10.6977/IJoSI.201007_1(2).0002
Zhen Li, Derrick Tate / Int. J. Systematic Innovation 10-26 (2010)

Patent Analysis for Systematic Innovation: Automatic Function Interpretation and Automatic Classification of Level of Invention using Natural Language Processing and Artificial Neural Networks

Zhen Li, Derrick Tate*
Department of Mechanical Engineering, Texas Tech University, Lubbock, TX, USA
* Corresponding author, E-mail: d.tate@ttu.edu
(Received 14 April 2010; final version received20 September 2010)

Abstract

With advances in computing power and the processes of globalization, the analytical and engineering science skills that contribute to innovation are becoming a commodity, and the activities of research and development—and innovation—are being outsourced. These trends leave the creative and systems integrative skills of engineering design as the value-added part of innovation. This paper presents a framework to address this challenge, termed mass innovation, which can be defined as expanding and diffusing innovation activities to the general population through connecting inventors and entrepreneurs with the engineering tools and services needed to assess and realize their novel design concepts. As part of mass innovation, this paper presents the development of an approach for automatic function interpretation, and an example is given, in the context of sustainable design, of the application of automatic function interpretation and automatic classification of level of invention to a means for producing compressed earth blocks. The method for automatic function interpretation is based on text extraction, natural language processing using a parser, and semantic definition of functional requirements and design parameters. The classification of level of invention is based on a machine-learning model using inputs based on patent citation measures.

Keywords: mass innovation, functional representation, natural language processing, TRIZ level of invention

1. Introduction

With advances in computing power and the processes of globalization, the analytical and engineering science skills that contribute to innovation are becoming a commodity, and the activities of research and development—and innovation—are being outsourced. (Engardio and Einhorn, 2005) These trends leave the creative and systems integrative skills of engineering design as the value-added part of innovation. (Uchitelle, 2006) This paper presents a new framework to address this challenge by integrating engineering design and social science innovation research, termed mass innovation, which can be defined as expanding and diffusing innovation activities to the general population through connecting individual inventors and entrepreneurs with the engineering tools and services needed to assess and realize their novel design concepts. (Adams and Tate, 2009; Tate et al., 2009) The approach presented in this paper in the context of sustainable design applications. (Tate et al., 2008a; Tate et al., 2010; Tate et al., 2008b)

The goal of mass innovation may be considered as making innovators into better engineers. That is, in coming up with a design idea, potential innovators should incorporate the engineering knowledge embodied in it and its connections to prior designs in the assessment of its innovative potential. The mass innovation approach combines fast and quantifiable assessment of engineering design innovation in terms of the potential transformative impact of a design idea with means for communicating the design idea with others for engineering analysis, prototyping, manufacture, and intellectual property protection. Both assessment and communication of the design idea make use of functional descriptions of the design idea, and this paper presents initial work for the automatic generation of functional description of design ideas and application of automatic classification of the design according to the theory of inventive problem solving (TRIZ) level of invention (LOI).

The assessment of engineering design innovation in terms of the potential transformative impact of a design idea is achieved by integrating several activities as shown in Fig. 1: use of design methods for functional representation and creativity enhancement; use of natural language processing (NLP) and latent semantic analysis

(LSA) for the extraction and interpretation of functional and physical data from patent databases; predicting the transformative impact of a design idea through using machine learning to identify and predict design outcomes, such as TRIZ level of invention or forward patent citation measures; and finally communication of the design idea to others for product realization through engineering analysis, prototyping, manufacture, etc. This paper focuses on the development of an approach for automatic function interpretation that is used throughout the mass innovation framework. The method for automatic function interpretation presented here is based on text extraction, natural language processing using a parser, and semantic definition of functional requirements and design parameters.

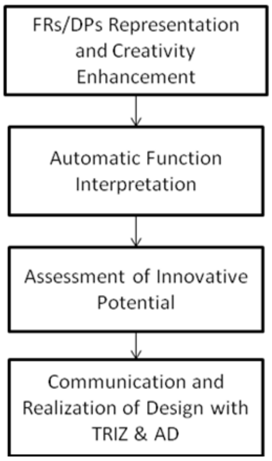

Fig. 1. Framework for Mass Innovation

Globalization and cyberinfrastructure provide new mechanisms to create opportunities for mass innovation, which is defined here as expanding and diffusing innovation activities to the general population through connecting individual inventors and entrepreneurs with the engineering tools and services needed to assess and realize their novel design concepts. The first piece of this vision is to provide fast and quantifiable assessment of engineering design innovation in terms of the potential transformative impact of a design idea. Quantifying the expected rate and breadth of adoption of new products and services remains a key uncertainty in design and development.

For sustained economic development and industrial competitiveness, participation in innovation activities needs to be broadened. The future of the innovation process should provide opportunities for individuals—especially expanding opportunities for additional individuals with or without engineering and scientific backgrounds—to participate in the genesis and realization of novel products and services. Ideas for novel products can arise from disparate sources: surgical tools and medical devices from a pathologist, sustainable building equipment from a rancher/contractor (Williamson, 2007), automotive power train components from a machinist (Dubose, 1996), a back brace from a physical therapist (McKinney, 2007), and so on. In these cases, as with all invention, an individual or small number of users have perceived unmet needs or shortcomings with existing products (Petroski, 1992), and they stand to benefit from resolving the shortcomings of the existing design or system (von Hippel, 1998; von Hippel, 2005).

The mass innovation approach seeks to provide a scientific foundation for the future of collaborative engineering designs. It is motivated by the needs of entrepreneurs and inventors and the desire to leverage cyberinfrastructure and globalization to expand and diffuse innovative activity. Once a person forms an idea, a set of computer tools should be available to state their idea formally, to assess the originality of the idea, and to quantify its prospects to have an innovative impact. Many of the pieces needed for mass innovation already exist, and others are in development. The piece that needs the most work is the first—the cyber-tools for modeling, communicating, testing, and refining of an idea to predict its innovative potential. This work is motivated by the search for the best means for non-technical individuals to formulate and develop their inventive or innovative ideas.

1.1. Sustainable Design

Sustainable design can be defined as incorporating larger environmental, resource, and social issues into decisions of the conceptualization, design, manufacture, operation, and end-of-life of products and systems. These larger issues include, for example, environmental concerns, energy independence, economic viability, and social impact. Sustainability as applied to engineering design is perhaps best understood in terms of energy resources, environmental issues, economic factors, and social impact. It is difficult for individual engineers to be conversant with the many technologies, social, and economic focuses bearing on new designs, and it is also difficult for engineers to define the right problems to be addressed (Tate et al., 2007). Radical, transdisciplinary approaches are needed for product conceptualization, development, and business models that incorporate environmental profiles, manufacturing processes, emissions, and resource consumption to achieve order-of-magnitude improvements (Ertas et al., 2000; Gumus et al., 2008; Tate et al., 2007). The example discussed in this paper is that of a means for producing compressed earth blocks (CEBs).

Earth can be formed into walls using dried mud bricks (adobe), dried poured earth, rammed earth, and compressed earth blocks. With rammed earth, forms are first built similar to cast-in-place concrete forms, and earth is then added in shallow layers and rammed. Compressed earth blocks are defined as earthen blocks created by means of compression in hand-operated or hydraulic machines. (Eko et al., 2006) Currently commercially available CEB machines make blocks up to about 25 x 35 x 10 cm which are stacked to form a wall. (Advanced Earthen Construction Technologies, 2009) Stabilizers such as Portland cement, lime, gypsum, and others can be used along with the soil in the blocks; however, in some cases, stabilization can also be achieved physically without chemical additives by using compaction and granular stabilization. (Burroughs, 2001; Minke, 2006) The Texas Tech University Whitacre College of Engineering and TTU College of Architecture have been working with EarthCo Building Systems to develop a comprehensive building system for efficient and low-cost manufacture and placement of earthen building envelopes using large-scale compressed earth blocks (CEBs). By scaling up the production and placement of CEBs, manual labor and production time can be minimized, and CEB technology can be made cost competitive with traditional building technologies. (Tate et al., 2008a; Williamson, 2007)

1.2. Functional Description of Design Intent

Formal methods used for representing functions during problem formulation describe a system's functions and how they interact. (Antonsson and Cagan, 2001; Chakrabarti, 2002) They are intended to facilitate communication among designers and stakeholders, build group consensus, and support the development of innovative and collaborative designs. (Hirtz et al., 2002) Problem formulation has been observed to be the most difficult task in design (Suh, 1990), and it is critical because design programs and designed artifacts will fail if problem formulation never stabilizes or is based upon incorrect premises. Recent research in engineering design has started with a "functional basis" for representing engineering designs, yet this is only one of many approaches to modeling function that have been proposed. (Antonsson and Cagan, 2001; Chakrabarti, 2002) The approaches to representing function can be divided into two categories—(1) "functional basis" or "black box" approaches that trace various flows through a system (typical examples include functional basis (Altshuller, 1984; Pahl and Beitz, 1996; Stone et al., 2002; Stone and Wood, 2000), black box, and structured analysis and design technique (SADT) (Marca and McGowan, 1993; Ross, 1977; Ross, 1985)) and (2) those that alternate between functions and physical means, progressing from systems to components to create a hierarchy of functions (for example, function means tree (FMT) (Andreasen et al., 1995; Andreasen and Hein, 1987; Hubka and Eder, 1992) (compare with (Marples, 1961) and (Suh, 1990; Suh, 2001)), enhanced FMT (Johannesson, 2004), Gero's function—behavior—structure (FBS) ontology (Dorst and Vermaas, 2005; Galle, 2009; Qian and Gero, 1996), and SysML (Hause et al., 2005)). Recent publications by Erdena et al. and van Eck et al. have compared and contrasted prominent approaches to functional modeling. (Erdena et al., 2008; van Eck et al., 2007) In this paper, the second type of approach will be followed that alternate between functions and physical means in a hierarchical manner.

Data mining should be useful for mining repositories of design intent (patents, electronic design notebooks, etc.) as noted at several NSF-sponsored workshops. (Kusiak, 2007; Schunn et al., 2006; Shah et al., 2005) Engineering design researchers have proposed or developed databases for searching for physical means to provide functionality, and several approaches to engineering design innovation incorporate the use of databases for stimulating or documenting conceptual engineering design. Early efforts to systematize engineering design information in repositories include design catalogs by German researchers (see examples in (Pahl and Beitz, 1996)), morphological analysis (Norris, 1962; Pahl et al., 2007; Zwicky, 1969), and a database of physical effects included as part of TRIZ. (Altshuller, 1984; Fey and Rivin, 2005; Savransky, 2000) More recently the biomimetic approach of Tinsley et al. uses a repository for storing biological functions that can serve as stimuli for engineering designers. (Tinsley et al., 2007) Work by Wood and colleagues proposes a design by analogy method to create transformative designs (defined as changing state or configuration to provide new functionality) (Skiles et al., 2006). Yang has investigated data mining of electronic design logbooks and the development of thesauri for retrieving design information. (Yang et al., 2005) A challenge of repository-based approaches is the effort required to populate the repository as well as efforts to ensure consistency, usefulness, and uniqueness of the information stored within the repository. This work addresses data mining of design intent using natural language processing from a large repository of U.S. patent documents. One of the outputs of this work are expected to be sets of functional and physical design data, organized by discipline, that can be used in populating design repositories.

1.3. Automatic Function Interpretation

The goal of engineering design is to create a product that can carry out certain tasks in order to satisfy the needs of customers (Hirtz et al., 2002; Suh, 1990). Modern marketing has been rephrased as (1) discovering needs and wants of its target customers, and (2) satisfying these needs in a better way than competitors (Wagner and Hansen, 2004). Typically, customer needs can be obtained by gathering market data and by analyzing these data with techniques such as customer analysis, product research, competitor analysis, trend forecasting, risk analysis, etc. However, this approach is both time-consuming and costly. To reduce potential cost, researchers may take the advantage of computational approached to interpret design intention by means of natural language processing (NLP) techniques and axiomatic design theories. The former is widely used for text understanding and text generation while the later provides a framework for representing solutions in terms of explicitly stated functional requirements (FRs) and design parameters (DPs) (Suh, 1990).

Given a description of an engineering design, such as given in a patent document, functional requirements (FRs) and design parameters (DPs) can be extracted by taking advantage of a computational linguistic model. Extracted FRs and DPs not only serve as source of inspiration for designers but also help designers focus on fulfilling customer needs (CNs). In order to rank FRs and DPs extracted from design descriptions, assessment of innovative potential is carried out to classify the level of invention.

1.4. Assessment of Innovative Potential and TRIZ

Goel and Singh (1998) suggest that product design is a goal-directed problem-solving activity that relies heavily on creative thinking, drawing analogies with related knowledge, and experience. Also, they indicated that this work should be done by integrating creativity and innovation tools with engineering design methods. However, there is still a remaining question: How can the innovative potential of a design be measured? The answer to the question above is TRIZ metrics such as degree of ideality and level of invention (Fey and Rivin, 2005). TRIZ provides a systematic process to define and solve given problems which helps increase creativity. In TRIZ, there are five level of invention. The relative percentages of the five level of invention are given in Table 1 (Clausing and Fey, 2004; Fey and Rivin, 2005; Savransky, 2000).

These levels of invention are based on a combination of the resolution of engineering contradictions and interdisciplinarity—borrowing of a solution from another discipline. These levels of invention are based on the resolution of system conflicts (or functional coupling) through transdisciplinary approaches (Altshuller, 1984; Fey and Rivin, 2005). In a previous paper, Adams and Tate demonstrated the use of natural language processing for patent data and the use of a neural network model to estimate the TRIZ level of invention and TRIZ level of ideality for patents. (Adams and Tate, 2009) Adams (2009) also predicted innovative potential by constructing transdisciplinary metrics and training an artificial neural network. He concluded that such metrics helped not only integrate new technologies but also measure the success of a design based on the levels of integration across diverse fields and different parts of a company.

Two related works for evaluating level of invention include (Regazzoni and Nani, 2008) and (Verbitsky, 2004). Regazzoni and Nani use intellectual property density, given by the ratio of number of patents over the number of International Patent Classification (IPC) 4 digit classes per year, to define a break event year that separates patents according to TRIZ level of invention (“breaking” between levels 2 and 3). They identify the LOI of a series of patents having the term “x-rays” in title, abstract, or claims. (Regazzoni and Nani, 2008) Verbitsky presents a measure of level of invention based on the actual number of citations a patent receives versus an expected number of citations, calculated based on the patent’s position in a series of patents. (Verbitsky, 2004)

1.5. Communication and Realization of the Design with TRIZ and Axiomatic Design

After the originality and feasibility of a design idea are validated, the next step in the mass innovation process involves the inventor communicating the idea to others. Engineering analysis can be accomplished through a variety of means, depending on the nature and complexity of the project: doing the analysis oneself, automated analysis with software, using virtual reality and other computer-aided engineering tools, outsourcing the analysis to domestic or overseas engineers, or collaboration with academic or industrial partners. Once the design and engineering analysis have been conducted, a prototype can be created. Again this can be accomplished through several possible methods: rapid prototyping, outsourcing, etc. Within a short time—a few weeks or days—an idea should go from germination to physical implementation. The inventor can then use the physical device for experimental validation, robust design, etc.

Table 1. TRIZ Level of Invention (Fey and Rivin, 2005; Savransky, 2000)

Level	Description	% of Patents (Fey and Rivin, 2005)
Level 1	Apparent solution: A component intended for a task is used.	32%
Level 2	Small improvement: An existing system is slightly modified.	45%
Level 3	Invention inside paradigm: At least one system component is radically changed or eliminated; the problem and solution are within one discipline.	19%
Level 4	Invention outside paradigm: A new system is developed using a solution that is interdisciplinary.	<4%
Level 5	Discovery: A pioneering invention is created, often based on recently discovered phenomenon.	<0.3%

Additional steps in the entrepreneurial process to be considered include the development of business plans and strategy, quantifying the financial prospects of the design, raising capital, etc. as well as the need for protecting intellectual property and intellectual capital. These steps can be tied to existing architectural frameworks for modeling operational, functional, node connectivity, and other business and strategic aspects of a new design.

The paper is structured as follows: After the introduction, section 2 presents an overview of methods used in the framework. Section 3 presents a simple example of sustainable design centered on compressed earth block (CEB) technology, and section 4 discusses the results. Finally, conclusions and future work are given at the end of the paper.

2. Methods for Automatic Function Interpretation

In this section, the methods adopted in this paper are discussed. The importance of analyzing patents is described in the first sub-section, and the formation of FRs/DPs from a given patent follows. The last part of this section describes the evaluation approach for innovative potential.

2.1. Patent Analysis

Tseng et al. (2007) state that patent documents contain valuable information for industry, business, law, and policy-making communities. Innovative solutions, business trends, technological details, and their relationships can be revealed if careful patent analysis is made. On the other hand, a patent has highly structured content which enables researchers to carry out multiple kinds of analysis. A typical U.S. Patent includes several sections: abstract, related U.S. patent documents, references cited, claims, and description.

By manually reviewing patents, functional requirements and design parameters can be obtained from both claims and descriptions. However, the sentences in claims are usually too long for the parser which results in low efficiency, and parsing performance is also less satisfactory. Therefore, the authors chose to implement the NLP techniques on the description section, especially the summary of invention section which is high-quality abstraction of the invention that has been summarized by a human.

2.2. Text Extraction, Function Generation, and Interpretation of Design Intention

The structure of functional requirement interpretation can be divided into the three steps shown in Fig. 2. They are text extraction, natural language processing, and FRs/DPs generation. Each of these three steps interact with a local database to save or load data.

In the first step, the program downloads patents from United States Patent and Trademark Office (USPTO) website for future processing. Patent content extracted and stored locally makes future steps faster and easier than searching online repeatedly. Also, during the extraction, the content of a patent is automatically segmented into different sections by using regular expression. These sections include patent title, abstract, reference, citations received, claims, and description. Table 2 demonstrates a set of regular expressions used for extraction tasks.

The second step is to implement two NLP techniques for extracted and segmented patents stored in database. These two NLP techniques include part-of-speech (POS) tagging and probabilistic parsing. In this paper, the POS tagger and statistical parser developed by Stanford Natural Language Processing Group1 is adopted. The former technique helps clarify the identification of a word in a sentence by using maximum entropy approach (Toutanova and Manning, 2000). The tagging annotation adopted by Stanford POS tagger is from the Penn TreeBank which contains 40 different tags2. An example of a tagged sentence extracted from U.S. Patent 6736626 following the Penn TreeBank tags is shown in Table 3.

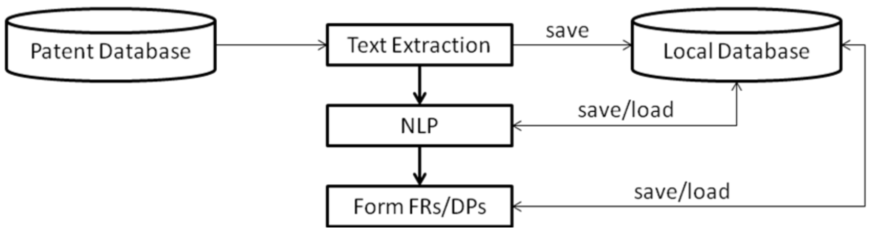

Fig. 2. Framework of Function Generation

Table 2. Regular expression used for text extraction

<table>
<tr><td>SECTION</td><td>REGULAR EXPRESSION</td></tr>
<tr><td>Patent No.</td><td><TITLE>United States Patent(.*)</TITLE></HEAD></td></tr>
<tr><td>Title</td><td>(.*)</td></tr>
<tr><td>Class</td><td>Current U.S. Class:(.*)Current International Class:</td></tr>
<tr><td>Citations</td><td><[aA][^>]*[Hh][Rr][Ee][Ff]=((\"[^>]+\")|([^>]+))>([^<>]+)</[aA]></td></tr>
<tr><td>Abstract</td><td>(<CENTER>|<B>|<I>|\\s)+Abstract(</B>|</CENTER>|</I>|\\s)+(.*)(</P>)</td></tr>
<tr><td>Claims</td><td>(<CENTER>|<B>|<I>|\\s)+Claims(</B>|</CENTER>|</I>|\\s)+(.*)<HR>\\s*(<CENTER><B><I>)</td></tr>
<tr><td>Description</td><td>(<CENTER>|<B>|<I>|\\s)+Description(</B>|</CENTER>|</I>|\\s)+(.*)<HR>\\s*<CENTER></td></tr>
</table>

According to Klein and Manning (2003), the tagger provides 97.24% accuracy on Penn TreeBank Wall-Street Journal. However, to form readable functional requirements and design parameters, single tagged words are still too ambiguous even with a given tag. Consider the simple word run as an example. According to explanations in

1 http://nlp.stanford.edu/index.shtml
2 http://www.cis.upenn.edu/~treebank/

Merriam-Webster online dictionary, the word run has 15 different meanings as an intransitive verb3. Therefore, it's extremely vague for readers if the single word instead of a phrase is used. Fortunately, the later technique, parsing, enables one to determine the grammatical structure given in a sentence. In other words, phrases can be used instead of single words in the output parse tree to eliminate the ambiguity of single words. Also, by parsing a sentence, pairs of dependent subjects, actions, and objects (SAO) can be found. This facilitates the generation of functional requirements and design parameters in the next step. An example of the parser output is shown in Table 4. In this example, the main subject of the sentence is "The Homeland Secuirty secretary" and main action is "said". The sub-subject of the sentence is "legislative efforts" and sub-action is "will begin". As Klein and Manning (2003) indicated in their paper, the Stanford parser adopted un-lexicalized straightforward probabilistic context free grammars (PCFGs) approach that provided performance of 86.36% when the length of a sentence was less than 40 words.

Table 3. Penn TreeBank POS Tag and Tagged Sentence from U.S. Patent 6736626

Penn TreeBank Tags

CC - Coordinating conjunction	**PRP$** - Possessive pronoun (prolog version PRP-S)
CD - Cardinal number	**RB** - Adverb
DT - Determiner	**RBR** - Adverb, comparative
EX - Existential there	**RBS** - Adverb, superlative
FW - Foreign word	**RP** - Particle
IN - Preposition or subordinating conjunction	**SYM** - Symbol
JJ - Adjective	**TO** - to
JJR - Adjective, comparative	**UH** - Interjection
JJS - Adjective, superlative	**VB** - Verb, base form
LS - List item marker	**VBD** - Verb, past tense
MD - Modal	**VBG** - Verb, gerund or present participle
NN - Noun, singular or mass	**VBN** - Verb, past participle
NNS - Noun, plural	**VBP** - Verb, non-3rd person singular present
NNP - Proper noun, singular	**VBZ** - Verb, 3rd person singular present
NNPS - Proper noun, plural	**WDT** - Wh-determiner
PDT - Predeterminer	**WP** - Wh-pronoun
POS - Possessive ending	**WP$** - Possessive wh-pronoun (prolog version WP-S)
PRP - Personal pronoun	**WRB** - Wh-adverb

Sentence before tagging: The press foot is then lowered to a second level in the breech to receive a volume of the loose earth from the feed drawer into the breech.

Sentence after Tagging: The/DT press/NN foot/NN is/VBZ then/RB lowered/VBN to/TO a/DT second/JJ level/NN in/IN the/DT breech/NN to/TO receive/VB a/DT volume/NN of/IN the/DT loose/JJ earth/NN from/IN the/DT feed/NN drawer/NN into/IN the/DT breech./NN

The last step is to concatenate corresponding noun phrases and verbal phrases to form functional requirements and design parameters by finding keywords such as "to" or "for" in verbal phrases. The keyword "to" in verbal phrases serves as a part of an inifitive to express design intention, and the keyword "for" in verbal phrases also express the intention to carry out a certain task. Therefore, by combining the verbal phrases and corresponding objectives, functional requirement can be formed as shown in Table 5. The subject of the sentence is the design intention for implementing designated tasks. Thus, it will be the design parameter for fullfiling funtional requirements that have just been defined before.

Table 4. Example of Parsing Output using Stanford Parser

3 http://m-w.com/dictionary/run

Sentence to be parsed: A press foot is raised in a breech to a first level even with an open upper end of the breech.

Parsing Tree:
```
(ROOT
 (S [137.482]
  (NP [25.250] (DT [4.555] A) (NN [7.572] press) (NN [8.896] foot))
  (VP [111.090] (VBZ [0.144] is)
   (VP [106.729] (VBN [5.600] raised)
    (PP [38.288] (IN [1.552] in)
     (NP [35.080]
      (NP [15.890] (DT [1.419] a) (NN [12.699] breech))
      (PP [18.649] (TO [0.003] to)
       (NP [15.008] (DT [1.419] a) (JJ [4.217] first) (NN [6.390] level)))))
    (PP [59.247] (RB [3.378] even) (IN [2.594] with)
     (NP [46.543]
      (NP [29.399] (DT [3.221] an) (JJ [6.991] open) (JJ [7.968] upper) (NN [6.046] end))
      (PP [16.603] (IN [0.666] of)
       (NP [15.536] (DT [0.650] the) (NN [12.699] breech)))))))
  (. [0.002] .)))
```

Table 5. Extraction of FR and DP from a Sentence

Example: The press foot is then lowered to a second level in the breech to receive a volume of the loose earth from the feed drawer into the breech.

SAOs:
Main subject: *The press foot*
Main action: *is then lowered to*
Main object: *a second level in the breech*
Sub subject: -
Sub action: *to receive*
Sub object: *a volume of the loose earth the feed drawer into the breech*

FRs: *receive a volume of the loose earth the feed drawer into the breech*
DPs: *The press foot is then lowered to a second level in the breech*

2.3. Application of Innovative Potential Assessment Metrics

The TRIZ level of invention of a patent can be estimated by using patent citation analysis. The measure of originality is calculated using the following equation (Jaffe and Trajtenberg, 2002):

$$O_i = 1 - \sum_{k=1}^{n} \left(\frac{b_k}{b}\right)^2 \qquad (1)$$

where b is the number of patents cited in current patent, and k indicates the subclass of the cited patent. For example, if one patent cites 3 patents and 2 of the patents are from subclass X and 1 patent is from subclass Y, then the originality measure is $1-((2/3)^2 + (1/3)^2) = 0.44$.

A patent's generality is measured in a similar way, but considers the forward patent citations by patents from multiple subclasses (Jaffe and Trajtenberg, 2002).

$$G_i = 1 - \sum_{k=1}^{n} \left(\frac{f_k}{f}\right)^2 \qquad (2)$$

where f is the number of patents that cite the current patent, and k indicates the subclass of the patents that cite the current patent.

By combining the number of citations made, citation received, originality, and generality measures, the input for classification can be constructed. Also, the level of invention of each patent serves as the class label in a supervised machine learning method such as an artificial neural network (ANN) or support vector machine (SVM). The training sample in the example includes 140 patents of mechanical devices with manually assigned levels of invention (Adams, 2009). Part of the training data is listed in Table 6.

3. Example of Sustainable Design Application

As mentioned earlier, the case study of this paper centers on an application of sustainable design. Compressed earth block (CEB) is a promising construction material for manufacturing building envelopes by mechanically compressing into blocks a mix of dirt, non-expansive clay, and possibly stabilizers. Since the materials for building CEBs can be all natural, the manufacturing process has minimal impact on the environment.

U.S. Patent 6736626 is an example that introduces a method for manufacturing CEBs. The first step of the case study is manually analyzing functional requirements and design parameters in the patent using axiomatic design in this section. Then, the results of implementing NLP techniques and assessment of innovative potential are presented in the following two sub-sections respectively and compared with the manual analysis.

3.1. Manual Analysis

In the description of U.S. Patent 6736626, six key components are introduced: breech, press foot, feed drawer, bucking foot, hopper, and hydraulic system. Except the hydraulic system, the other key components are marked as 10, 20, 30, 50, and 60 in Fig. 3.

By carefully analyzing the summary of invention, 15 pairs of FRs and DPs can be obtained. This result is shown in Table 7.

By further investigating these FRs and DPs, a hierarchical structure can be formed as some of FRs and DPs belong to a sub-level rather than the higher level of the design. For example, the block is formed by moving the press foot to a designated place to compress loose earth. Therefore, FR_3 and DP_3 belong to the higher level in the structure. On the other hand, the press foot is moved by a hydraulic system, thus FR_{10} and DP_{10} belong to a lower level. The detailed dependencies are described in Fig. 4.

3.2. Automatic FRs/DPs Interpretation for this Case study

According to the description in section 2, the first step for interpreting FRs and DPs is to extract patents from the USPTO web patent databases (USPTO) and save the content of patents such as title, patent number, citations, abstract, claims, and description to a local database.

Instead of implementing NLP on all the sections of patents, only the description section of a patent is analyzed with the parser and POS tagger. The reason is that the length of sentences in the claims are usually too long to be parsed and the parsing performance is not satisfactory. Therefore, this paper mainly focuses on using the two NLP techniques on the description section, especially the summary of invention.

In the last step, cause-effect relationships are searched throughout all the sentences by locating keywords such as "to" and "for". A verb is concatenated together with its object to form functional requirements, while the subject remains as the design parameter.

The programming language used in this project is the Java[4], and the Integrated development environment (IDE) is MyEclipse[5]. MySQL[6] is selected as the local database. SQLyog serves as the GUI for manipulating the local database. The running result is shown in Table 8. In total, 11 functional requirements and design parameters are extracted from U.S. Patent 6736626. As can be seen, the first functional requirement is irrelevant, and some of phrases in sentences such as the 2nd FR and 3rd FR contain mistakes that may cause ambiguity for readers.

Extending this method to several patents about compressed earth block machine, a comparison between automatic analysis and manual analysis is shown through Fig. 5 to Fig. 8. The result shows that the method adopted in this paper is strongly dependent on writing style of patent authors. As the writing style varies dramatically among different patent authors, the task of interpreting design purpose of patents becomes very sophisticated. However, the

---

4 http://www.java.com/en/
5 http://www.myeclipseide.com/
6 http://www.mysql.com/

result is still encouraging as it shows the interpretation of author's design purpose is feasible with the support of NLP techniques.

Table 6. Example of Level of Invention Training Data (Adams, 2009; Adams and Tate, 2009)

Patent #	Citation made	Citation received	generality	originality	Level of Invention
4118531	11	190	0.86	0.82	2
4367924	2	401	0.85	0.50	4
4310440	7	213	0.84	0.48	5
4031519	24	47	0.84	0.84	4
4194041	12	163	0.83	0.66	3
3229759	1	20	0.83	0.00	4
5143854	34	162	0.82	0.88	2
4049997	5	20	0.81	0.38	1
3702886	1	382	0.81	0.00	3
3906324	10	19	0.80	0.48	1
4230463	24	223	0.80	0.73	2
4063271	5	20	0.79	0.32	1
4440871	14	273	0.77	0.74	3
4907340	27	19	0.77	0.70	3
5053074	9	8	0.75	0.59	3
4133814	4	219	0.74	0.50	5
4983886	8	19	0.73	0.53	1
4688900	51	171	0.71	0.77	3
4036012	5	9	0.70	0.63	3
4060023	5	7	0.69	0.44	1
4399209	15	231	0.68	0.27	2
3753145	1	20	0.67	0.00	4
4061724	1	202	0.62	0.00	5
4072541	8	20	0.62	0.24	1
4706216	1	194	0.61	0.00	5
5109824	6	7	0.57	0.48	2
4265990	2	202	0.52	0.00	5
5108350	22	12	0.51	0.59	2
5108349	3	2	0.50	0.67	1
4435047	19	192	0.49	0.83	2
4061389	9	3	0.44	0.44	1
4491628	12	170	0.44	0.28	2
4060980	7	20	0.42	0.41	1
4380635	4	174	0.33	0.63	2
4035047	8	20	0.32	0.22	1
4100324	7	261	0.32	0.63	4
3982201	3	33	0.27	0.00	3
5274650	5	10	0.18	0.48	2
5572914	3	1	0.10	0.00	1

3.3. Estimation of Innovative Potential for this Case Study

The prediction is made by taking advantage of Matlab Neural Network Fitting Tool (abbreviated as nftool). The network is a two-layer feed forward network with 20 hidden neurons in hidden layer, and the training algorithm is back-propagation. 147 training samples are divided into 3 parts: 70% of them are used for training purpose, 15% of them are used for validation, and the remaining 15% of them are used for testing. The training completes in 33 iterations with 0.067 mean square error on validation sample.

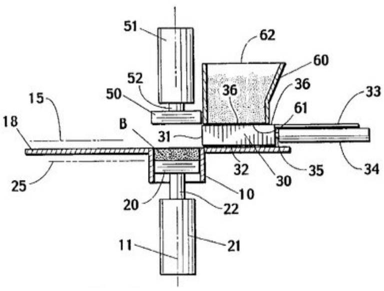

Fig. 3. Proposed CEB Manufacturing Machine from U.S. Patent 6736626[7]

[7]http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=6736626.PN.&OS=PN/6736626&RS=PN/6736626

Table 7. FRs/DPs from Manual Analysis

- *FR_1: receive a volume of the loose earth*
- *DP_1: the press foot is then lowered to a second level in the breech*
- *FR_2: remove or screed the excess loose earth*
- *DP_2: feed drawer is withdrawn laterally across the planar surface*
- *FR_3: compress the loose earth in the breech*
- *DP_3: the press foot is raised to a third level in the closed breech*
- *FR_4: permit vertical ejection of the block*
- *DP_4: The bucking foot is then raised to a level higher than the top of the feed drawer*
- *FR_5: refill the feed drawer*
- *DP_5: feed drawer will be aligned under a hopper storing loose earth*
- *FR_6: push the previously-made block*
- *DP_6: abutment of a three dimensional face of the previously-made block with a leading face of the feed drawer*
- *FR_7: open and close the upper end of the breech*
- *DP_7: bucking foot is aligned above the breech for vertical reciprocal movement along the Z-axis*
- *FR_8: move the feed drawer across a surface coplanar*
- *DP_8: a hydraulic cylinder*
- *FR_9: move the bucking foot*
- *DP_9: the second hydraulic cylinder*
- *FR_{10}: move the press foot*
- *DP_{10}: the third hydraulic cylinder*
- *FR_{11}: provide the lateral tongue-and-groove of the block*
- *DP_{11}: the breech is substantially rectangular in the X-Y plane with two-dimensional surfaces in its Y-Z side walls and complementary three-dimensional surfaces*
- *FR_{12}: provide the vertical tongue-and-groove of the block*
- *DP_{12}: the press foot and the bucking foot have complementary three-dimensional surfaces in their upper and lower X-Y walls*
- *FR_{13}: close the hopper*
- *DP_{13}: trailing plate coplanar with its open upper end*
- *FR_{14}: pass over the three dimensional surface*
- *DP_{14}: feed drawer has a fixed wall with a lower edge notched*
- *FR_{15}: screed along the open upper end of the breech*
- *DP_{15}: hinged wall following the fixed wall with a level lower edge*

Table 8. Automatic Generated FRs and DPs from U.S. Patent 6736626

1st FR is: making a block pressed earth
1st DP is: accordance with the invention a method is provided

2nd FR is: receive a volume of the loose earth the feed drawer the breech
2nd DP is: The press foot is then lowered to a second level in the breech

3rd FR is: remove or screed the excess loose earth the open upper end of the breech
3rd DP is: The feed drawer is withdrawn laterally across the planar surface out of registration

4th FR is: close the upper end of the breech
4th DP is: A bucking foot is then lowered

5th FR is: compress the loose earth in the breech a block
5th DP is: The press foot is raised to a third level in the closed breech

6th FR is: permit vertical ejection of the block the open upper end of the breech the lateral path of the feed drawer
6th DP is: The bucking foot is then raised to a level the top of the feed drawer

7th FR is: refill the feed drawer
7th DP is: additional loose earth will be dispensed from the hopper

8th FR is: open and close the upper end of the breech
8th DP is: The bucking foot is aligned above the breech for vertical reciprocal movement along the Z-axis

9th FR is: receive a volume of loose earth
9th DP is: the loose earth the breech against the bucking foot form a block of pressed earth

10th FR is: provide the lateral tongue-and-groove of the block
10th DP is: the breech is substantially rectangular in the X-Y plane with two-dimensional surfaces in its Y-Z side walls and complementary three-dimensional surfaces in its X-Z side walls

11th FR is: provide the vertical tongue-and-groove of the block
11th DP is: All preferably, the press foot and the bucking foot have complementary three-dimensional surfaces in their upper and lower X-Y walls, respectively

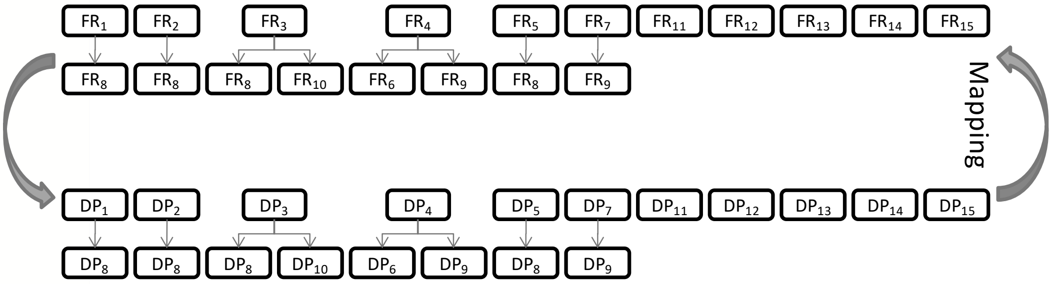

Fig. 4. FRs and DPs in a Hierarchical Structure

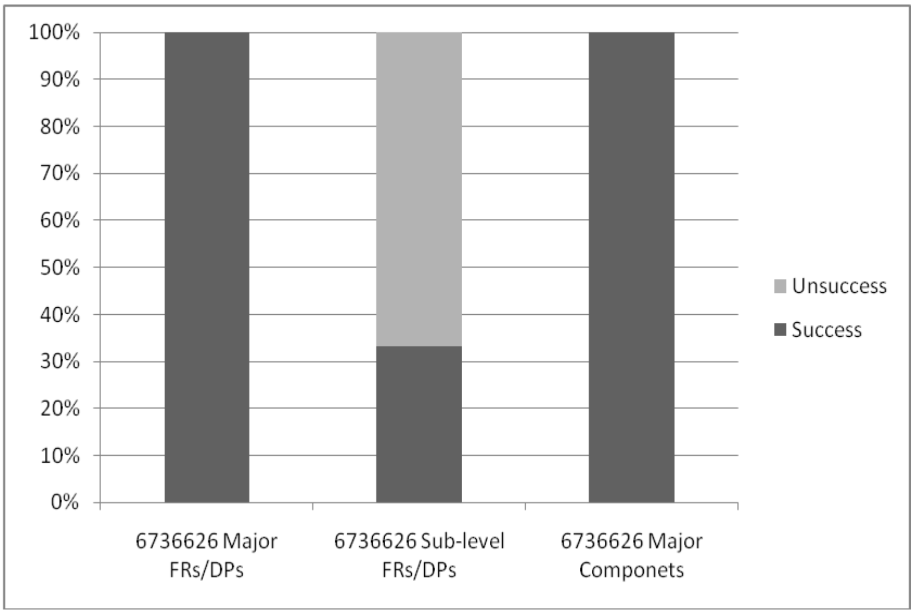

Fig. 5. Comparison between manual analysis and automatic analysis of U.S. Patent 6736626

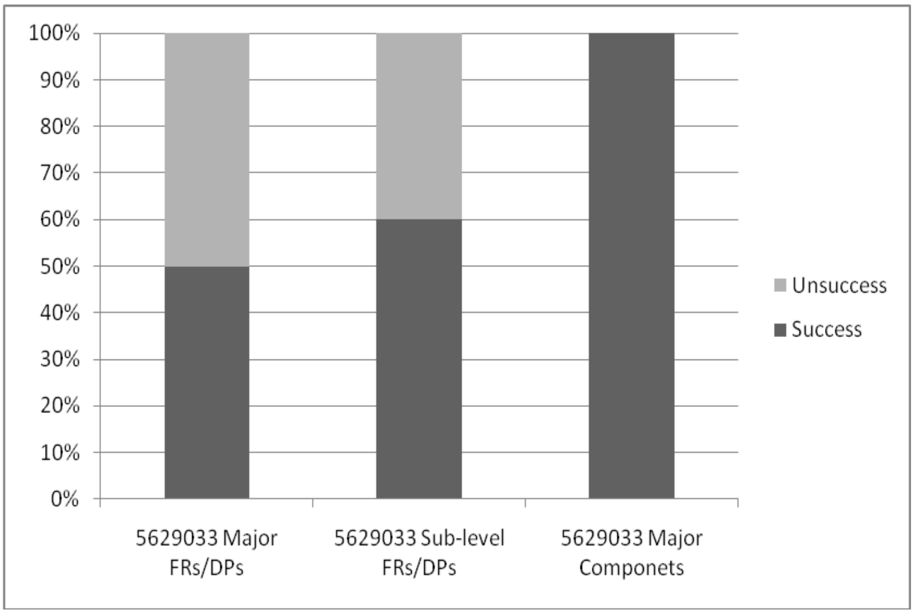

Fig. 6. Comparison between manual analysis and automatic analysis of U.S. Patent 5629033

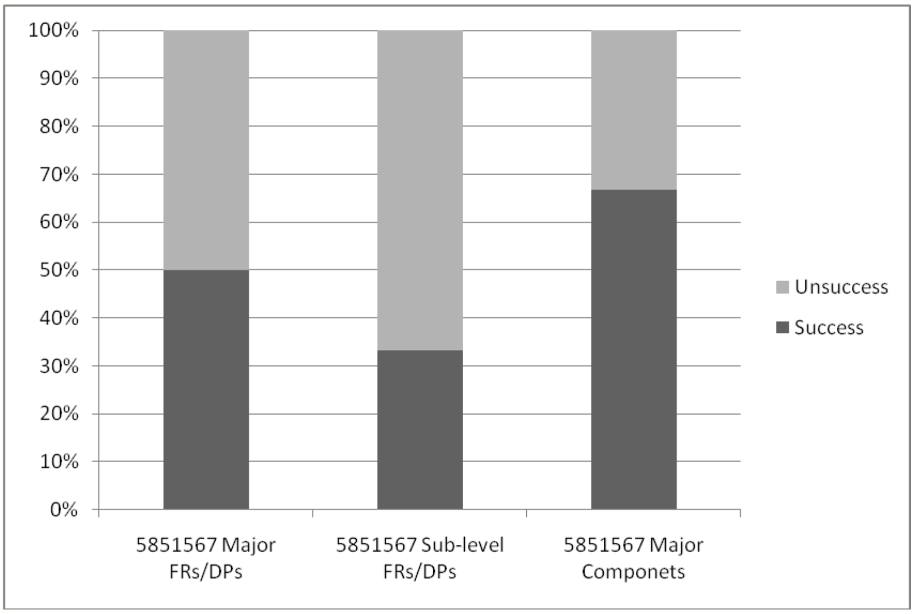

Fig. 7. Comparison between manual analysis and automatic analysis of U.S. Patent 5851567

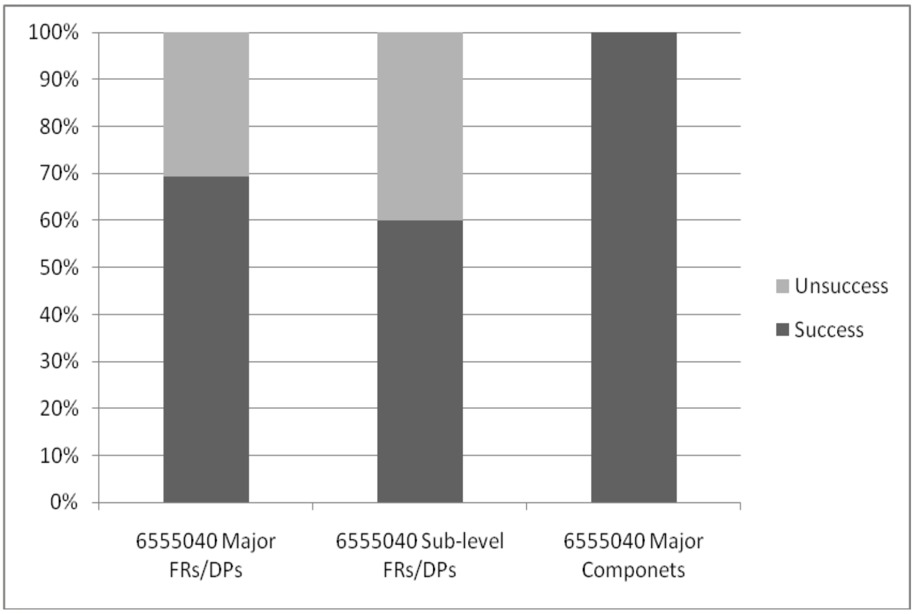

Fig. 8. Comparison between manual analysis and automatic analysis of U.S. Patent 6555040

4. Results and Discussion

The classification result and network performance may vary as the limited training sample is randomly divided into three parts for training, validation, and testing. However, this effect can be cancelled if a sufficient training sample is presented for training the network.

After the network is trained, test samples are applied to the network for classification. Table 9 indicates the automatic estimation of four patents. As all solutions in these four patents are apparent, the level of invention for test samples should be considered as 1. Therefore, this result shows that the estimation is reasonable.

By selecting FRs/DPs from patents ranked with level of invention, designers have sufficient knowledge regarding the scope of their designs. With the help of the framework of axiomatic design or TRIZ, more innovative solutions can be found cheaply and quickly.

Table 9. Level of invention estimation made by ANN

Patents No.	Level of invention estimation
6736626	1.36
5629033	1.47
5851567	1.28
6555040	1.19

Generating functional requirements and design parameter pairs from given patents has not been done previously because high quality text abstraction requires sophisticated natural language processing techniques that are still immature. Most of the work done in this area concentrates on extracting words instead of phrases or sentences to represent functions which can cause vagueness for readers. In this paper, the authors present the effort that has been done to show that this goal is feasible through using parsing and tagging techniques combined with axiomatic design theories.

Although the result indicates that the method adopted is still mechanical and inflexible, the result is still encouraging as most of statements of functional requirements and design parameters are highly readable and understandable compared with single words.

As this is a fresh attempt in this field, the method adopted is inevitably immature. For example, because both the parser and tagger used in this paper are statistically based, the training sample used will undoubtedly affect performance. Unfortunately, because there is no dedicated parser or tagger for patents, the accuracy may not be satisfactory in some cases. Also, the method proposed cannot be used so far for constructing functional requirements and design parameters in a hierarchical way, resulting in a loss of information.

The proposed evaluation of innovative potential is simple but effective. However, as the training sample used thus far is limited, the classification performance can be improved by preparing a larger sample in the future. Furthermore, the methodology for evaluating innovative potential in this paper depends on the number citations received which makes it less accurate for classifying patents that have received few citations. To reduce this dependency, the classification should be made based solely on the content of patent or design idea instead.

5. Conclusions and Future Work

In this paper, a framework for enhancing creativity by combining engineering design concepts, automatic function generation, and evaluation of innovativeness was proposed. By doing these steps, novel design concepts can be assessed and realized which facilitates innovation in engineering design activities. In this paper, the authors present the effort that has been done to generate functional requirements and design parameter pairs from given patents to show that this goal is feasible through using parsing and tagging techniques combined with engineering design theories. The result is still encouraging as most of statements of functional requirements and design parameters are highly readable and understandable compared with single words. The proposed evaluation of innovative potential is simple but effective for classifying patents that have already received citations.

In the light of the preliminary result, the authors will extend the work in the future by taking several steps. WordNet developed in Princeton University has been shown to be a useful tool in natural language processing. By combining this lexical database, phrases that have the same meaning can be grouped as one to make functional generation more accurate. Additionally, taking advantage of the axiomatic design framework to express functional requirements and design parameters in a hierarchy is another topic to be covered in future. In assessment of innovative potential, the authors will extend the application of NLP techniques to patents to create a training sample for a machine-learning model based on functions for classification instead of using the number of citations received or made. This step helps evaluate or predict the potential of an innovative work more independently. Also, this step will be helpful for entrepreneurs or inventors to evaluate their work even without citations. Finally, the authors intend to incorporate function generation and assessment of innovative potential into a standalone software suite.

References

Adams, C., "Developing Transdisciplinary Engineering Metrics using Data Mining Techniques," Ph.D. Dissertation, Texas Tech University, Lubbock, TX, 2009.

Adams, C., and Tate, D., "Computer-Aided TRIZ Ideality and Level of Invention Estimation Using Natural Language Processing and Machine Learning." 3nd IFIP Working Conference on Computer Aided Innovation (CAI): Growth and Development of CAI, 2009, International Federation of Information Processing (IFIP), Harbin, China.

Advanced Earthen Construction Technologies, "AECT Compressed Earth Block." 2009, San Antonio, Texas, http://www.aectceb.com/.

Altshuller, G. S., Creativity as an Exact Science, 1984, Gordon and Breach, New York.

Andreasen, M. M., Hansen, C. T., and Mortensen, N. H., "On Structure and Structuring." 6. Symposium on 'Fertigungsgerechtes Konstruieren', 1995, Erlangen/Egloffstein, Germany.

Andreasen, M. M., and Hein, L., Integrated Product Development, 1987, Springer-Verlag, New York.

Antonsson, E. K., and Cagan, J., "Formal Engineering Design Synthesis." 2001, Cambridge University Press, Cambridge, UK.

Burroughs, V. S., "Quantitative Criteria for the Selection and Stabilisation of Soils for Rammed Earth Wall Construction," Ph.D. Thesis, University of New South Wales, Sydney, Australia, 2001.

Chakrabarti, A., "Engineering Design Synthesis." 2002, Springer, London, UK.

Clausing, D., and Fey, V., Effective Innovation: Developing Winning Technologies, 2004, ASME Press, New York, NY.

Dorst, K., and Vermaas, P. E., "John Gero's Function-Behaviour-Structure model of designing: a critical analysis." Research in Engineering Design 2005, 16, 17–26.

Dubose, G. D., "Variable Orbital Aperture Valve System for Fluid Processing Machines." 5558049, 1996, US.

Eko, R. M., Mpele, M., Doumtsop, M. D., Minsili, L. S., and Wouatong, A. S., "Some Hydraulic, Mechanical, and Physical Characteristics of Three Types of Compressed Earth Blocks." Agricultural Engineering International: the CIGR Ejournal, 2006, 8, Manuscript BC 06 007.

Engardio, P., and Einhorn, B., "Outsourcing Innovation." Business Week, 2005.

Erdena, M. S., Komotoa, H., Beeka, T. J. v., D'Amelioa, V., Echavarriaa, E., and Tomiyama, T., "A review of function modeling: Approaches and applications." Artificial Intelligence for Engineering Design, Analysis and Manufacturing 2008, 22, 147-169.

Ertas, A., Tanik, M. M., and Maxwell, T. T., "Transdisciplinary Engineering Education and Research Model." Journal of Integrated Design and Process Science, 2000, 4(4), 1-11.

Fey, V., and Rivin, E., Innovation on Demand, 2005, Cambridge University Press, Cambridge, UK.

Galle, P., "The ontology of Gero's FBS model of designing." Design Studies, 2009, doi:10.1016/j.destud.2009.02.002.

Goel, P. S., and Singh, N., "Creativity and innovation in durable product development." Computers & Industrial Engineering, 1998, 35(1-2), 5–8.

Gumus, B., Ertas, A., Tate, D., and Cicek, I., "The Transdisciplinary Product Development Lifecycle (TPDL) Model." Journal of Engineering Design, 2008, 19(3), 185-200.

Hause, M., Thom, F., and Moore, A., "Inside SysML." Computing & Control Engineering Journal, 2005, 16(4), 10-15.

Hirtz, J., Stone, R. B., McAdams, D. A., Szykman, S., and Wood, K. L., "A functional basis for engineering design: Reconciling and evolving previous efforts." Research in Engineering Design, 2002, 13(2), 65-82.

Hubka, V., and Eder, W. E., Engineering Design, 1992, Heurista, Zürich, Switzerland.

Jaffe, A. B., and Trajtenberg, M., Patents, Citations, and Innovations: A Window on the Knowledge Economy, 2002, MIT Press, Cambridge, MA.

Johannesson, H., "Function-Means Based Conflict Analysis In Conceptual Design of System Products." 7th Workshop on Product Structuring-product platform development, 2004, Chalmers University of Technology, Goteborg.

Klein, D., and Manning, C. D., "Accurate Unlexicalized Parsing." 41st Meeting of the Association for Computational Linguistics, 2003, 423-430.

Kusiak, A., "Data Mining and Innovation Science." National Science Foundation Symposium on Next Generation of Data Mining and Cyber-Enabled Discovery for Innovation (NGDM '07), 2007, Baltimore, MD.

Marca, D. A., and McGowan, C. L., IDEF0/SADT, 1993, Eclectic Solutions, San Diego, CA.

Marples, D. L., "The Decisions of Engineering Design." IRE (Institute of Radio Engineers) Transactions on Engineering Management, 1961, EM-8(2), 55-71.

McKinney, W., "Support device ", Application # 20090095308 2007, U.S.

Minke, G., Building with Earth: Design and Technology of a Sustainable Architecture, 2006, Birkhäuser, Basel, Switzerland.

Norris, K. W., "The Morphological Approach to Engineering Design." Conference on Design Methods, J. C. Jones and D. G. Thornley, eds., 1962, Macmillan, New York, 115-140.

Pahl, G., and Beitz, W., Engineering Design, 1996, Springer, London.

Pahl, G., Beitz, W., Feldhusen, J., and Grote, K.-H., Engineering Design, 2007, Springer, London.

Petroski, H., The Evolution Of Useful Things, 1992, Vintage, New York, NY.

Qian, L., and Gero, J. S., "Function-behavior-structure Paths and Their Role in Analogy-based Design." Artificial Intelligence for Engineering Design, 1996, 10, 289-312.

Regazzoni, D., and Nani, R., "TRIZ-Based Patent Investigation by Evaluating Inventiveness." Computer Aided Innovation (CAI), 2008, Springer, 247-258.

Ross, D. T., "Structured Analysis (SA): A Language for Communicating Ideas." IEEE Transactions on Software Engineering, 1977, SE-3(1), 16-34.

Ross, D. T., "Applications and Extensions of SADT." Computer, 1985, 18(4), 25-34.

Savransky, S. D., Engineering of Creativity, 2000, CRC Press, Boca Raton, FL.

Schunn, C. D., Paulus, P. B., Cagan, J., and Wood, K., "Final Report from the NSF Innovation and Discovery Workshop: The Scientific Basis of Individual and Team Innovation and Discovery." NSF Award BCS0623421, 2006

Shah, J. J., Finger, S., Lu, S., Leifer, L., Cruz-Neira, C., Wright, P., Cagan, J., and Vandenbrande, J., "ED2030: Strategic Plan for Engineering Design (NSF GRANT # DMI-0411591)." 2005 NSF Design, Service and Manufacturing Grantees and Research Conference, Scottsdale, AZ, 2005.

Skiles, S. M., Singh, V., Krager, J., Seepersad, C. C., Wood, K. L., and Jensen, D., "Adapted Concept Generation and Computational Techniques for the Application of a Transformer Design Theory." IDETC/CIE 2006, 2006, ASME, Philadelphia, PA.

Stone, R. B., Hirtz, J., McAdams, D. A., Szykman, S., and Wood, K. L., "A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts." Research in Engineering Design, 2002, 13, 65-82.

Stone, R. B., and Wood, K. L., "Development of a Functional Basis for Design." Journal of Mechanical Design, 2000, 122(4), 359-370.

Suh, N. P., The Principles of Design, 1990, Oxford University Press, New York.

Suh, N. P., Axiomatic Design: Advances and Applications, 2001, Oxford University Press, New York.

Tate, D., Agarwal, A., and Zhang, L., "Assessing Design Methods for Functional Representation and Concept Generation: Strategies and Preliminary Results." International Conference on Engineering Design (ICED'09), 2009, Stanford, CA.

Tate, D., Ertas, A., and Maxwell, T., "Transdisciplinary Approaches for Design, Process, and Systems Education." ConnectED 2007 International Conference On Design Education, Sydney, Australia, 2007.

Tate, D., Ertas, A., Maxwell, T., Park, K., and Lawson, W., "Design and Development of a Large-Scale Compressed Earth Block Building System for Developed Countries." Clean Technology 2008, 2008a, Boston, MA.

Tate, D., Maxwell, T., Ertas, A., Zhang, H.-C., Flueckiger, U. P., Lawson, W., Fontenot, A. D., and Chandler, J., "Transdisciplinary Approaches for Teaching and Assessing Sustainable Design." International Journal of Engineering Education, 2010, 26 (to appear).

Tate, D., Maxwell, T., Flueckiger, U. P., Park, K., and Parten, M., "Development of a Program in Innovative and Sustainable Design of Automotive and Building Technologies." ASME Energy Sustainability 2008, Jacksonville, FL, 2008b.

Tinsley, A., Midha, P. A., Nagel, R. L., McAdams, D. A., Stone, R. B., and Shu, L. H., "Exploring The Use of Functional Models as a Foundation for Biomimetic Conceptual Design." ASME 2007 International Design Engineering Technical Conferences, Las Vegas, NV, 2007, DETC2007-35604.

Toutanova, K., and Manning, C. D., "Enriching the Knowledge Sources Used in a Maximum Entropy Part-of-Speech Tagger." Joint SIGDAT Conference on Empirical Methods in Natural Language Processing and Very Large Corpora (EMNLP/VLC-2000), 2000, 63-70.

Tseng, Y. H., Lin, C. J., and Lin, Y. I., "Text mining techniques for patent analysis." Information Processing and Management 2007, 43 1216–1247.

Uchitelle, L., "Goodbye Production (and Maybe Innovation)." New York Times, 2006, New York, NY.

USPTO, "USPTO Web Patent Databases." http://www.uspto.gov/patft/.

van Eck, D., McAdams, D. A., and Vermaas, P. E., "Functional Decomposition in Engineering: A Survey." IDETC/CIE 2007, 2007, ASME, Las Vegas, NV, DETC2007-34232.

Verbitsky, M., "Semantic TRIZ." 2004, Invention Machine Corporation, Boston.

von Hippel, E., Sources of Innovation, 1998, Oxford University Press, New York, NY.

von Hippel, E., Democratizing Innovation, 2005, MIT Press, Cambridge, MA.

Wagner, E. R., and Hansen, E. N., "A method for identifying and assessing key customer group needs." Industrial Marketing Management 2004, 33 643– 655.

Williamson, L. D., "Block-ramming machine." 7311865, 2007, US.

Yang, M. C., Wood III, W. H., and Cutkosky, M. R., "Design information retrieval: a thesauri-based approach for reuse of informal design information." Engineering with Computers, 2005, 21, 177-192.

Zwicky, F., Discovery, Invention, Research through the Morphological Approach, 1969, MacMillan, New York.

AUTHOR BIOGRAPHY

Zhen Li received his Bachelor degree in mechanical engineering from the Beijing Jiaotong University, Beijing, China, in the year of 2005. He is currently pursuing the Ph.D. degree at the Texas Tech University, Lubbock, Texas. And his current work involves applying data-mining, machine learning and natural language processing techniques to online patents in order to understand design purpose and to estimate patent creativeness.

Derrick Tate, Assistant Professor of Mechanical Engineering at Texas Tech University, aims to impact society through bringing design thinking to areas of strategic importance: developing sustainable approaches for building systems, transportation, and manufacturing; facilitating mass innovation; and enabling innovation in enterprises. His current and recent projects include development of sustainable wall systems funded by EarthCo Building Systems, and a US-Tanzania Workshop: Advancing the Structural Use of Earth-based Bricks, funded by NSF.

Manuscript Received: Apr. 14, 2010

Revision Received: Jun. 8, 2010

and Accepted: Jun. 20, 2010