

Design Creativity for Every Design Problem: A Design-by-Analogy Approach

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In this article, we propose Design-by-Analogy (DbA) as an approach with the potential to effectively support designers' creativity during ideation stage for design problems from Product, Service or Product Service Systems (PSS). We start by contrasting natural evolution and selection of species to economical human systems survival, where the options for companies are adaptation or mutation, where mutation offers innovation and a more immediate response to changing market conditions. We then present results from available DbA studies conducted in engineering and architecture domains as well as some recent studies in service domain that support our conjecture that DbA may be able to support the development of innovative ideas for design problems from any source. We hope this article triggers discussion about possible avenues and pitfalls for DbA research and broaden our understanding of design related cognitive processes.

Introduction

The phrase "struggle for existence" used independently by Charles Darwin and Alfred Wallace to support the theory of natural selection and evolution presents the need for survival as one key trigger for a response, which in the case of the species such responses may be adaptation or mutation. Both responses can be seen as evidence of design. Adaptation can be interpreted as a gradual or incremental change to a stimulus that usually corresponds to a requirement or need that is not fully or is just in part met (design variant). Mutation, on the other side occurs when a feature not pre-

sent before is exhibit, it entails a more dramatic change when compared to adaptation such as a shorter time for the attribute to emerge or a change in configuration, in this sense, mutation may be considered as novel, creative and even innovative design.

In the case of human systems and individuals, the need for survival at the system level may be presented as market share, trends and competition, while at the individual level it can emerge as means to improve one's surroundings or the way we interact with it. Responding to such triggering factors requires from systems and individuals creativity, energy and time; and how to respond to those triggers in a creative, fast and less resource consuming manner is itself a challenge.

In the case of organizations, design outcomes may come in a range from physical (tangible artefact), to transactional/virtual (service or process) or a combination of both, and the need for fast, resource intelligent and reliable production of innovative solutions imposes a challenge not only to designers from all domains, but to design methods and processes as well.

Design process' early stages where concepts are developed are critical to increase the likelihood of obtaining innovative results. Therefore, research oriented to understand the cognitive processes related to creativity along with design methods that enable the ability of producing novel ideas in a consistent manner for any kind of design problem are both critical and needed in design research.

Products, Services and Product Service Systems

Shostack defined product as a tangible object that exists in both time and space, while service are acts that only exist in time [1]. Vermeulen extracted four features that differentiate services from products: intangibility, simultaneity of production and consumption, heterogeneity and perishability (cannot be kept in stock) [2].

The view that considers products and services as different and opposing terms have been subject of debate [3, 4], however, in contemporary economies, it is clear that services and products are interconnected in varying degrees. This intermediate state that provides solutions at the interface of products and services has been termed product-service systems (PSS) [5, 6]. PSS enables the development of systemic solutions that involve partnerships between companies, stakeholders and customers [6, 7]. Interest in PSS from research and practice viewpoint has seen a strong increase.

Design's Early Stages Research

Some authors have stated that in the early stages where solution ideas are proposed and developed, design processes for products and services are no different, and that it is at the detailed design phase where they diverge [19], this however, requires further investigation considering that most of current approaches and methods for idea generation have been interdisciplinary and developed in the product domain.

A significant amount of studies to assist designers to improve creativity in design problem solving through the understanding of cognitive processes as well as development and testing of ideation techniques has been carried out over the last three decades. However, such studies have been carried out mostly on ideation methods for products, while services have not been studied as much. If we consider that services have had a steady growth over the last three decades, that they add now more than 65% of global economic value [8]; and that it is more frequent to find design solutions that require a combination of both, product and service; it is relevant to explore the transferability and efficacy of physical product ideation methods to virtual product design to expand current understanding of ideation methods.

Available studies on PSS are not focussed in its early stages of design. Most publications come from Europe (Sweden, Germany, Netherlands, Italy and UK) [9, 10] and some from Asia [11, 12, 13, 14].

Analogies in Cognition and Design-by-Analogy

Analogy is the association of a situation from one domain (source) that is typically poorly understood, to another (target) that is well-understood and that is possible due to relations or representations [15, 16]. Previous studies show a solid relationship between analogical reasoning and the cognitive processes associated with linguistics, long term memory retrieval, and categorization [17, 18].

Analogical design requires first accessing and then transferring elements from an existing solution for a design problem to the solution for another design problem. Such elements may be components, relations between them or more complex combination of components and relations [19]. The analogical transfer is enabled by the use of abstractions and analogical encoding [16].

Design-by-Analogy (DbA) is an approach recognized for its theoretical and practical support for fostering innovation in physical product design in engineering and architectural domains [20, 21, 22, 23, 24, 25].

DbA is based in the premise that the solution to a given design problem may already exist either in an analogous domain or in an analogous solution, and therefore, such solution may be extracted once the analogy connections between source and target are made.

The available DbA methods have a range of sources for analogical inspirations such as exploration of analogical categories by means of questions [26, 27], finding inspiration in the natural world [28], through biomimetic and bio-inspired concepts [29, 30, 31, 32, 33], from abstractions of functional models and flows [34, 35, 36], by means of design problem re-representation and semantic mappings [37, 25], through search engines and algorithms to identify potential analogies within digital sources, databases, and repositories [38, 39].

The result presented in the set of studies for product design are positive improving metrics such as quantity, quality and novelty of ideas, and shedding light on the potential for this approach as a consistent and reliable mean to achieve innovation.

DbA in Service Design

As stated in previous sections, there has been less exploration about design methods and techniques to support idea generation for service design and even less for PSS.

There have been some recent studies that investigate analogical reasoning using DbA methods such as WordTree and SCAMPER [40, 41] to assist designers during ideation stage. These studies engaged 97 experts (domain knowledge and experience) from around 38 companies to work on a service design problem through a semantic exploration of analogous solutions and domains. The studies evaluated the impact that the selected DbA methods had in creativity metrics (semantic transfer, quantity, quality and novelty) and design fixation when solving service design problems contrasted to non-assisted scenarios.

The exploration of DbA ideation methods for service design will provide designer with tools that may assist them to solve problems from diverse sources in a resource and time effective manner. If DbA ideation methods and techniques that have shown effectiveness to improve creativity metrics and manage design fixation are transferable from problem design to service and PSS without sacrificing effectiveness, then the effort,

time and resources invested to solve design problems may be reduced while the probability of developing innovative ideas may increase.

Both studies showed that DbA approaches will yield novel ideas, and that the quality of such ideas will be equivalent to the ones that service industries consider to be innovative or worth being awarded.

It is worth notice that quantity was not an absolute metric to assess creativity, since at least for service design problems the level of design variants was considered a fixation indicator and the repeated ideas (variants) were removed from total quantity of ideas produced.

From these studies, a base level for design fixation was exhibited in non-assisted scenarios, and it had different levels for the tested DbA methods. In the case of WordTree, the level was controlled (maintained) and in SCAMPER, the level increased. It is interesting to notice that design fixation in the case of SCAMPER did not negatively affect generation of novel ideas, but fostered idea refining.

Both DbA methods allowed overcoming the intangible nature of the problem, promoted semantic search and analogy transfer to develop novel solutions for the service design problem.

Discussion

How to support designers' creativity is essential to assure a reliable generation of innovative and successful designs. The nature of the design problem to be solved imposes an additional load to designers because the characteristics/attributes of products, services and PSS may not necessarily be the same.

New analogical connections when designing may be the answer to innovation. The development of new element combination through the establishment of different relations within available and maybe even distant elements while developing solutions along with its effectiveness validation will be key for the survival of the product, service and PSS companies.

The aim of this paper is to present available results about DbA ideation methods to successfully assist designers when solving product and service design problems. One tacit conclusion that may be drawn from these results is that DbA may -by extention- also be able to support PSS design as effectively as it does for product and service design.

The "struggle for existence" for human systems emerges in the form of design and development of product, service and PSS, where adaptation (design variant) and mutation (innovation) will continue to appear. However, according to the available exploration of DbA for ideation, it is very

likely that reliable innovation for any design problem will come from our better understanding and application of analogies and analogic reasoning.

This conjuncture will require further studies to understand creative cognition with DbA in the area of service and PSS innovation, studies that build upon the work done in cognitive science, and in engineering and architectural design, in order to develop a holistic DbA approach that benefits innovation in all domains. Therefore, we hope this article promote discussion about avenues for DbA implementation and improvement.

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