SUPPORTING CREATIVITY ACROSS PRODUCTS, SERVICES AND PRODUCT-SERVICE SYSTEMS THROUGH DESIGN BY ANALOGY

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ABSTRACT

Design-by-Analogy (DbA) is the process of developing solutions for design problems through the mapping of attributes, relations and purposes that a source problem or situation may share (or at least partially share) with an existing target solution or situation. There is a range of available DbA methods that have been developed to assist designers during the ideation stage to identify potentially useful analogies to solve design problems. However, generally these methods have been developed and applied in the product domain rather than in the service and product service systems domains. The purpose of this article is threefold: first, to identify the characteristics and nature of products, services and product service systems, second, to give an overview of existing DbA methods and their features, and third, to map these characteristics and features so as to evaluate the potential transferability of DbA across domains.

***Keywords**: Design methods, Design by Analogy, Creativity*

1 INTRODUCTION

Humans are continuously solving design challenges in their quest to improve their surroundings, to improve society and the human condition, or the ways they interact with their environment and with other humans. Developing solutions for such design challenges requires effort and in most cases creativity. Markman and Wood (2009) discuss three possible sources for new ideas: serendipity (by coincidence), research and development or discovery (systematic exploration of a well-defined problem), and analogical reasoning (cognitive processes when solving problems) From these sources, reasoning (specifically analogical processes) is an area that has been explored to support designers when developing innovative solutions and overcome fixation as part of an existing paradigm or an existing solution. Some well-known designs that have been developed using analogies are: DaVinci's bat-like wings for his flying machines, or natural cooling systems for buildings taken from termite mount designs.

To enhance designer's analogical capabilities and support the development of solutions in a continuous and consistent manner several Design-by-Analogy (DbA) methods have been developed. Some have been derived from the synthesis of cognitive findings related to analogical reasoning, others have been based on functional analysis and problem framing.

Most of the existing DbA applications have been in product domains such as engineering and architecture (Dahl & Moreau, 2002; Linsey, 2007; Linsey, et al., 2008; Linsey, et al., 2012; Segers & De Vries, 2003) (Segers, et al., 2005) This poses a question about the transferability of existing DbA methods to solve design problems in the service and product service systems (PSS) domains. In particular, because design processes for products and services are considered to be the same in the early stages, which includes the ideation stage, and then diverge in the detailed design phase (Cagan & Vogel, 2013).

To provide perspective and an answer to this question, this article will examine product, service and PSS characteristics and review existing DbA methods to identify opportunities in the methods that may enable them to be successfully implemented across domains.

2 PRODUCTS, SERVICES AND PRODUCT SERVICE SYSTEMS (PSS)

Various definitions for products, services and PSS can be found. Products have been defined as tangible objects that exists in both time and space, while services have been defined as acts that only exist in time (Shostack, 1982). Vermeulen (2001) extracted a set of characteristics that differentiate services from products: intangibility, simultaneity of production and consumption, heterogeneity and perishability. In earlier work, we added two additional characteristics: research and data nature (qualitative, quantitative) and statistical distribution (parametric on non-parametric) (Moreno, et al., 2014). The collated set of characteristics can be found in Table 1.

Table 1. Characteristics of products and services

CHAR.	PRODUCT	SERVICE
Tangibility	Tangible	Intangible
Production	Separation of production and consumption: costumers do not normally participate in production	Simultaneous production and consumption: costumers participate in production
Uniformity	Homogenous	Heterogenous
Storability	Can be kept in stock	Perishable: cannot be kept in stock
Statistical distribution	Typically parametric statistics (normal distributions)	Typically non-parametric statistics
Data Nature	Typically expressed with quantitative data	Typically expressed through qualitative data

There has been some debate about the degree of differentiation between products and services. However, it has become more accepted that services and products are interconnected in varying degrees. The design solutions that combine products and services have been termed product service systems (PSS) (Goedkoop, et al., 1999; Morelli, 2002)], or functional products (Reed, et al., 2010; Lindström, et al., 2012). Baines, in his review of PSS research, defined PSS as "an integrated product and service offering that delivers value in use. A PSS offers the opportunity to decouple economic success from material consumption and hence reduce the environmental impact of economic activity.” (Baines, et al., 2007). This definition highlights the inclusion of environmental and social gains in the value added.

Interest in PSS from research and practice has seen a strong increase. From a business point of view, the delivery of PSS requires a different business model involving a more intensive and continuing relationship with the customer, and a shift from income based on selling a product to income based on selling a (continuous) functionality (hence the use of the term functional product).

3 DESIGN-BY-ANALOGY

Analogy is the association of a situation from one domain (source) that is usually poorly understood, to another domain (target) that is well-understood. The association is possible due to relations or representations (Gentner & Markman, 1997; Kurtz, et al., 2001).

Design by analogy (DbA) requires 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 configurations of components and relations (Goel, 1997). Gentner and Markman (1997) defined analogy as a two dimensional design space defined by ‘relations shared’ and ‘attributes shared’. Hey et al. (2007) added a third dimension, ‘purpose’, to expand the understanding of analogy within the design context.

DbA is based on the premise that the solution to a given design problem may already -or partially- exist, either in an analogous domain or in an analogous solution, and that it can be extracted or mapped once the analogy connections between source and target are made (Moreno, et al., 2014)

We reviewed 100 papers related to design and analogy. The subset of papers selected for this article are the ones that explicitly discuss and propose DbA methods. In some cases the selected subset concerns the same methods or slight variations of these. Considering the source of inspiration for the analogies, two main categories of methods are distinguished in this section: those inspired by nature and those that do not use nature as source of inspiration. The former use terms such as bio-inspired, bio-mimetics and bionics. We aggregated these under the term BioX-driven analogies. This section contains a short description of the selected methods. A comparison can be found in Section 4.

3.1 BioX-driven analogies

This category comprises all methods that use nature, its principles, structures, functions or behaviours as possible sources of analogy for mapping a given design problem characteristics/elements. There are a number of formal and informal BioX design approaches currently available; however, below we are describing those found by Fu et. al. (2014) to have structured formal methods and tools.

3.1.1 Biomimicry and AskNature

Biomimicry comprises: a method, a taxonomy and a web-based tool, AskNature, developed by Benyus and colleagues (Deldin & Schuknecht, 2014). The drivers behind the analogical process of this approach are functions and physical principles.

The method requires a designer to define the context of the problem and identify functions. The designer then uses AskNature, the taxonomy, or both to find analogies. AskNature searches its database for examples of how nature fulfils the function identified by the designer. The taxonomy, which contains biological information in terms of functions and physical principles, can be used by a designer to find related or alternative functions, which can trigger ideas for solutions directly, or be used as alternative inputs into AskNature. The collection of examples in the repository of AskNature is dynamic and enriched through social networking and sharing of biological knowledge.

3.1.2 IDEA-INSPIRE

IDEA-INSPIRE is a computational tool developed by Chakrabarti et al. [13], which allows a systematic search that enables analogical reasoning using inspirations from natural as well as artificial systems [13,14]. The approach is function-driven: the tool requires that the design problem be expressed as a triplet, verb–noun–adjective/adverb (VNA), to find natural or artificial systems that fulfil the same function. It may be necessary to divide the problem into sub-problems to focus the solution finding process.

3.1.3 Biomimetic Design Through Natural Language Analysis

The approach proposed by Cheong et al. (Cheong, et al., 2008) extends the Functional Basis terms (Stone & Wood, 2000) with biological keywords that can then be used to search and explore available biological knowledge. The approach involves identification of functions (key action verbs) and flows (nouns), then a semantic expansion of key action verbs by means of Princeton's WordNet® and the categorization of biologically relevant nouns that may correspond to the expanded set of verbs.

3.1.4 Engineering-to-Biology Thesaurus and Function-Based Biologically Inspired Design

Nagel et al. stated that to abstract problems in engineering design it is common to use functions (actions) instead of specific forms (components), where this approach enabled connections to biological systems which can be described in a similar (functional) way (Nagel, et al., 2010). Their approach uses an engineering-to-biology thesaurus (Nagel, et al., 2010), which is a tool that facilitates the association of terms from the biological domain to the design problem domain. This approach differs from other BioX design approaches in the fact that it starts from a biological system to extract analogical elements (Nagel, et al., 2013; Nagel, et al., 2011). This approach is driven by functional basis terms (Stone & Wood, 2000).

3.1.5 Design by Analogy to Nature Engine (DANE) (Computational Tool)

DANE provides access to a repository of biological and engineering systems, supports analogical mapping between biological and engineering systems by means of representations of the structure–behavior– function (SBF) type, and delivers a model with additional inspirational multimedia content such as schemas, texts, photographs, diagrams, graphs, etc (Vattam, et al., 2010).

3.2 Non-BioX driven analogies

3.2.1 WordTree Method

This method begins with the identification of "key problem descriptors (KPDs)" which can be functional requirements, customer needs, or clarifying descriptions of the design problem. KPDs are then located in a diagram known as a WordTree, which is constructed by populating the branches through selected hyperonymys and troponyms extracted from Princeton's WordNet or VisualThesaurus™. From the WordTree diagram, potential analogies can be researched and analogous domains explored to discover solutions (Linsey, et al., 2008; Linsey, et al., 2008; Linsey, et al., 2012).

3.2.2 SCAMPER Method

This method provides designers with seven sets of questions to steer the finding of analogies to solve a design problem. The seven sets are called operator categories (Eberle, 1996). These are (S) Substitute, (C) Combine, (A) Adapt, (M) Modify/Magnify/Minimize, (P) Put to other uses, (E) Eliminate, and (R) Reverse/Rearrange. Each operator category comprises a set of questions that allows to redirect the analogical search to solve a problem.

3.2.3 Synectics

Synectics is related to SCAMPER and represents a group problem-solving approach to expand creative thinking capabilities (Gordon, 1961) by guiding problem analysis and supporting analogical and metaphorical reasoning to develop possible solutions. There are a number of variations of the method, one of such has been formalized by Rettig and Canady (2013). They propose the following steps: (1) problem definition and identification of keywords, (2) direct analogies creation of previous step words, (3) personal analogy creation, where participants select and become a direct analogy of the previous step, (4) conflict identification in the list of personal analogies generated of previous step, (5) generate new direct analogies for the conflicting personal analogies, (6) original problem re-examination to produce solutions that make use of the ideas previously generated, (7) results usefulness evaluation.

3.2.4 TRIZ-Based Methods

TRIZ is the Russian acronym of Theory of Inventive Problem Solving, which was developed by Altshuller in 1946 after analysing an extensive patent database. He found that almost all design problems could be modelled as contradictions of 39 technical characteristics (39x39 matrix named "Contradiction

Matrix") and that those contradictions could be solved by applying a set of 40 principles (Hirtz, et al., 2002). The process is supported by analogy or meta-analogy starting from a specific problem then defining the contradiction problem that already approaches or characterizes for developing a specific solution.

TRIZ has been extensively applied in fields such as product development and Bioinspired design, where the representation of the design problem can be in terms of function and formulated as contradictions (Vincent & Mann, 2002).

3.2.5 Visual-Based Methods

This approach proposes the use of visual analogies to enhance problem solving. Studies of the design process have found that visual prompts may be a potential source of analogies for designers, who can establish mappings through structural or surface relations (Goldschmidt, 1994; Goldschmidt, 1995; Casakin & Goldschmidt, 1999; Casakin & Goldschmidt, 2000). The available empirical studies indicate that the use of visual analogy improves the quality of design solutions (Casakin & Goldschmidt, 1999; Casakin, 2004).

3.2.6 Search engines and Algorithm-Based Methods

There are a number of computational approaches based on cognitive science to support designers with forming and identifying analogical connections between terms. An example is the Structure Mapping Theory (SMT) (Gentner, 1983), which is implemented in the Structure Mapping Engine (SME) (Falkenhainer, et al., 1989). SMT describes a set of implicit constraints that enable interpretation of analogy and similarity. Falkenhainer, et al. (1989) argued that the best search engine results could be achieved when problems were decomposed with a psychological motivation, i.e. were based on a computational model of how people form analogies. SME uses such a model to produce analogical mappings between the source and target representations.

Computational approaches to analogy focus on either attributional similarity (appearance), relational similarity (analogy), or a combination of both (literal similarity) (Medin, et al., 1990). Latent Semantic Analysis (LSA) measures the degree of attributional similarity between words (Landauer & Dumais, 1997) based on a mathematical and statistical technique for extracting, representing and identifying relations of words within a semantic context (Landauer, et al., 1998). Latent Relational Analysis (LRA) measures relation similarity and determines analogies. It starts from a query and produces a similarity-ranked list of documents (high to low) (Turney, 2005). The Latent Relation Mapping Engine (LRME) combines SME and Latent Relational Analysis (LRA) and seeks the mapping that maximizes the sum of the relational similarities.

These computational approaches have been employed to assist designers to overcome design fixation, to support novice designers, to identify new and unexpected analogies and analogous domains. Theselgorithms have been enriched by other authors adding Bayesian approaches and including refined searches in patent databases to discover relationships and extract near and far field analogies, resulting in clusters of source analogies, connected by their relative similarity (Fu, et al., 2011; Fu, et al., 2012; Fu, et al., 2013; Fu, et al., 2014).

4 QUALITATIVE LITERATURE ANALYSIS

DbA methods can be analysed using different dimensions. For the purpose of understanding and predicting the transferability and suitability of analogy driven approaches across products, services and PSS, we have elaborated two separate qualitative analyses. The first analysis concerns the current application domains of the DbA methods in order to identify potentially dominant method drivers across the spectrum from Product to Service. The second analysis consists of a mapping of the DbA methods against the characteristics of Product, Service and PSS, to identify potential gaps that may be impairing or limiting their application across the spectrum from Product to Service.

4.1 DbA methods and design problem type

We first mapped the methods across the Product to Service continuum where they have been applied. From Figure 1 it can be seen that BioX-driven methods have been applied in the product domain, and that half of the non-BioX driven methods have been applied in the service domain. However, beyond the domain of application of the DbA methods, it is interesting to analyse the drivers that each method uses to support idea generation, and compare this for product, service and PSS.

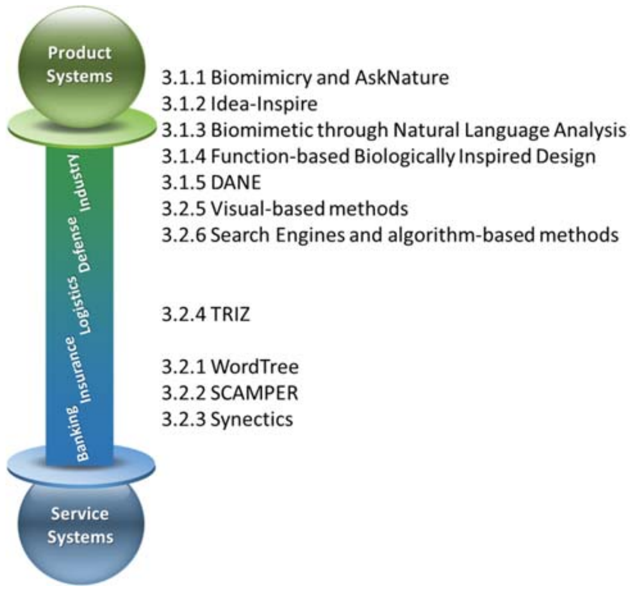

Figure 1. DbA Methods by application

All BioX-driven methods (3.1.1-5) were used in the product domain and enabled/supported the analogical process by functions. This is also the case for TRIZ, which has been implemented in both product and service domains.
Visual-based methods are mainly used in the product domain and rely on structural or surface relations, which in most cases match functions. The search engines and algorithms have the capability to find analogies for any type of word or text, but tend to focus on discovering analogies in patent databases through function and surface mappings.

WordTree and SCAMPER have been applied in product and service domains. They include a functional as well as relational and attributional component. Synectics has also been applied in product and service domains, however, the method has been applied in the form of brainstorm sessions and their full capabilities have been limited.

Table 2. Mapping of DbA methods to Product, Service and PSS characteristics

	Characteristic	***Tangibility***		***Production***		***Uniformity***		***Storability***		***Statistical Distribution***		***Data Nature***	
Area	**Method**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**	**P**	**S**
BioX driven	Biomimicry and AskNature	☑		☑		☑		☑		☑		☑	
	Idea-Inspire	☑		☑		☑		☑		☑		☑	
	Biomimetic Design Trough Natural Languaje Analysis	☑		☑		☑		☑		☑		☑	
	Function-based Biologically Inspired Design	☑		☑		☑		☑		☑		☑	
	DANE	☑		☑		☑		☑		☑		☑	
Non-BioX driven	WordTree	☑	☑	☑		☑	☑	☑	☑	☑	☑	☑	☑
	SCAMPER	☑	☑	☑		☑	☑	☑	☑	☑	☑	☑	☑
	Synectics	☑	☑	☑	☑		☑		☑		☑		☑
	TRIZ-based Methods	☑	☑	☑		☑	☑	☑	☑	☑		☑	
	Visual-based Methods	☑		☑		☑		☑		☑		☑	
	Search Engines and Algorithm-based Methods	☑		☑		☑		☑		☑		☑	

4.2 DbA and Product, Service and PSS characteristics

Our second analysis consists in a mapping of the DbA methods against the characteristics of product and service that were listed in Table 1. This allows the identification of enablers that contribute to their successful use in their current domain of application, and of gaps that may need to be addressed to allow their application across the spectrum of Product to Service, and hence thirs use for PSS.

For the Tangibility characteristic, Wordtree, SCAMPER, Synectics and TRIZ have overcome the intangible nature of service design solutions, perhaps because service problems are usually expressed verbally, textually or as a semantic construct, rather than through physical models. These methods have a linguistic/semantic support that enables metaphorical or analogical reasoning at the attributional and relational levels.

An area of opportunity for all the methods is related to Production and Uniformity, because if we consider that products and artefacts follow the logic of being produced, delivered and consumed (at least initially), a considerable gap of stake-holder/costumer interaction is missing at the design stage to provide flexibility and customization; these attributes can usually be found in services, where the consumer takes part in the production process.

For Storability, the methods can take advantage of the functional definition of the design problem in the product domain to develop solutions for service domain problems to exhibit a given functionality only when it is required.

Another area of opportunity emerges in the statistical distribution and data nature for product-design oriented methods, where more qualitative information sources could be considered. Current product oriented methods could be 'relaxed' from and over parametrical or computationally modelled to consider the stake-holders-users, the systems and the subtle perceptions that those have in the design context.

5 DISCUSSION

Finding means to support designers' creativity during the ideation stage is crucial to assure a continuous and reliable generation of innovative and successful solutions for design problems.

Despite the different characteristics of products, services and PSS, the ideation processes in these domains are considered to be the same. This means that the use of design by analogy, which currently is more typical for the ideation of product, could bea promising approach across domains.

One conclusion from our qualitative literature analysis is that DbA can be transferable across product, service and PSS domains, provided the identified gaps have to be addressed to effectively support ideation.

Function driven DbA are the most likely candidates for transfer from the current product domain to the other domains, as functions are abstract descriptions that offer the capability to overcome the intangible nature of services and PSS. Currently, however, the applicability of the functionally driven methods is limited due to their product-focused supporting material (product repositories, technical language and representations). For example, TRIZ has been applied to develop solutions for both product and service design problems, even though the 39 technical characteristics and 40 principles of TRIZ were abstracted from patent data bases, i.e. products. Several characteristics and principles are general enough to be applied services and PSS, but others require translation or interpretation of the technical terminology.

Functional, SBF, and / or affordance analysis offers the capability to overcome the intangible nature of services and PSS; therefore, functionally- based approaches and related representations should be able to be transferred, but currently the functionally driven methods have limitations on their applications due to their supporting material (product repositories, technical language and representations).

Services and PSS can be supported through semantic approaches, therefore search engines and algorithm-based methods offer tremendous potential to support ideation across domains. Dynamic repositories or search tools, where designers can include functional and related representations, languages and solutions would also enhance DbA capabilities to support ideation across domains.

Approaches that make use of search repositories such as Ask Nature, Idea-Inspire, DANE, WordTree, search engines and algorithm-based methods, should be expanded or redirected to include diverse entry forms, not only patents, certain codified biological phenomena or product databases that correspond to solutions in the form of a product or artefact, but solutions in a broader sense as well as functions, activities, processes, human interactions and principles.

Semantic approaches such as WordTree and SCAMPER could also embed broader semantic explorations to include not only functions (action verbs) but function modifiers (adverbs), attributes (adjectives), gerunds, and entities (nouns), which may enhance analogical retrieval for design problem solving across domains.

These findings will require further studies to understand creative cognition with DbA in the area of service and PSS innovation, building upon the work carried out in cognitive science, in engineering and architectural design, to develop more holistic DbA approaches that benefits innovation across domains.

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