative workshops were used as the setting for capturing as they allow for contextual walkthroughs and task analysis to be conducted by the researcher in a controlled environment where the support tools being evaluated are the foremost variable (Magnusson et al., 2011)(Ørngreen and Levinsen, 2017). The workshops were designed using the guidelines

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outlined in Thoring et al.'s (2020) work emphasizing the connection between the desired goals, outcomes and data capturing methods.

The context of the workshops was to develop a moonshot PSS solution for their given prompt and plan how to prototype their initial milestone(s). The PSS moonshot portion was framed using a locally designed canvas called the 10x canvas (Andrén and Sjöberg 2016) (an example can be seen in figure 1) through which the teams utilized forecasting to conceptualize an ultimate 10x impact PSS solution and backcasting to identify notable milestones which would enable their attainment of the moonshot.

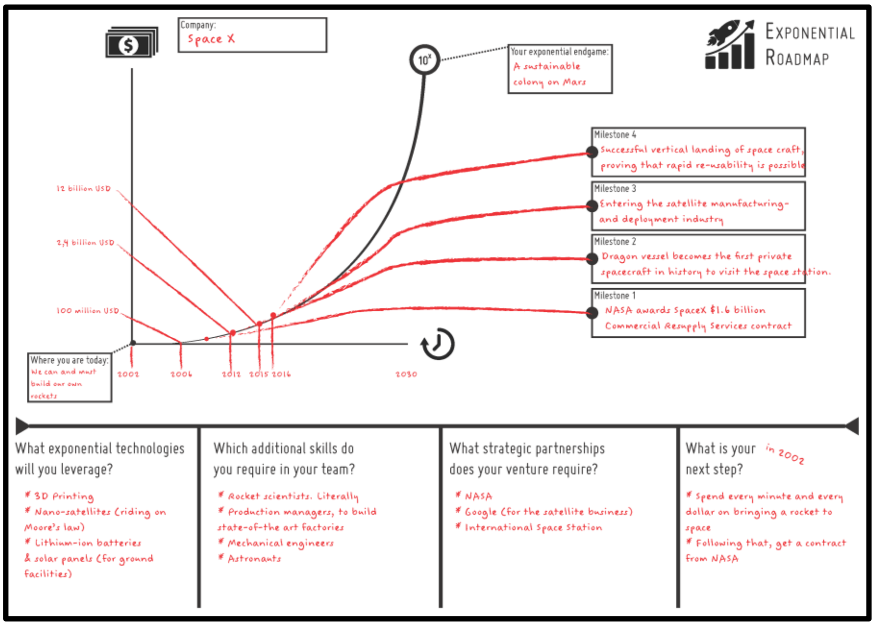

Figure 1. 10x Moonshot canvas example based on early goals of SpaceX '(Andrén and Sjöberg 2016)

Following this was the prototyping phase, where the participants were introduced to their canvas through two instructional videos as well as being supplied with examples for reference. The canvas used in the workshop was Lauff et al.'s prototyping canvas (2019) as well as supporting materials (an example can be seen in figure 2). Upon completion of the session, the participant teams presented their PSS moonshot concepts and prototyping plans.

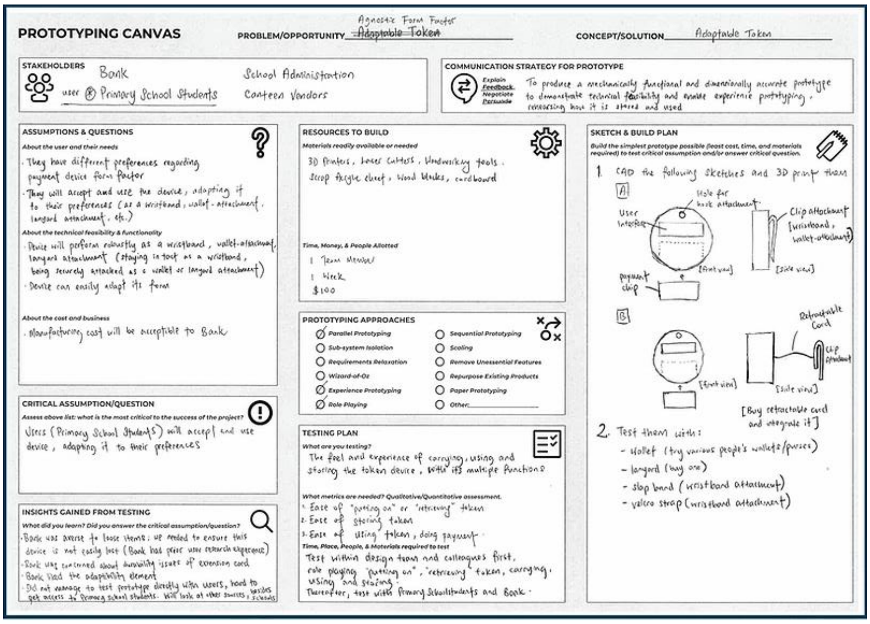

Figure 2. Prototyping canvas example of prototyping a physical product concept (Lauff 2019)

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The qualitative data was gathered through direct observations and notes, periodic inquiry during the session, feedback and short interviews. The scope of this research is not to fully validate existing tools to support the emerging nuanced requirements of a more ground-up PSS design, but to assess their various positive elements and establish preliminary guidance for further development of a targeted tool. As per this scope, the investigation workshop is targeted to generate insight on the two mentioned canvases' applicability. The workshops were conducted on two separate occasions following the general outline depicted in figure 3. This format is aimed to simulate an early phase loop of more solution-focused PSS design steering the participants away from servitization or pure product development. While the workshops are conducted in artificial environments as opposed to long-term industrial partnerships, studies have shown this is where a big part of research experiments testing new tools and methods are conducted (Ellis and Dix 2006). The first session of the workshop involved 18 fifth-year master's level design engineering students split into 4 groups working on their own problem prompts, the second being conducted at the Design 2020 conference with 1 group of 4 including academics and design practitioners working on a prompt generated for the session. The students in this research can be considered advanced beginners as Kleinsmann et al. (2012) state, who understand how to conduct design and take into account situational factors. This sample of participants while not broad is a diverse and representative sample of novice designers and more seasoned practitioners from academia.

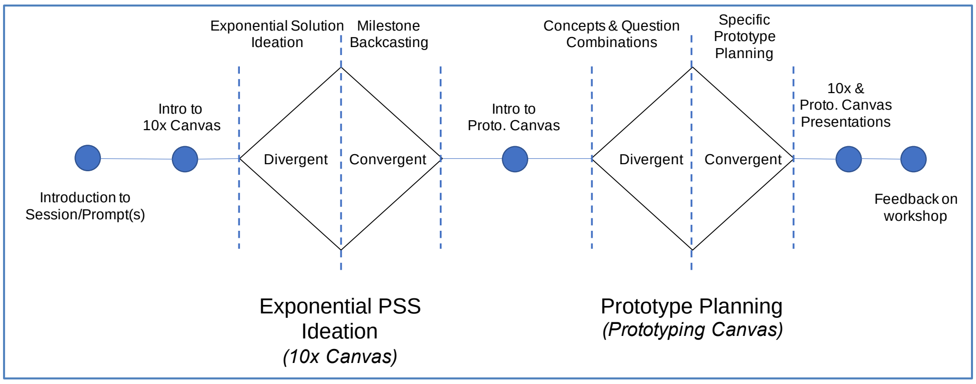

Figure 3. Workshop sessions outline

Synthesis of the results data was conducted through triangulation between the direct observations, direct feedback and analysis of the related frameworks and support tools. As the collected data is qualitative and contextual in nature the results are presented embedded in the discussion where they reinforce the insights and implications being presented.

4 PSS IMPACTS

Traditional PSS design, consisting of a product combined with add-on services, managed through waterfall or cascading style structural or organizational means does not support the more holistic PSS design being promoted in current literature. The flip side of this is that no complete method for accomplishing a holistic PSS design exists to date either. In this research we are focused on illuminating early stage challenges, particularly how they relate to innovating towards systemic changes through PSS. The driving term here is system, while dedicated support exists specifically for the area of system visualization in the form of business model canvas, service blueprinting or PSS blueprinting, actor network maps, these tools are entirely 2D representations and deemphasis tangible representations of even the potential tangible artifacts in the PSS concept. The design prototyping support tended to facilitate a narrow interpretation by the participants of the canvas towards pure artifacts of the system, or sub-systems as evident by the observation below:

Workshop participants displayed a lack of awareness connecting their "solution concept" to the larger system being addressed. This was evident both directly from the completed canvases and during the presentation phases. Of the 5 teams involved only one canvas called out a particular tangible prototype while most chose to implement apps or immediately into software for testing, while omitting the potential earlier functional prototyping steps.

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PSS solutions consist of two fundamental types of elements Products and Services, also referred to as "hardware" and "software". The generally accepted differentiation is that products are different from services, or more precisely, that manufactured things are different from activities, processes, or facilitation to support another party in some way (Grönroos, 2011). These components exist with interdependencies determining how the overall system will function to satisfy the problem, this was omitted from the presented concepts leading to the following analysis:

Participant concepts and prototypes had a weak connection to identifying or testing their overall core value adding elements. This was most evident in the lack of connection between their moonshot, assumptions being explored and the identified testing metrics. Best exemplified by a team working towards in home healthcare solutions who wanted to radically decrease loneliness of elderly through in-home connected devices. Then in the prototyping phase they got immediately immersed into tech challenges which would take months of coding to test instead of utilizing some smoke and mirrors or sub system isolation to gauge interest of their potential customer base.

The implication of leaning towards radical solutions is that the problem space is less bounded, exponentially increasing the ambiguity. One term used to categorize these problems is wicked where the unknown unknowns are rampant. Designers often struggle early with these type of problems identifying how or where to begin. In DT prototypes are recommended as a means for exploring concepts for their solution-problem fit. Teams' concepts and prototypes exhibited a red thread throughout the workshop connecting their moonshot concepts down to a narrow prototype. Typically, this is viewed as a success when aiming for a project milestone prototype where convergence is at the core of the decisions. These decision making milestones are prevalent in the analytical process management of design projects and they can result in a more narrow interpretation of prototypes as a negotiating object. It fulfils the greater purpose of representing ideas, communicating concepts across disciplines, yet when aimed at convergence designers are inclined to identify only flaws or components to retain. Neglecting one of the driving forces of early divergence, critical to the exploration of both problem and solution space, is evident in all of the participants' work. This is best summed up in the following observational note:

Although explicitly stated as an option on the canvas, in the instructional materials and apparent in the provided examples, participants did not express interest in the communicative power of prototypes to explore the unknown unknowns. This refers directly to the top right box on the prototyping canvas, where it guides the users to identify the overall interaction strategy of the prototype. Most of these teams were working in the early conceptual phases yet nearly every team jumped straight into technical challenges of feasibility sans one team which focused on the interaction with their customer. The prototypes focused on direct feedback on a component or feature if the testing included a potential customer interaction at all.

This type of prototype is critical to enable designers or teams to measure bidirectionally the concept fit to the problem and critically also the problem comprehension. Neglecting to explore the problem space is not unique to PSS design, but is perhaps more important as the problem space is exponentially larger. It is possible to reflect that this could be influenced by the novice designers' limited tacit knowledge, but when it is clearly stated as possible in multiple places and forms, inferences a need for particular support here is warranted. Simultaneously it could be perceived that the participants lacked the cognition of their current design phase. This was evident in the presented prototyping activities chosen not being conducive with early phase exploration.

5 REFLECTION ON POTENTIAL SUPPORT GUIDANCE

Direct feedback from the participants yielded provocative yet actionable insight towards improvements resonating with the above observations and analysis. In combination, these encompass the core guidance of what is needed to support this early PSS concept generation and prototyping.

- Addition of a timeline to retain the reference to project phases

In this context, the timeline refers to the project or concept timeline represented linearly on the canvas similar to the 10x canvas but more subtly as a reminder. Effectively the timeline could serve as a

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consistent reminder to the designer or team of where in the process they are and it could be reasonably suggested that it would support the cognition of the following underlying designer's needs: *The phase, The fidelity, The type and The desired outcomes*. We imply this cognition capability based on the same principles that support the canvas as an effective tool. The timeline potentially grounds the concepts to a point in time if taken into account instead of allowing all concepts to exist in the same temporal plane the designers could more rationally organize them based on feasibility or functional limitations for investigation. This could enable a decoupling from or better identification of perceived limitations in pursuing radical challenges by more easily segmenting concepts into attainable today or attractive to pursue for the future.

- More functional model connection to view overall interactions

To enable transparent visibility of the functional interactions could satisfy the following needs: Tracing connection to larger system, Product and Service interdependencies and Enabling tracking of core value solution components. This implies the capability of function mapping to better identify the tangible and intangible components comprising the overall concept and how it plugs into or merges with the existing system. This is increasingly important in radical innovation of systemic intervention.

- The creation of a meta-tool to identify appropriate approaches

Each designers' tacit understanding of how/when/why to prototype is different due to their background and design experience. To account for this a meta-tool in the form of a chart or semi-intelligent digital tool suggesting the optimal prototyping approaches could enable novice designers to make better prototyping decisions and support experienced designers by perhaps expanding their repertoire. This potential engine could best function for this purpose if based on the suggested variables below in table 1:

Table 1. Suggested variables to drive prototyping approach recommendations

Variable	Description
Objective (hardware/PSS)	e.g. are we creating a crash beam or a mobility solution?
Phase (early-stage/late-stage)	e.g. are we in the earliest conceptual stages or at the detail design stages?
Type (lo/hi fidelity)	e.g. are we talking paper mockups or fully functional prototypes?
Purpose (diverge/converge)	e.g. do we want to create new solutions, critique current solutions, or decide on a solution?
Stakeholder (provider/user)	e.g. who do we communicate with, the end-user, partner companies, the boss, the team colleagues, the department across the hall?
Engagement (hands-on/hands-off)	e.g. are we interacting with the prototype to gain insights or do we rather passively view it?

To visually illustrate a potential meta-tool, figure 4 is a mock-up example if it took the form of a digital tool driven by a recommendation algorithm (not present in the example) based on the computer or smartphone both of which are ubiquitous tools in modern work. Further investigation is needed to identify if a six variable static recommendation chart can be clearly interpreted or if it would cause more problems than benefits for those who prefer paper-based tools.

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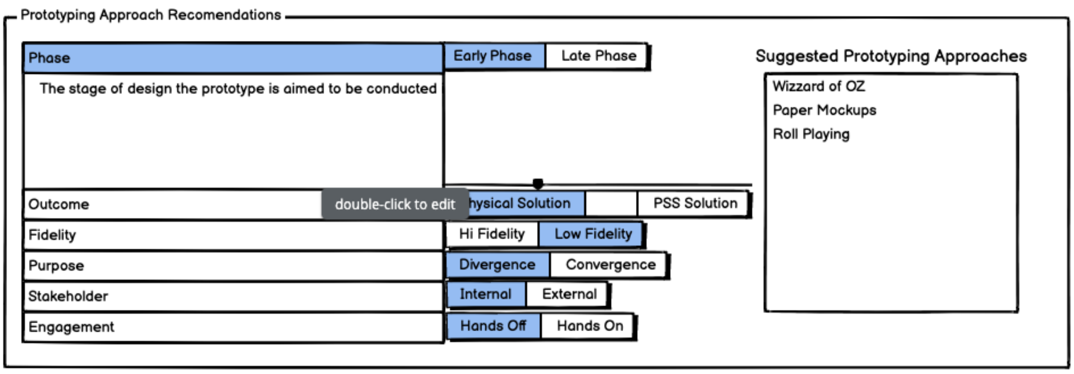

Figure 4. Visual mock-up example of how a suggested digital tool could potentially look

5.1 Delimitation

It is not the opinion of these researchers that one support tool should serve as a catch-all to alleviate all challenges. Suggestions for improving guidance provided here could take many forms as a workshop, canvas sequence, online tool, playbook, etc. It is worth noting that although the workshops were not conducted in a way where all variables can be controlled, this is the nature of design research. Some of the observations, although triangulated, could also reflect issues with novice designers at large, yet it is our opinion that when attempting to design radically innovative system-based PSS solutions perhaps we are all novices in this area.

6 CONCLUSIONS

Circling back to the research questions we deduce many dimensions of the existing support are practically translatable to PSS prototyping. Specifically, the canvas format had the desired effect of increasing cognition of multiple factors imperative to successful rapid prototyping and prototyping planning evidenced by the completed canvases' internally consistent logic from assumption to prototype plan. Many of the dimensions across the existing support tool including sketching, stakeholders, learnings and approach suggestions showed a positive impact on enabling the participants to rapidly increase their capability to generate clear prototype concepts. However, analysis of the observations and insights depict a shallower engagement with each stage of the canvases leading to poorer quality constructive alignment with the tenets of DT and requirements of early phase design. That said, the expertise of the designer using the tool may be a larger implication of the tool's success. If we invert that presumption, the "paint by numbers" nature of canvases mixed with ambiguously suggested approaches for prototyping potentially being interpreted as "all approaches are valid regardless the relevant variables" the tool format may also be considered to fail the novice designer in areas where they struggle.

Answers to the second question have provided a provocative base on which to begin modification of the existing tools and/or creation of meta-tools towards enabling the creation of early phase PSS concept prototypes which raise or reflect core design questions. These core question prototypes should aim to engender the power of generative inquiry to better equip the designers as they navigate and explore the ambiguity associated with these early PSS design phases.

The suggested guidelines could be acted upon towards the creation of additional support or towards meta-support for the selection of appropriate approaches. Both are identified as impactful towards the end result. They could also be reflected upon to run a larger inquiry to better validate the results. The overall outcome of any further tools should be to enable designers to better align their needs with those of the current design situation. This could also benefit practitioners who unknowingly suffer from a lack of creative confidence in applying less familiar approaches to prototyping, although this would need to be verified as a need before expending research resources. Additional inquiry in this area could also focus on the identification and classification of prototyping approaches which best support the suggested variables in section 5 or a review of the most impactful variables for determining the prototyping approach to situation fit.

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