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INVENTION ENGINEERING – A NOVEL APPROACH TO SUPPORT CREATIVITY IN ENGINEERING, PRACTICE AND RESEARCH

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ABSTRACT *In engineering education, practice and research, a central issue is how traditional thought patterns can be broken up by creative tools and impulses. This paper presents the outline for a method that supports the discovery of new sources of inspiration in search fields such as literature, film, fine art or music, and enables engineers to generate design alternatives in high speed and quantity. For this end, techniques from the design sciences, creativity and innovation research as well as digital information and knowledge technologies are reviewed and integrated into the conceptual approach of Invention Engineering. The aim is to develop and validate a process which provides artistic inspirations to engineers and is supported by algorithmic creativity and association tools. Thus four separate research challenges need to be addressed: a) Analysis of creative processes in engineering disciplines (inspiration, association, ideation, innovation) and their comparison to "Creative Patterns" of other domains; In addition, visions of the past and the socio-technical framework conditions of their implementation need to be explored in order to establish a model for the validation of the overall Invention Engineering method; b) Development of an "Inspiration Mining" method for obtaining creative impulses from non-engineering areas (e.g. literature, music, visual arts, film et al.); Respective search results need to be referenced with a semantic model and processed in a knowledge system (Idea Bank), which – as a kind of associative search engine – provides input for idea generation; c)Translation of established creativity and innovation research into an "Idea Engine" for generation of a large number of productive ideas; This can be done through combinatorial algorithms and methods of remote association, textual and visual-spatial idea matrices, that provide a fertile basis for radically new design and engineering ideas; d) Integration of the separate methods into a coherent process and validation of the creative support effect of the generated innovations by means of engineering psychology. This can be done on the basis of selected visionary ideas from the past (e.g. science fiction) that can be simulated on the basis of their associative foundations and implementation probabilities.*
Keywords*: Invention Engineering; Creative Technique; Innovation Management*

ВИНАХІДНИЦЬКА ІНЖЕНЕРІЯ - НОВИЙ ПІДХІД ДО ПІДТРИМКИ ТВОРЧОСТІ В ІНЖЕНЕРІЇ, ПРАКТИЦІ ТА ДОСЛІДЖЕННІ

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АНОТАЦІЯ *В галузі інженерної освіти, практики та досліджень центральним питанням є те, як традиційні моделі мислення можуть бути розбиті творчими інструментами та імпульсами. В статті представлено схему методу, який підтримує відкриття нових джерел натхнення у таких сферах пошуку, як література, кіно, образотворче мистецтво чи музика, і дозволяє інженерам створювати альтернативні дизайни швидко та у великій кількості. З цією метою методи з дизайнерських наук, творчості та інновацій, а також цифрової інформації та технологій пізнань переглядаються та інтегруються в концептуальний підхід винахідницької інженерії. Метою є розробка та підтвердження процесу, який забезпечує художнє натхнення інженерам та підтримується алгоритмічними інструментами творчості та асоціації. Таким чином, потрібно вирішити чотири окремі проблеми дослідження: а) аналіз творчих процесів в інженерних дисциплінах (натхнення, асоціація, ідеї, інновації) та їх порівняння з «креативними моделями» інших областей; крім того, необхідно вивчити бачення минулого та соціально-технічні рамкові умови їх впровадження, щоб встановити модель для валідації загального методу винахідницької інженерії; б) розробка методу «Натхнення для натхнення» для отримання творчих імпульсів з інженерних галузей (наприклад, літератури, музики, образотворчого мистецтва, кіно та ін.); відповідні результати пошуку повинні посилатися на семантичну модель і оброблятися у системі знань (Банк Ідеї), яка, як своєрідна асоціативна пошукова система, дає внесок для генерування ідеї; в) переклад встановлених досліджень творчості та інновацій у «двигун ідеї» для генерації великої кількості продуктивних ідей; це можна зробити за допомогою комбінаторних алгоритмів та методів віддаленої асоціації, текстових та візуально-просторових матриць ідей, які дають плодовиту основу для радикально нових дизайнерських та інженерних ідей; г) інтеграція окремих методів у цілісний процес і перевірка ефекту творчої підтримки створених інновацій засобами інженерної психології; це можна зробити на основі відібраних уявних ідей із минулого (наприклад, наукової фантастики), які можуть бути змодельовані на основі їх асоціативних основ та ймовірностей реалізації.*
Ключові слова*: винахідницька інженерія; креативні методи; інноваційний менеджмент*

Introduction

The history and practice of engineering disciplines such as architectural or civil engineering show that the potential of new possibilities from the introduction of new techniques or materials remained unused for a long time, because it was based on old thinking and design patterns that did not meet the potential of the new technical achievements. New design rules and applications are usually discovered slowly and often by chance. In

contrast, visionary artists and works of art such as Kasimir Malevich's suprematist paintings, Italo Calvino's "Invisible Cities" or Fritz Lang's science-fiction movie "Metropolis" have anticipated radical innovations in an astonishing manner, and have become sources of inspiration for the engineers and designers. The Art Nouveau, Italian Futurismo or poststructuralist architecture were inspired by such external sources.

Our central issue in this paper therefore is how traditional thought patterns in engineering can be broken up by creative tools and impulses. We aim at the development of a novel method, which should enable engineers and designers to open up non-specialist sources of inspiration, to generate and evaluate radically other design and construction ideas in high speed and quantity. We assume that new sources of inspiration can be discovered in search fields such as literature, film, fine art or music, and be made useful for the generation of ideas. Their creative processes, structural models and formal languages are to be accommodated as alternatives to otherwise path-dependent patterns of thinking in design and engineering.

Objectives

In order to explore new conceptual paths and to increase the output rate of ideas and innovations, we review approaches and techniques from the design sciences [1,2], creativity and innovation research [3-5] as well as digital information and knowledge technologies [6,7], in this paper, in order to prepare the merger into a comprehensive method of Invention Engineering. Doing so, we fundamentally ask how radical new ideas are coming into the world of design and engineering, and what creative impulses and processes are central for the discovery of radically new approaches in engineering, design, and constructions. The attempt to harness artistic works as inspiration for engineering by way of algorithmic methods (e.g. semantic search, machine learning) has not been undertaken so far and has high exploration and venture character.

Methods

The paradigm shifts in civil and architectural engineering that result from radical innovations in material and construction only take place over long periods of time. Due to the large construction and utilization periods of artefacts like buildings, only slow innovation cycles and low reproduction rates are possible. Engineering disciplines thus have a particular need to accelerate the research and innovation process, to purposefully break up established thought patterns and systematically exploit new impulses and resources of ideas. Above all, there are in creativity and innovation research as well as the attempts to scientifically depict the design and construction process ("design sciences") pioneering approaches that should be pursued further for this purpose.

Research on creativity, established in the cognitive and behavioural sciences sees as critical creativity factors in individuals and groups the "out of box" breaking-up of existing thought patterns [5] and the semantic linkage of distant objects (Remote Association) [8]. In addition, many of the established learning and creativity techniques such as Synectics [4,9] are based on principles of exploration and the ability to use disturbances productively [10].

Innovation research, which, in contrast to creativity research, primarily investigates the effects of inventions and discoveries in socio-technical systems, emphasizes the principles of openness and disruption as central factors. Classical innovation research emphasized the moment of creative disturbance, even destruction [11]. More statistically oriented and dependency-oriented scenario methods for technology forecast (Kondratjew cycles, Delphi method) [12] also see external impulses and disturbances as decisive trigger for surprising new technical solutions. Such, the open innovation approach describes how valuable impulses in innovation ecosystems are based on the absorption of external innovations [13], through targeted involvement of end and extreme users [14] as well as through hacking processes [7]. They also show the risks arising from path dependencies and non-observance of external inventions ("not invented here" syndrome) [15].

Especially in ICT and software development, these findings have led to innovation processes such as Agile Development or Scrum, which ensure high creative output as well as successful implementation in markets and organizations. They enable the rapid uptake of external impulses and an "agile" realignment of the development processes. This responsiveness and openness is a fundamental condition of the innovation power of the current ICT and software industry. In the civil and architectural engineering and the related construction industry, however, comparable procedures are lacking.

Although the added value of disturbances, openness and agility has long been recognized in the field of creativity and innovation research, they are not very present and hardly used in the engineering sciences. The few existing approaches to scientifically comprehend the creative process for the creation of complex technical artifacts are based on the systematic solution of complex engineering problems by rule-based problem solving strategies e.g. the decomposition of complex problems into less complex problems [1,2]. Well-established design science methods such as Genrich Altshuller's TRIZ [16], Christopher Alexander's Pattern Language [17] or Richard Buckminster Fuller's Synergetics have at best led to practical computer aided invention tools, but not to surprisingly new solutions.

More aggressive innovation is created at the interface between Open Innovation and Design Science: the Design Thinking process pursues external and transdisciplinary impulses to generate disruptive product and solution visions. Going beyond this result-oriented approach again, more recent concepts of Art Thinking try

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to use results-oriented, exploratory processes instead of the forced product and visions of Design Thinking [18].

On technical level, such approaches are broadly employed in the research and innovation departments of large technology companies (Fig. 1) where they are increasingly being supported by “intelligent” interaction and analysis technologies. Here established creativity and innovation methods are enhanced with AI and database procedures, thus forming a Digital Innovation Engineering approach.

Fig. 1 –Fujitsu Digital Future Center: Pattern Library of creative solutions to support systematic generation of innovations

While broadly established methods such as Pattern Language or Design Thinking do not stand up to scientific validation, the more robust Design Science methods (Simon, Altshuller) only lead to incremental, path-dependent innovations or optimizations. Discipline-bound within their respective technical and conceptual possibilities, they do not lead to radical innovation leaps, as it may be expected from the discovery of ground-breaking new engineering materials or processes. The thinking of “hard” engineering can hardly integrate the success factors of radical innovation (openness, disruption, agility), while on the other hand a translation of the methods of innovation and creativity research into engineering-scientific conception processes and their support by advanced digital tools is rarely attempted.

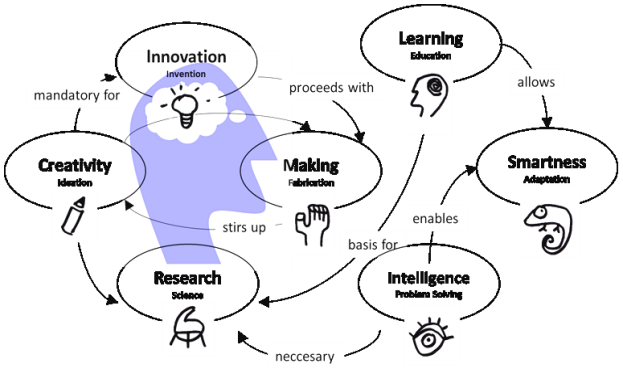
Results

It is necessary to provide non-specialist sources of inspiration, e.g. from the visual arts, literature, music, film, science fiction, etc., as a source of inspiration in order to achieve radically different design and construction ideas. In the future, engineers need to have valid algorithmic procedures upon which - after careful description of their particular challenges - they can receive inspiring impulses and associations, leading them towards radically new approaches in design work, experimentation, modelling, etc. In order to effectively explore new ideas paths and to generate and evaluate new visions in high speed and quantity, structured concept-finding processes are necessary Therefore we aim to fuse useful approaches and principles from the fields of design sciences, design and art thinking as well as creativity and innovation research into a method of Invention Engineering. Advanced methods of machine learning and creativity-oriented data analysis open up excellent opportunities to use previously unknown sources of knowledge for engineers, and for inspiring radical new conceptual paths [19].

As basic elements of the intended method we see a digital AI assistant based on bot functionality which proposes decision paths. Also, we have conceived a tool for creating associative as well as logically linked idea matrices in which users can freely navigate and ideas "grow" quickly.

Our schematic future research outline combines approaches and techniques, as outlined above, from the design sciences, creativity and innovation research as well as digital information and knowledge technologies. The concrete goal of developing and validating a process supported by algorithmic creativity and association tools for the provision of artistic inspirations in order to discover radically new engineering and constructions approaches may be broken down in following four separate research challenges, each of which targets at a single method.

This research challenge aims at the analysis of creative processes (inspiration, association, ideation, innovation) commonly used in engineering disciplines, and the comparison to "patterns of thought" of other domains and open creativity techniques. In addition, visions of the past and the socio-technical framework conditions of their implementation need to be explored in order to establish a model for the validation of the overall Invention Engineering method.



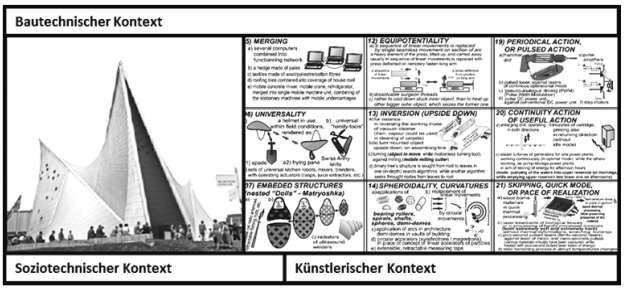


Fig. 2 – Creative Patterns: Investigating the structures of creative thought and inventions

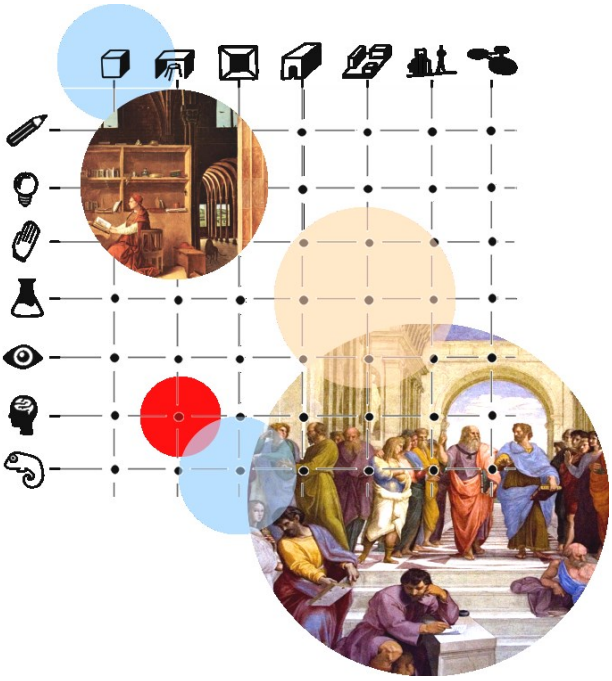


Fig.3 – Inspiration Mining: Searching inspirational objects with ML algorithms

This challenge comprises the development of techniques and technologies for use in areas outside engineering such as literature, music, visual arts, film et al. To be able to discover ideas and concepts that can provide creative impulses for engineering research, IT technologies such as text mining, web crawling or machine learning are available [21,22]. Respective search results need to be referenced with a semantic model and processed in a knowledge system (Idea Bank), which – as a kind of associative search engine – provides input for idea generation.

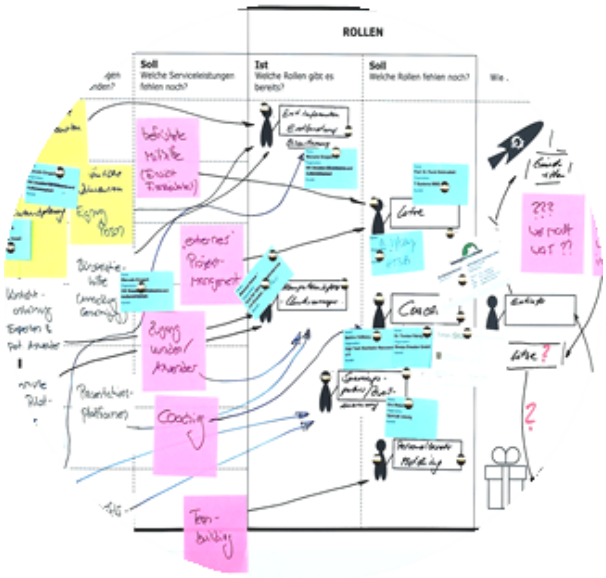


Fig.4 – Idea Engine: Creative ideation based on Inspirational Matrices

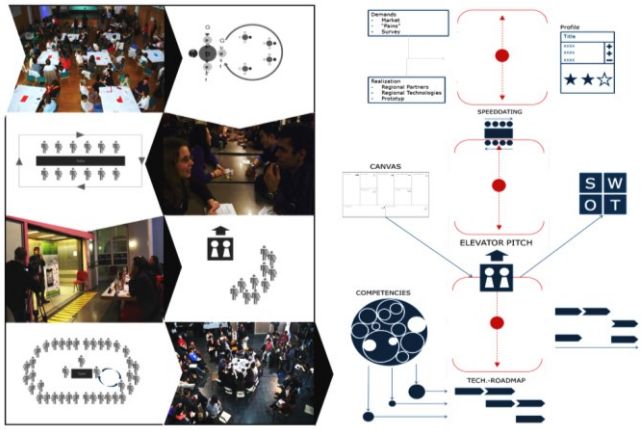


Fig.5 – Integration: Establishing a coherent process and methodology

Built on established creativity and innovation and IT and AI technologies, an association-assisting tool needs to be developed that helps engineers to quickly generate a large number of productive ideas and to evaluate them. With combinatorial algorithms and methods of remote association, textual and visual-spatial idea matrices can be developed that provide a fertile basis for radically new design and engineering ideas [20].

The fourth research challenge addresses the integration of above mentioned processes and tools into a coherent methodology and process. Their validation is possible on the basis of selected visionary ideas from the past (e.g. science fiction) that can be simulated on the basis of their associative foundations and implementation probabilities. The creative supportive effect of the method and the realization potential of the generated innovations need to be assessed with means from fields like engineering psychology.

Conclusion

The initial research program sketched above will be pursued over the next months and years by the WISSENSARCHTEKTUR Laboratory of Knowledge Architecture at TU Dresden within larger research consortia and projects. We target at implementing and testing a complete Invention Engineering Process at TU Dresden within the next two years, and explore the research and innovation potential of the approach also beyond the scope of engineering education, research and practice.

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АННОТАЦИЯ *В области инженерного образования, практики и исследований центральным вопросом является то, как традиционные модели мышления могут быть разбиты творческими инструментами и импульсами. В статье представлена схема метода, который поддерживает открытие новых источников вдохновения в таких сферах поиска, как литература, кино, изобразительное искусство или музыка, и позволяет инженерам создавать альтернативные дизайны быстро и в большом количестве. С этой целью методы из дизайнерских наук, творчества и инноваций, а также цифровой информации и технологий познаний пересматриваются и интегрируются в концептуальный подход изобретательской инженерии. Целью является разработка и подтверждение процесса, который обеспечивает художественное вдохновение инженерам и поддерживается алгоритмическими инструментами творчества и ассоциации. Таким образом, нужно решить четыре отдельные проблемы исследования: а) анализ творческих процессов в инженерных дисциплинах (вдохновение, ассоциация, идеи, инновации) и их сравнение с "креативными моделями" других областей; кроме того, необходимо изучить видение прошлого и социально-технические рамочные условия их внедрения, чтобы установить модель для валидации общего метода изобретательской инженерии; б) разработка метода «Вдохновение для вдохновения» для получения творческих импульсов по инженерным областей (например, литературы, музыки, изобразительного искусства, кино и др.) соответствующие результаты поиска должны ссылаться на семантическую модель и обрабатываться в системе знаний (Банк Идеи), которая, как своеобразная ассоциативная поисковая система, дает вклад для генерирования идеи; в) перевод установленных исследований творчества и инноваций в «двигатель идеи» для генерации большого количества продуктивных идей; это можно сделать с помощью комбинаторных алгоритмов и методов удаленной ассоциации, текстовых и визуально-пространственных матриц идей, которые дают плодовитую основу для радикально новых дизайнерских и инженерных идей; г) интеграция отдельных методов в целостный процесс и проверка эффекта творческой поддержки созданных инноваций средствами инженерной психологии; это можно сделать на основе отобранных воображаемых идей из прошлого (например, научной фантастики), которые могут быть смоделированы на основе их ассоциативных оснований и вероятностей реализации.*

Ключевые слова: *изобретательская инженерия; креативные методы; инновационный менеджмент*

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