Review: Special Issue on Artificial Intelligence in Design, Journal of Computing and Information Science in Engineering 2010

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Abstract

This paper will present a literature review on the Special Issue on Artificial Intelligence in Design from the Journal of Computing and Information Science in Engineering that was published in 2010. The special issue includes 14 articles that are introduced by the editors in 4 different topics which are 1) functional decompositions of designs, 2) evolutionary computing in design, 3) communication of design knowledge, and 4) others. What these papers have in common are their studies on computer science and mechanical engineering along with the examination, evaluation, development and/or proposal of codes (programmes) that may enhance engineering design practice. Information on these research areas have barely come together with information on design management that also seeks to increase design practice in a wider perspective, from specific product development to social innovation. The combination of these disciplines may benefit each other both in research and in practice. Thus, this paper will re-categorise and review the 14 articles by the following 5 topics, considering what technology actually means to (brings to) a society; 1) functioning, 2) categorisation and identification of products, 3) reasoning and rational thinking, 4) human senses (creativity, affective cognition, linguistic recognition and inspiration) and 5) methodology for research of artificial intelligence in design engineering. Whilst the current focus on computer science and engineering is placed on the application of artificial intelligence for better functions and efficiency in the product design process, the future design research and practice may further benefit by combining the knowledge regarding design across disciplines.

Keywords:

artificial intelligence, engineering design, design management, design methodology

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Ⅰ. Introduction

There is a relation between technological development and socio-cultural structure, with both exerting equal influence on each other. Their dynamic interaction alters the way of production and consumption, and thus changes our lives by creating new products (Anderson, 2010). Subsequently, the nature of a developing society may be regarded as a continuous series of activities that seek to integrate (emerging) technology and socio-cultural factors that shape our world (Shigemoto, 2017). This way of grasping social development, namely innovation, has been theorised as "design-driven innovation" that evaluates and discusses innovation practice on two axes. That of change in technology, and meaning of product (Verganti, 2009). Consequently, it is important to investigate both technology and socio-cultural structures that can independently and integrally improve our society.

One of today's emerging technologies is artificial intelligence (see Chan, Yuen, Palade & Yue, 2016). The technology has been applied in a diverse range of industries that make our life easier and more efficient (see Parunak, 1996); for example, interactive voice response, home automation, Internet of Things (IoT), and so forth. Whilst these "supportive" roles for human beings has been increasingly investigated and applied in practice, there is ample space for research and discussion on the potential for artificial intelligence to carry out "independent" production. In other words, little is known about the probability that artificial intelligence could imitate, and possibly transcend, human intelligence in terms of its design capabilities (Boden, 2003; Frey & Osborne, 2013). Thus, this paper will review articles which have been published in the *Special Issue on Artificial Intelligence in Design, Journal of Computing and Information Science in Engineering* that came out in 2010. This is one of only two issues that have been hitherto published with a clear focus on "artificial intelligence" and "design" in their titles.

Ⅱ. Paper objective

The special issue includes 14 articles, and the editors explain that the papers can be categorised into 4 topic groups; 1) functional decompositions of designs, 2) evolutionary computing in design, 3) communication of design knowledge, and 4) others (Goel & de Silva, 2010) [1]. Table 1 shows the editors' categorisation of the articles in each topic.

Table 1 The editors' categorisation of articles by topics which is based on knowledge of computing

Functional decompositions of designs	Function Semantic Representation (FSR): A Rule-Based Ontology for Product Functions (Yang, Patil & Dutta, 2010)
	A Constraint-Based Approach to the Composition Relation Management of a Product Class in Design" (Yvars, 2010)
	Topological Information Content and Expressiveness of Function Models in Mechanical Design (Sen, Summers & Mocko, 2010)
	A Method for Function Dividing in Conceptual Design by Focusing on Linguistic Hierarchal Relations (Yamamoto, Taura, Ohashi & Yamamoto, 2010)
Evolutionary computing in design	A System Framework With Online Monitoring and Evaluation for Design Evolution of Engineering Systems (Gamage & de Silva, 2010)
	Case-Based Reasoning for Evolutionary MEMS Design (Cobb & Agogino, 2010)
	In Search of Design Inspiration: A Semantic-Based Approach (Setchi & Bouchard, 2010)
	Impacting Designer Creativity Through IT-Enabled Concept Generation (English, Naim, Lewis, Schmidt, Viswanathan, Linsey, McAdams, Bishop, Campbell, Poppa, Stone, Orsborn, 2010).
Communication of design knowledge	A Semantic Information Model for Capturing and Communicating Design Decisions (Rockwell, Grosse, Krishnamurty & Wileden, 2010)
	A New Design Rationale Representation Model for Rationale Mining (Liu, Liang, Kwong & Lee, 2010)
Others	Hybrid Association Mining and Refinement for Affective Mapping in Emotional Design (Zhou, Jiao, Schaefer & Chen, 2010)
	Ontology-Based Multiplatform Identification Method (Li, Chang, Terpenn, & Gilbert, 2010)
	Transformation Design Theory: A Meta-Analogical Framework (Weaver, Wood, Crawford & Jensen, 2010)
	An Integrated Model of Designing (Srinivasan & Chakrabarti, 2010)

Despite the difference in topics, what these papers have in common is their examination, evaluation, development and/or proposal of codes (programmes) that may enhance engineering design practices. These points regarding design have rarely been combined with the knowledge of design management on design as an artificial and creative process that aims to coordinate diverse physical factors in order to embody a conceptual solution to a social need (Rosenman & Gero, 1998: Shigemoto, 2017). In this respect, the design knowledge which has been studied by computer scientists may enrich the knowledge for design management research and managerial practice. Consequently, this paper will review these articles considering what impact and interpretations these research outcomes would bring to industrial designing.

Considering what technology actually means (brings to) a society, the author would humbly re-categorise the papers into the following 5 themes; artificial intelligence that copes with 1) functioning, 2) categorisation and identification of products, 3) reasoning and rational thinking, 4) humanly senses (creativity, affective cognition, linguistic recognition and inspiration), and 5) methodology for research of artificial intelligence in design engineering (see Table 2). The next chapter will begin reviews on these articles in the following order.

Table 2 The authors categorisation of articles in terms of knowledge of design management

Functioning	Function Semantic Representation (FSR): A Rule-Based Ontology for Product Functions (Yang, Patil & Dutta, 2010)
	Topological Information Content and Expressiveness of Function Models in Mechanical Design (Sen, Summers & Mocko, 2010)
Categorisation and Identification of products	A Constraint-Based Approach to the Composition Relation Management of a Product Class in Design (Yvars, 2010)
	Ontology-Based Multiplatform Identification Method (Li, Chang, Terpenn, & Gilbert, 2010)
Reasoning and Rational thinking	A Semantic Information Model for Capturing and Communicating Design Decisions (Rockwell, Grosse, Krishnamurty & Wileden, 2010)
	A New Design Rationale Representation Model for Rationale Mining (Liu, Liang, Kwong & Lee, 2010)
	Case-Based Reasoning for Evolutionary MEMS Design (Cobb & Agogino, 2010)
Humanly senses (creativity, affective cognition, linguistic recognition and inspiration)	A Method for Function Dividing in Conceptual Design by Focusing on Linguistic Hierarchal Relations (Yamamoto, Taura, Ohashi & Yamamoto, 2010)
	In Search of Design Inspiration: A Semantic-Based Approach (Setchi & Bouchard, 2010)
	Impacting Designer Creativity Through IT-Enabled Concept Generation (English, Naim, Lewis, Schmidt, Viswanathan, Linsey, McAdams, Bishop, Campbell, Poppa, Stone, Orsborn, 2010)
	Hybrid Association Mining and Refinement for Affective Mapping in Emotional Design (Zhou, Jiao, Schaefer & Chen, 2010)
Methodology for research of artificial intelligence in design engineering	Transformation Design Theory: A Meta-Analogical Framework (Weaver, Wood, Crawford & Jensen, 2010)
	An Integrated Model of Designing" (Srinivasan & Chakrabarti, 2010)
	A System Framework With Online Monitoring and Evaluation for Design Evolution of Engineering Systems (Gamage & de Silva, 2010)

Ⅲ. Review

1. Artificial intelligence for "Functioning"

To begin with, "Function Semantic Representation (FSR): A Rule-Based Ontology for Product Functions", Yang, Patil and Dutta (2010) highlight the importance of having a set of common metrics that enables software processes to interpret and judge product function so that effective decision-making in various stages of product development can be achieved. Subsequently, they propose Function Semantic Representation (FSR) that is a new Web Ontology Language (WOL) for description and evaluation of product function. The new language was aimed to precisely describe various factors – such as design synthesis, modelling and analysis – involved in the engineering design process that pre-existing computing systems were unable to accurately capture. As the researchers say, "the primary goal of product development is to create an artefact satisfying a certain *function*" (Yang et al., 2010: p.031001-1), their particular interests involve controlling the product life cycle and its sustainability by gaining increasingly accurate information on product function.

In "Topological Information Content and Expressiveness of Function Models in Mechanical Design" written by Sen, Summers and Mocko (2010), two new approaches are presented for the aim of making software processes simple and consequently more efficient. Topology can be understood as software channels through which orders are communicated as flows among function sets, and the new approaches additionally achieve a reduction of uncertainty by managing the number of orders among functions and their flows. The background focus of this research is the representation of product information in computer systems, something that computer scientists in engineering design commonly seek. More accurate and more efficient representation is aimed to ensure better and faster conveyance of product information, and Sen, Summers and Mocko attempted to achieve this mission by developing the constraint network.

2. Artificial intelligence for "Categorisation" and "Identification" of products

A research focus that is similar to that of Sen, Summers and Mocko's work can be seen in Yvars' (2010) "A Constraint-Based Approach to the Composition Relation Management of a Product Class in Design" that is presented from another perspective in this paper, specifically, through that of categorisation and identification of products. Yvars also utilises constraint among software networks to manage product classification which is defined by the composition of items. What is interesting regarding this study is that the researcher understands and judges product information in terms of *function* and *structure (composition)* of products; in other words, products are computerised according to the ways in which the items are expected to function, and the ways in which they are composed. This approach is able to generate possible design patterns which meet product function and composition that are originally required by a person who wishes to develop a new product.

Another article "Ontology-Based Multiplatform Identification Method" (Li, Chang, Terpenn, & Gilbert, 2010) presents a method that seeks to (re)produce items that share similarities with existing products. Such similar product groups are regarded as a product family of which replication and extension are paid attention to in this article. Their replication and extension are looked at in this article. For this purpose, their "application of ontology knowledge provides a way to manage and integrate a large amount of information related to engineering design" (Li et al., 2010: p.031011-9), and it overcomes a weakness in the pre-existing single platform strategy where a limited amount of product information was communicated.

3. Artificial intelligence for "Reasoning" and "Rational thinking"

Rockwell, Grosse, Krishnamurty and Wileden's (2010) beginning sentence of "A Semantic Information Model for Capturing and Communicating Design Decisions" features their attitudes towards design knowledge; "many engineering design tasks can be classified as *redesign or adaptive* design tasks, in which a solution is realized by modifying a prior solution (or solutions) to meet new requirements" (Rockwell et al., 2010: p.031008-1). Subsequently, they aim for the achievement of accurate communication and the sharing of (engineering) design information between designers at different R&D processes and/or in different projects. To achieve this, they have integrally developed decision support ontology and decision method ontology (analytic hierarchy process, in particular), both of which have been used in order to better capture a *design rationale* and *design artefact*. This can be understood as the functional requirements for a product, and evaluation and selection of a new idea (design) to better achieve the functions, respectively. Their extreme goal was to attain interoperability between machines, as is the case between humans.

Knowledge regarding design rationale has also been explored by Liu, Liang, Kwong and Lee (2010) who discussed the limitations of the Issue-based information system (IBIS), and investigated utility of Issue, solution and artefact layer (ISAL) in "A New Design Rationale Representation Model for Rationale Mining". The IBIS exploited the accumulated knowledge of R&D process that have been previously conducted. On the other hand, the ISAL seeks to take advantage of (big) data mining through archival documents, especially patent information. The latter is capable of outputting picturesque images of a new product from computer-supported text mining into rich narrative information, whilst the former provides implicit ideas for a new product, and limited information can be used through the manual operation of the database. Subsequently, the ISAL, as its name suggests, can also evaluate the possible outputs by issue, solution and layer phases.

In "Case-Based Reasoning for Evolutionary MEMS Design" written by Cobb and Agogino (2010), a case-based reasoning (CBR) was adopted for development of microelectromechanical system (MEMS) products. CBR is an artificial intelligence method that looks into previous situations from which supportive designs (solutions) for challenging the current issues are chosen and evaluated. As a result, they showed a process where CBR helped to compare and combine multiple design samples (options) to develop a new MEMS product.

4. Artificial intelligence for the "Human senses (Creativity, Affective cognition, Linguistic recognition and Inspiration)"

"A Method for Function Dividing in Conceptual Design by Focusing on Linguistic Hierarchal Relations" (Yamamoto, Taura, Ohashi & Yamamoto, 2010) makes an attempt to develop a function system that handles qualitative information by syntactical perspective. The proposed method seeks to evaluate a functional goal described in a sentence. This is done by focusing on each constituent word of the sentence. Subsequently, possible alternatives for the meaning of each word that aim to achieve the objective function are considered; for example, "a rice cooker *supplies* rice" can be rephrased as "a rice cooker *keeps* rice *warm*" and "a rice cooker *cooks* rice." This paper presents four dividing techniques; movement decomposition, structure replacement, decomposition-based dividing and causal-connection-based dividing, and thus the proposed approach enables a more creative approach to goal functions that can be achieved by accessing the natural language that humans speak.

Setchi and Bouchard (2010) who wrote "In Search of Design Inspiration: A Semantic-Based Approach" conducted a project-based study that aimed to develop a software tool for identifying images used in webpages. The software tool was developed based on a semantic database where a collection of web images and keywords that described them were accumulated and stored. Based on this knowledge, the software provides the searcher with the webpages that are represented by the search term (keyword). This system was meant to help designers in the early stages of concept creation for new products.

"Impacting Designer Creativity Through IT-Enabled Concept Generation" (English, Naim, Lewis, Schmidt, Viswanathan, Linsey, McAdams, Bishop, Campbell, Poppa, Stone, Orsborn, 2010) presents an interesting perspective along with empirical results regarding the influence of IT support for designer creativity. The results show that designers can think of ideas more freely (i.e. more creatively) for new product development when they do not use the computer-supported visualisation tools for idea generation. Whilst the tool provides designers with suggestions for the making of new ideas, the algorithm that logically and visually leads designers has proven to restrict their way of thinking. This study may involve a lot of implications to research and practice of design management.

"Hybrid Association Mining and Refinement for Affective Mapping in Emotional Design" (Zhou, Jiao, Schaefer & Chen, 2010), the last paper of this chapter, deals with computing system that aims for quantitative evaluation of human sensory interaction with products in an affective dimension. Although this perspective has been approached in Kansei engineering (see Nagamachi, 1995), the authors point out that "concrete mechanisms of affective mapping relationships seldom exist in practice (p.031010-1)". This situation resulted in the impaired communication of consumers' affective needs to designers. Subsequently, the authors propose a hybrid association mining and refinement (AMR) system for decision support during development of affective items. A particularly interesting point about this paper is that the study sought to understand and improve emotional product development from both customers' and designers' perspectives that have been barely investigated and discussed together (Crilly, 2011; Shigemoto, 2018). Thus, the approach and perspective of this paper may provide meaningful insights for design management.

5. Methodology for research of artificial intelligence in design engineering

Weaver, Wood, Crawford and Jensen (2010) theoretically explored the potential for the transformation of products in "Transformation Design Theory: A Meta-Analogical Framework". Some products alter their forms to achieve multiple functions and/or change their impressions (e.g. swiss army knives, collapsible umbrellas, folding tables). This paper introduces some insightful perspectives regarding transformation design. They explain that transformation may benefit from *Packaging, Related processes* and *Common flow* (Transformation Indicators):

ways of transformation can be summarised as *Expand/collapse*, *Expose/cover* and *Fuse/divide* (Transformation Principles): and 20 design constructs that facilitate transformation (Transformation Facilitators).

"An Integrated Model of Designing" of Srinivasan and Chakrabarti (2010) addresses the lack of attention and challenge with the integration of diverse facets of designing. They propose and tested a new integrated model that combines *activities*, *outcomes*, *requirements*, and *solutions* of a given designing process. The "empirical validation of the model confirmed that all the proposed activities, outcomes, requirements, and solutions are present in the natural design processes. However, it has also been found that an adequate number of phenomena, effects, and organs were not explored, resulting in a lower variety and novelty" (Srinivasan & Chakrabarti, 2010: p.031013-9).

"A System Framework With Online Monitoring and Evaluation for Design Evolution of Engineering Systems" (Gamage & de Silva, 2010) presents a methodology for design evolution for an engineering system that aims to automatically develop (redesign) an already existing product. The methodology was developed from the incorporation of a Health Monitoring System and an expert system with a technical base of bond graph modelling, genetic programming. The combined approach yielded multiple advantages that overcame the weaknesses of previous methods that sought to develop new products, and "is particularly suitable for the design evolution of mechatronic systems (Gamage & de Silva, 2010: p.034501-6).

Ⅳ. Discussion

In this special issue, the research interest regarding artificial intelligence in design seems to focus on the extraction, communication, and reproduction of design knowledge which specifically aims to give functional replication. Furthermore, Rockwell, Grosse, Krishnamurty and Wileden (2010) and Liu, Liang, Kwong and Lee's (2010) beginning sentences that feature their attitudes towards design knowledge is insightful for design managers; "many engineering design tasks can be classified as *redesign or adaptive* design tasks, in which a solution is realized by modifying a prior solution (or solutions) to meet new requirements" (Rockwell et al., 2010: p.031008-1): "in general, DR refers to the explanation of why an artefact is designed the way it is (Liu et al, 2010: p.031009-1). As a review, Liu, Liang, Kwong and Lee's (2010) statement may be complementarily understood as *why it is designed* *(in this way to achieve certain functions/to work functionally properly).* Their approaches to improve product design are basically user-oriented, which may have been a principle and dominant objective for engineers for a long time. In this respect, the viewpoint of computer scientists and engineers may be emphasised as "*artificial intelligence*", *one with potential to assist the engineering design process that aims for better functions and efficiency*. By contrast, researchers of design management focus on "*design*" *itself which uses artificial intelligence for the better understanding and practice of the whole process – from concept creation to market introduction – of designing products*. There are different perspectives indicating the necessity for further exploration and systemisation of academic disciplines where design is involved as an object of scientific research.

In nature, artificial intelligence technology may contribute to an increase in accessibility and replicability of the specification of products (see Benjamin, 2008; Fujimoto, 2007). The nine years since the publication of this special issue has seen a world that has been changing in order to achieve this way of production; anybody can participate in open innovation by gaining and sharing information on the internet, and 3D printing technology enables us to replicate products anywhere with ease (Anderson, 2010). On the one hand, this type of production is only based on the achievement of utilitarian value, which is brought about by the functional aspect of a product. On the other hand, the future product should be designed to offer greater hedonic value to consumers (Shigemoto, 2017). Related to this business, one should consider and ask oneself "why do consumers want it?" rather than "why was is designed?" – this question leads to the development of affective products that strongly engage consumers. More specifically, in the chapter of "Artificial intelligence for "Humanly senses (Creativity, Affective cognition, Linguistic recognition and Inspiration)" the papers introduce the notion that there may have been a potential to combine computer science, engineering and management studies and develop a new system that supports open innovation for the development of affective products.

V. Conclusion

This paper reviewed the Special Issue on Artificial Intelligence in Design from the Journal of Computing and Information Science in Engineering. The 14 articles were reviewed in five domains that were categorised from the point of view of design management. The categories are: functioning, categorisation and identification of products, reasoning and rational thinking, humanly senses (creativity, affective cognition, linguistic recognition and inspiration) and methodology for research of artificial intelligence in design engineering. The articles have proposed, developed and tested various function models that aim for the improvement of product development for a particular theme. The current focus on computer science and engineering is on the application of artificial intelligence for better functions and efficiency in the product design process. Meanwhile, future design research and practice may further benefit by combining design knowledge across multiple disciplines to attain affective product development.

Note

1) Note that there is a typographical error for the title for Yamamoto, Taura, Ohashi and Yamamoto's paper that is described as "Thesaurus for Natural-Language-Based Conceptual Design" in the editorial preface. But this article is the one that is included in *ASME 2009 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp.1023-1032).* The correct title found in this issue is "A method for function dividing in conceptual design by focusing on linguistic hierarchical relations".

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