

Benefits of External Representations in Service Design: A Distributed Cognition Perspective

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ABSTRACT A defining characteristic of service design is the use of external representations, which support designers in making intangible aspects of services accessible and shareable. Both current and future states are externally represented, using different service design techniques, for the purposes of articulating insights, learning, communicating, collaborating, and maintaining empathy for customers. The purposes of, and techniques for, making external representations were compared with benefits of using external representations to think, suggested by the theory of distributed cognition. The analysis indicated that the service design techniques could be divided into two

groups: definite and ongoing. The analysis also revealed that none of the included techniques explicitly supported designers in making multiple simultaneous representations of services. The research contributes knowledge about how the externalizations relate to benefits of making external representations, and about how to choose and use different service design techniques based on theories of distributed and situated cognition.

KEYWORDS: external representations, service design, cognitive science, distributed cognition

Introduction



Early service design discourse has to a large extent focused on the tools and techniques used in the field.

In the first few years a category of techniques which are often referred to as visualizations were discussed at the Service Design Network conferences, on blogs and social media. As the discipline has matured the prototyping of services has received much discussion in the public discourse. A common trait of visualizations and (service) prototypes is that they represent¹ services in an external way, moving them out of the single designer's head to a shareable medium.

Much research has been dedicated to how representations support service design, indicating that it is a central aspect of service design practice to make representations of services. This means that to become a successful service designer one needs to be skilled in the craft of creating representations of services. Doing so means using design techniques, which can be seen as the available tools for a designer. Using a toolbox metaphor: one has to fill one's toolbox with various tools, but just having a full toolbox does not make someone into a craftsman. It is just as important to learn which tool to use for which purpose and to be able to find new solutions when the existing tools are not enough.

This paper will investigate the techniques or tools used for creating external representations in service design with the help of the theory of distributed cognition. The investigation will highlight the pros and cons of the techniques from a novel perspective for service design research, thus making it possible to help service designers hone their skills in choosing which technique to use when, as well as aid educators in planning their teaching of aspiring service designers.

Distributed Cognition²

Distributed cognition has its roots in cognitive science. The birth of cognitive science³ as a research field can be traced back to the mid-1950s when important steps were taken in both the fields of

artificial intelligence (computer science) and linguistics. Together with psychology, philosophy, anthropology and neuroscience, they form cognitive science: a 'multidisciplinary scientific study of cognition and its role in intelligent agency. It examines what cognition is, what it does, and how it works' (Bechtel and Graham, 1999: 3). As the field developed, criticism grew against a focus of cognitive research on disembodied processes in individual minds, and a lack of research exploring how humans think and act in different contexts, using a lens of humans as socially and culturally situated beings (Clancey, 2009; Hutchins, 1995; Wærn, 1999).

The emphasis on finding and describing 'knowledge structures' that are somewhere 'inside' the individual encourages us to overlook the fact that human cognition is always situated in a complex sociocultural world and cannot be unaffected by it. (Hutchins, 1995: xiii)

Clark (1999) later expressed a similar view and added an embodied perspective: '[b]iological brains are first and foremost the control systems for biological bodies. Biological bodies move and act in rich real-world surroundings' (Clark, 1999: 506). These views of humans as socially and culturally situated beings with embodied cognition constitute the distributed cognition perspective.⁴

Distributed cognition can be seen as a framework for understanding how people think and act, not as a result of brain activity alone, but as a result of the constant interplay between brains, bodies and situations. External representations play a special role in this interplay, and allow for more elaborate and complex 'thinking' than would otherwise be possible. One of the main actors involved in the development of distributed cognition is Edwin Hutchins (1995). The theory of distributed cognition was a result of observations of human activities, where Hutchins and others saw that humans use their surrounding environment to enhance memory and other aspects of cognition. For Hutchins it was clear that 'there is nothing metaphorical about talking about the bearing record books [in a ship's cockpit] as a memory, or about viewing the erasure of lines drawn in pencil on a chart as forgetting' (Hutchins, 1995: 363). According to the theory, cognition is distributed in time, location and across agents (individuals and artefacts). Together these form systems, a key notion in distributed cognition.

Key concepts within the distributed cognition framework are the 'cognitive system' and the 'communicative pathways', which are the way in which people communicate through the system i.e. phones, email etc; and 'propagation of representational states' which refers to how information is transformed across different media such as maps, paper, human memory etcetera [...]. (Nilsson, 2010: 39)

This means that a designer, or a design team, form a cognitive system with their techniques and other available material in studios or other locations. Design locations are often rich with external representations of design ideas and good solutions, which can be further refined or built upon (Binder *et al*, 2011). Hutchins (1995: 117) argued that '[r]epresentational states are propagated from one medium to another by bringing the states of the media into coordination with one another'. A major part of the work with coordinating the various states is thus done by the external representations being internalized in such a way that they can be re-represented into other states. Working in the distributed cognition vein of cognitive science, David Kirsh's research focuses on the different benefits of using external representations, and what is gained by using them.

Among Kirsh's research projects, several focus on exploring how designers and dancers use their cognition in the creative process, and the role external representations play in this. In 'Thinking with external representations' (Kirsh, 2010), many of the findings from those projects were summarized. For Kirsh, external representations are the things we humans make outside our heads to help us think, such as annotating texts, rearranging puzzle pieces and pointing. He identified seven reasons for why creating external representation aides thinking:

1. They ease the processing in inferential reasoning⁵: Take a jigsaw puzzle as an example – solving a puzzle in the real world where you can move around and test if the pieces fit is much easier than trying to solve the same puzzle mentally (imagine having a photo of the puzzle with all the pieces clearly visible).
2. External representations can serve as a shareable object of thought: 'When someone externalizes a structure, they are communicating with themselves, as well as making it possible for others to share with them a common focus' (Kirsh, 2010: 444).
3. They make persistent points of reference: by writing a thought down we are able to go back to that exact thought in the future, whereas we might forget it or change it unknowingly if it is kept only in mind. Another aspect important for designers is that it makes ideas more susceptible to critique, such as when prototypes are built to test ideas.
4. They facilitate re-representations: By using various tools it becomes easier to transform representations into new states, states which facilitate understanding and solving the mental task. Kirsh (2010) explains this with help of maths problems; it's much easier to solve $x = \sqrt{2209} - 5$ if one re-represents $\sqrt{2209}$ as 47, thus arriving at $x = 47 - 5$.
5. In comparison with internal representations, external representations are often more natural representations of structure: Kirsh (2010) explains this point with music as his example. Few (if any) can hear music in their heads the way it sounds outside of their

heads, 'so, for most people, to make sense of music the first thing to do is to play or listen to it' (Kirsh, 2010: 450).

6. They make it easier to deal with complex information by using multiple representations: 'Without interacting with multiple representations certain discoveries would simply be out of reach. Visual designers who move between pen and paper, 3D mockups and rapid prototypes are familiar with the [...] type of process' (Kirsh, 2010: 451).
7. They make it possible to create arbitrarily complex structures: By building models, we can easily test more complex structures than would be possible using only our minds; for example, a functional model of our solar system will easily tell you how other planets align given certain circumstances, whereas trying to figure that out mentally would be extremely difficult.

This list shows the many ways external representations facilitate our understanding and cognition. The next section introduces the most common ways of creating external representations in service design.

External Representations in Service Design

An important aspect of design is the ability to make models, sketches, and other representations of existing and future states. These representations are external representations of designers' thoughts, impressions, interpretations and ideas. External representations are used in all design disciplines, and are valuable for many reasons throughout the design process (Arvola and Artman, 2007), in service design as well as in older design disciplines. Researchers (Blomkvist, 2011; Kimbell, 2009; Segelström, 2013) and service design organizations (Service Design Network, n.d.) highlight two main types of external representations in service design: visualizations and prototypes. There are no clear-cut definitions of the two, and the exact meaning of the words depends on who uses them. However, they can roughly be described as follows.

Visualizations of services are depictions of current and/or future states of the service. To visualize services, service designers use techniques that have been adopted from other disciplines such as service marketing, interaction design and movie-making as well as having been developed within the field (Segelström, 2010). Due to their nature of being service depictions, visualizations are primarily used as summarizations of research on a current service or as the deliverable of a project, showing how the new service is suggested to be structured.⁶

Prototypes are used for prototyping, and aim at improving the quality of the ideas and solutions suggested by service design projects through the testing of whole or parts of service ideas (Blomkvist, 2011). The testing focuses on the customer's experience as well as the service delivery process. Prototyping is usually an iterative process, where ideas are refined over time, as problems or

opportunities in the original idea(s) are discovered. Similar to visualizations, prototypes and prototyping knowledge is based on what has been learned by older, related fields but has also been forced to find solutions to new issues which arise when it is services rather than products and interfaces which are prototyped (Blomkvist and Holmlid, 2011; Arvola *et al*, 2012; Blomkvist *et al*, 2012).

Visualizations and prototypes are tangible objects produced and used during service design projects. Rephrased into the language use of Kirsh, visualizations and prototypes are external representations of cognitive systems (services). Simultaneously, they are important parts of the cognitive system that is designing the service (a design team, the location and other stakeholders involved in the design work).

Why use external representations?

What external representations are and various perspectives on how to differentiate them is introduced above, but little has been said on the motivations for why external representations are used in design in the first place. When discussing design, Kirsh (2010) used the term models to denote a subgroup of external representations that designers use. For instance, he used the examples of scale models, used by architects, to show how external representations aid the design process. He suggested that:

- they serve as shared objects of thought that are not tied to the author of the representations, making them intersubjective,
- they enforce consistency in the sense that they prove that the parts of a representation can exist simultaneously, and
- they reveal unanticipated consequences by being persistent and independent, thus allowing different viewpoints and ways of interaction.

These motivations for using external representations are similar to the reasons mentioned by service designers, for using externalizations. Two interview studies (Blomkvist 2011; Segelström 2010, 2013) have contributed to our knowledge about service designers' motivations for using visualizations and prototypes respectively.

The study by Segelström (2010, 2013) found that there are three main reasons for visualizing according to service design practitioners:

- articulate insights
- communicate insights
- maintain empathy

Blomkvist had a somewhat wider focus for his research, focusing on the practice of prototyping. His middle bullet point, however, closely relates to Segelström's findings. Blomkvist found that for service designers 'service prototyping is an activity that is:

- central to their work [...],
- about making services visible, to learn and communicate about services and
- collaborative' (Blomkvist, 2011: 71–72).

The reasons for prototyping are to learn, through exploration or evaluation of service representations, to communicate and to collaborate. We thus see that reasons for using external representations that service designers highlight are about easing the communication about services and facilitating learning of new insights about the service's components. Put together, the reasons found among practitioners for making external representations in service design can be seen in Table 1.

Table 1 Combined findings about the reasons why service designers use external representations

<i>Reason for externalizing</i>	<i>Description</i>
Articulation	As information about stakeholders does not equal (actionable) insights, service designers need to have the skill to transform the information to insights which can be used as design inspiration through analysis of the material. Making external representations aid the analysis (see e.g. Segelström, 2013: 58–59).
Learning	Can be divided into explorative and evaluative approaches. Exploring means building something to generate insights and generate ideas, whereas evaluating means building something based on an idea about the intended outcome and then testing how the representation is experienced.
Collaboration	Coordination of activities and externalizations of ideas to make them shareable.
Communication	Using representations to show external stakeholders current or possible future states.
Maintaining empathy	The use of external representations to remember the insights gained during stakeholder research even as weeks and months have passed.

Service representation techniques

When discussing service designers' use of external representations in conjunction with theories on distributed cognition, it is interesting to think about which techniques are used today to represent services. As the goal of this paper is to provide knowledge about

how to improve the competence of choosing and using service design techniques, we examined a number of techniques for representing services.

The selection process of which techniques to analyse was as follows: all techniques for service design listed in the most prominent service design textbook to date (Stickdorn and Schneider, 2010) were surveyed. The techniques considered suitable to externally represent service processes (i.e. to represent services), but that were not considered a category of techniques in themselves (e.g. prototyping or storytelling), were selected. We considered techniques suitable to represent services if they represented parts or whole services, and if they could show change over time. For instance, a persona is not a representation of a service because it visualizes information about a customer, not a service. The analysis included both techniques that generate a persistent static representation of the service (e.g. customer journey), and techniques that do not (e.g. role-playing). The list of suitable techniques was then compared to the techniques which had been mentioned in the two sets of interviews (Blomkvist, 2011; Segelström, 2010, 2013). In total seven techniques were thus considered suitable for analysis through this process. The description of each technique is based on the descriptions in Stickdorn and Schneider (2010) who utilized a crowdsourcing approach to generate their list of service design techniques.

- Role-play – making enactments of specific touchpoints or service moments and exploring them, using e.g. theatre methods. Does not require props made for the occasion.
- Customer journey maps – a depiction of the customer's journey through a service with a focus on the experience.
- Blueprints – a depiction of all components, actions and interactions involved in a service delivery from back office procedures to receipts.
- Design scenarios – a description of a potential service use, used to explore certain aspects of the service.
- Storyboards – similar to customer journey maps, but focusing on the interactions and actions. The depiction is built in the same fashion as comic stories.
- Desktop walkthrough – using play dough, small figures and whatever is available a service location is created and explored.
- Staging – one or more locations are built, complete with props that support immersion in the service experience. The service is then enacted. Can be done together with external stakeholders.

Results

The reasons for visualizing and prototyping identified by Segelström (2013) and Blomkvist (2011) can be matched to Kirsh's (2010) suggested benefits of using external representations. It should, however, be noted that Kirsh has mainly used simple representations as

examples, rather than complex structures like services. The combined findings about the reasons for using external representations (Table 1) were mapped by the authors onto the benefits of making external representations. The mapping was done by looking at the descriptions of the reasons in the interviews, and by studying the benefits suggested in Kirsh (2010). The results of this mapping are shown in Table 2.

Table 2 reveals some interesting aspects of the purposes for creating external representations: the close matching of purpose for articulating insights and learning indicates similarities in the motivations for using external representations to reach those goals. Similarly, collaboration and maintaining empathy have the largest benefit for the same reasons identified by Kirsh – getting shareable objects of thought and creating persistent points of reference. Interesting for both the identified patterns is that one member stems from the prototyping interviews and one from the visualization ones. The one reason identified in both interviews, communication, is the only one which benefits from the more natural structure of external representation. Moreover, communication benefits from external representations being shareable objects of thought.

In total, five of the benefits of using external representations identified by Kirsh support the learning reason for making external representations, four support the articulation of insights, and

Table 2 Kirsh's suggested benefits of creating external representations matched with the reasons for using them in service design

<i>Benefit of external representation</i> <i>Source: Kirsh (2010)</i>	<i>Reason for using external representation</i> <i>Source: Combined interview results</i>
1. Eased processing in inferential reasoning	Articulation Learning
2. External representations can serve as a shareable object of thought	Communication Collaboration Maintaining empathy
3. External representations make persistent points of reference	Learning Collaboration Maintaining empathy
4. Facilitation of re-representation	Articulation Learning
5. External representations are often more natural representations of structure than internal representations	Communication
6. Easier to deal with complex information by using multiple representations	Articulation Learning
7. Possibility to create arbitrarily complex structures	Articulation Learning

Table 3 Mapping of service design techniques which serve as external representations to Kirsh's motivations for using external representations

Technique	Representation function							
	1	2	3	4	5	6	7	
Role-play	X	X		X	X			1. Eased processing in inferential reasoning
Customer journey maps		X	X	X				2. External representations can serve as a shareable object of thought
Blueprints		X	X	X			X	3. External representations make persistent points of reference
Design scenarios		X	X	X				4. Facilitation of re-representation
Storyboards		X	X	X				5. External representations are often more natural representations of structure than internal representations
Desktop walkthrough	X	X		X	X			6. Easier to deal with complex information by using multiple representations
Service staging	X	X		X	X			7. Possibility to create arbitrarily complex structures

collaboration, communication and keeping empathy are supported by two each. In the interview studies, the most strongly associated reasons for prototyping and visualizing were learning and articulating insights respectively.

Having explored how Kirsh's arguments for using external representations correspond to the reasons service designers say they use external representations, we now turn our attention to specific techniques. The techniques were also compared to the benefits of externalizing (see the matrix in Table 3), based on a thorough examination of Kirsh (2010). Most externalizations have all benefits to some degree, but for some techniques the benefits are more prevalent and have thus been plotted in the matrix.

Table 3 shows a pattern that creates two groups in the data: Role-play, Desktop Walkthrough and Service Staging on the one hand, and Customer Journey Maps, Blueprints, Design Scenarios and Storyboards on the other. The analysis also shows that none of the techniques represent complex information by using multiple representations and that most techniques also do not support the creation of arbitrarily complex structures, or at least not highly complex structures. The tables will be discussed further.

Discussion

We start by looking at the comparison between the reasons for externalizing with the suggested benefits. The investigation of Table 2 above showed that there was a linkage between reasons for visualizing and prototyping and the main benefits of using external

representation. One such pair were the activities of learning and articulating insights, which is supported by techniques that help designers improve inferential reasoning (benefit 1), facilitate re-representation (benefit 4), deal with complex information by using multiple representations (benefit 6) and create arbitrarily complex structures (benefit 7). Common to these benefits are their relation to active manipulation, at least in the case of benefits 4, 6 and 7. Unlike the other benefits suggested by Kirsh, they come into play by creating, using and re-representing external representations and are thus more suited for activities in design such as articulating insights or learning. Benefit 1 – eased processing in inferential reasoning – supports learning and articulation by making it possible to easily rearrange the representation, which in turn makes it easier to understand a service.

Among the more permanent benefits, we find that the activities of collaborating and maintaining empathy pair up in regard to how they relate to external representations. They both mainly make use of the persistency in point of reference and the shareable object of thought. The strength of being shareable objects also benefits communication about the service, just like the fact that external representations often are more natural representations than representations in people's heads. We thus see that being shareable objects of thought is one of the main benefits of external representations once they have been created and are stable in their form.

Comparing the techniques with the suggested benefits

Two groups of techniques, that follow similar patterns, emerge when you look at Table 3, comparing the service design techniques with the benefits of externalizing. What differentiates these two groups is whether they have a final stable state or not. We call the group of techniques that generate a final stable version of a service representation definite, and the other group is called ongoing, indicating that the representations are characterized by being instantaneous, extemporaneous and evanescent. The definite group consists of techniques where services are described using some kind of formal notation or convention for communication. The groups and their key traits are listed in Table 4.

Table 4 Two groups of external representations for service design

<i>Group type</i>	<i>Definite</i>	<i>Ongoing</i>
Techniques	Customer Journey, Blueprint, Design Scenarios and Storyboards	Role-play, Desktop Walkthrough and Service Staging
Key traits	<ul style="list-style-type: none"> – Shareable object of thought – Facilitating re-representation – Persistent points of reference 	<ul style="list-style-type: none"> – Support inferential reasoning – Shareable objects of thought – Facilitating re-representation – Provide a more natural representation of structure than internal representations

These two groups are very similar internally in regard to which traits they correspond to. In fact the only thing which breaks the pattern is that the blueprint technique can be used to create arbitrarily complex structures due to its highly formalized and abstract nature. Techniques in the ongoing group support inferential reasoning and are more natural representations of service. The ongoing group also has interactive representations, unlike the definite group where the final representation does not change as a result of interaction. The techniques in the definite group make persistent points of reference, enabling one type of collaboration. Collaboration is supported in both groups by shared representations of services. This should not be interpreted as a collaborative advantage for the definite group in the sense that e.g. blueprinting is more collaborative than role-playing. This is not an evaluation of the techniques in themselves, but rather an analysis of whether the representations of services used in the techniques can be used for certain purposes. The service representations of role-playing are highly situated (and can be evanescent), and thus cannot be used to collaborate in the sense of making persistent points of reference. Neither should the results be interpreted to mean that one group of techniques should be used for prototyping and not the other. Most techniques can probably be used both to visualize a current state as well as to prototype.

Dealing with complex information by using multiple representations

Being shareable objects of thought and facilitating re-representation are benefits associated with all the techniques, while none of them deal with complex information by using multiple representations. Multiple representations can be incorporated in many of the techniques but are not explicitly part of any one. In service design you might, for instance, combine a scenario, a storyboard and a persona to understand the current service offering. Using multiple representations like that helps designers think and understand the current situation better. Designers combine techniques and representations, and move between them in an action context (Arvola and Artman, 2007), to understand design situations from different perspectives. However, techniques that support this way of working in themselves are scarce.

One technique that does support multiple representations is sketching. Sketching is an activity used within all design disciplines to support both exploration and learning at early stages of ideation (Arvola and Artman, 2007; Buxton, 2007; Goldschmidt, 1994). It is also a useful form of external representation as it is easy to produce, and provides talkback (Schön, 1987) about the situation. By sketching out an idea, the designer gets quick feedback on its feasibility and can share it with others. Despite its apparent good match with the objectives of service design, sketching was not mentioned in Stickdorn and Schneider (2010), nor in the interviews conducted by Segelström

(2010, 2013) and Blomkvist (2011). Thus sketching seems to have been neglected this far, as a potentially important tool for service design, and could be one of the basic service design techniques.

For prototyping purposes there is no established technique that can be immediately applied in service design that supports multiple, simultaneous representations. Even though studies have shown that parallel prototypes have some associated positive effects (Dow *et al*, 2009), this is not exactly what is meant by supporting multiple representations. Instead, it would be interesting to explore ways of combining and/or adding elements of different techniques to support e.g. an understanding of both very detailed parts of services (touchpoints or service moments) at the same time as it allows manipulation of higher level service sequences and experiences.

Conclusions

Regardless of when representations are made and what they are called, they help designers think. Two groups of representations were identified in this research, definite and ongoing. The value of making persistent, stable representations that are not only tied to the current situation but can be saved, used and referenced was highlighted by this analysis. Without representations from the definite group, collaboration is constrained. Thus, only using the ongoing techniques: role-play, desktop walkthroughs, and enactments is not advisable as they do not result in persistent points of reference. The strengths of the ongoing group lie in their flexibility and their support for making choices based on natural and shared service representations. Only service blueprinting supports representation of complex structures sufficiently and no techniques utilize the benefit of multiple representations. This leaves the field open for new techniques, or the adoption of techniques from other fields that complement the existing service design toolbox.

The findings presented here should benefit service design educators in planning their teaching efforts. Students need to not only recognize a number of techniques; they also need to know how and why they should be used in specific contexts. This is something we should teach students of design in general and service design in particular. As definite and ongoing external representations support different aspects of the design process, teaching should be planned in such a way that students are familiar with both. Moreover, the importance of sketching for service design has been shown, meaning students should get ample practice in sketching service systems.

Notes

1. The term 'constitute' might be better suited to signify what is represented, especially in relation to prototyping. See Westerlund (2011) for a more extensive discussion. However, in this paper the more common 'represent' is used to imply that representations are the external representations of otherwise internal processes

or things which aid designers in thinking and exploring design situations and alternatives.

2. This section is based on parts of Segelström (2012).
3. In *A Companion to Cognitive Science*, cognitive science is described like this:

The expression cognitive science is used to describe a broadly integrated class of approaches to the study of mental activities and processes and of cognition in particular. Cognitive science is broad // in the sense that cognitive scientists tend to adopt certain basic, general assumptions about mind and intelligent thought and behaviour. (Bechtel and Graham, 1999: xiii)

4. Hutchins and Clark represent similar and related, 'but different (hopefully complementary), perspectives on cognition' (Hutchins, 2014).
5. The term inferential reasoning is problematic as there is no clear definition as is shown in Streumer's (2007) discussion of inferential and non-inferential reasoning. However, inferential reasoning can be described as reasoning based on facts (through abduction, induction or deduction) rather than beliefs. As shown by Luria (1976), these facts may in reality be culturally constructed.
6. The term visualization is used in various ways within design, which can be the cause of some confusion. The most common usage is information visualization (e.g. Spence 2007; Tufte 2001). Information visualization focuses on making (quantitative) data accessible through graphic visualization, whereas the starting point of service visualizations mostly is a qualitative story of the service experience. Furthermore, the word visualization has also been used to refer to how designers use sketching and similar techniques to help them think and move forward during ideation (Goldschmidt, 1994), whereas service design visualizations are used from user research to project delivery. That is, visualizations in service design encompass more aspects than those contrasted to here, with aspects of both information visualization and sketching being a part of visualizations for service design.

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Biographies

Johan Blomkvist has a background in cognitive science and interaction design. His current research, as a PhD student at Linköping University, aims to contribute knowledge about prototyping services. His licentiate thesis was based on an interview study with service design practitioners. Recently, the issue of how to extract knowledge about service prototypes, and a conceptualization of service prototyping situations have been the focus of his research.

Fabian Segelström works as a service designer at Usify. Prior to joining Usify he obtained a PhD in cognitive science with his thesis 'Stakeholder engagement for Service Design: How service designers identify and communicate insights'. Fabian's educational background is in design, cognitive science and anthropology. The research presented herein was conducted during Fabian's time as a PhD student at Linköping University.

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