# Editorial


## Eliab Z. Opiyo and Imre Horváth

Faculty of Industrial Design Engineering,
Department of Design Engineering,
Delft University of Technology,
Landbergstraat 15,
2628 CE Delft, The Netherlands
E-mail: e.z.opiyo@tudelft.nl
E-mail: i.horvath@tudelft.nl

## Ferruccio Mandorli

Faculty of Mechanical Engineering,
Design Tools & Methods Group,
Department of Mechanics,
Università Politecnica delle Marche,
Via Brecce Bianche, 60131 Ancona (AN), Italy
E-mail: f.mandorli@univpm.it

**Biographical notes:** Eliab Z. Opiyo is an Assistant Professor at the Faculty of Industrial Design Engineering, Delft University of Technology, the Netherlands. He earned his PhD (Computer Aided Engineering) from Delft University of Technology, The Netherlands, in 2003. His current research interests include product visualisation, applications of mobile and ubiquitous technologies in product development, prototyping and development of design support systems.

Imre Horváth is a Full Professor of Computer Aided Design and Engineering at the Faculty of Industrial Design Engineering, Delft University of Technology, The Netherlands. He earned his Dr. univ. title (1987) and PhD title (1994) from TU Budapest in Hungary. His current research interests include design application of mobile and ubiquitous technologies, systemisation of design research, affordance-based innovation and teleconferencing-based active learning.

Ferruccio Mandorli is a Full Professor at the Mechanical Engineering Department of the Università Politecnica delle Marche. He obtained a PhD in Engineering of Industrial Production from the Industrial Engineering Department of the University of Parma. His primary research interests are related to the tools and methods to support engineering design, with focus on design automation applications, lifecycle assessment and product lifecycle management. He is the author of more than 100 national and international publications.

## 1 Background

The whole of industrial product development is a creative process, which includes many activities that are strongly based on human intuition, heuristics, associations, analogies and experiences. Several attempts have been made to provide formal (waterfall type) models for driving product development projects from conception to launch and beyond by demanding product developers to perform activities, such as market and business analysis, needs analysis and requirements engineering, idea generation and screening, concept development and selection, embodiment and detail design, prototyping, production and so forth – see e.g., Ulrich and Eppinger (1999) and Rosenau et al. (1996). Creativity is a real concern at the levels of the individuals, teams and organisations throughout the product development process. In addition to the human creative potentials, successful product development also needs factual data, semantic information, meta-knowledge and problem-solving capability. Most industrial organisations recognise that knowledge and creativity constitute valuable intangible assets for being competitive. Organisations are increasingly making efforts to make their product development processes knowledge-inclusive and to increase the role of creativity and support it in these processes.

Since combination and fostering of creativity and knowledge are vital aspects for many organisations, knowledge-inclusion has received considerable emphasis in the last several decades. As a result, several explorative studies have been conducted, some explanatory theories have been developed, and various methodological frameworks and practical methods have been proposed (refer to Section 3 for further details). However, there are still many phenomena requiring deeper insights, premature theories and methodologies to further improve, and there is an explicit need for advanced creativity-support and knowledge engineering tools. The research in this area is motivated by several factors, including the growing importance of creativity in organisations, the reliance of creativity on knowledge and the ever-increasing use of ICT-based data and information management systems (Nov and Jones, 2005).

This special issue attempts to demonstrate the types and the diversity of directions of ongoing research activities in the area of knowledge inclusion in creative processes. It consists of reworked papers that were initially presented at the 8th International Symposium on Tools and Methods of Competitive Engineering (TMCE) held in Ancona, Italy, from 12 to 16 April 2010. Of course, the challenges dealt with in the selected papers are just examples, and only represent a tiny subset of numerous diverse challenges that organisations and researchers face. Apart from different problems and approaches addressed, the contributions in this special issue also show valuable examples of works carried out to increase knowledge intensiveness and to support creativity in various product development processes. This gives the scientific novelty and the thematic coherence for this special issue. As part of the preface, in the following sections we define the key terms, concisely present and discuss the types and sources of knowledge, explain the effects of different background knowledge in product development processes, and briefly review and analyse techniques and challenges for assimilating knowledge in these processes.

## 2 Knowledge in creative product development processes

Extending the product developers' knowledge and experiences and fostering creativity is one of the challenges faced by many industrial organisations involved in product development. Knowledge plays an important role in engineering product development and its influence over creativity is well documented. However, it is important to note that while extending the product developers' knowledge and experiences increases the probability of generating good solutions (Zeng and Yao, 2009), some studies have, by contrast, shown that prior knowledge of potential solutions could result in fixation problems (Jansson and Smith, 1991; Purcell and Gero, 1996).

### *2.1 Knowledge and creativity*

It is generally understood that there is a close association between creativity and knowledge (Edmonds and Candy, 2002; Nov and Jones, 2005). Creativity can be defined as mental processes or thinking that lead to new solutions, ideas and theories (Christiaans, 1992; Gurteen, 1998; Holt, 1988). It involves creation of something imaginatively rather than imitatively by relating concepts to a particular body of knowledge. It depends on the relevant skills of the individuals (i.e., on the individuals' ability to transform knowledge into use), but it can also be stimulated and supported through training (formal and informal education). Furthermore, it also depends on experience in idea generation, personality characteristics including, for instance, innate cognitive abilities, intuition or perceptual and motor skills (Christiaans, 1992; Amabile, 1983) and relies on intrinsic motivation of humans being enthusiastic and inspired. Creativity requires, among other things, the implicit or explicit heuristics knowledge for generating novel ideas as well as the understanding of the problem domain and special domain-relevant talent. As for the term 'creative process', it is used in this special issue to refer to a process that leads to creation of solutions, ideas or theories, which can subsequently be implemented (i.e., developed into real products and eventually commercialised).

Creativity as the act of generating solutions, ideas or theories is an essential and integral part of the product development process. For instance, the ideas generated and the decisions made in the predominantly creative conceptual design stage of the product development process typically have enormous influence on quality and acceptability of the final products. In general terms, knowing the factors that influence product design in advance and giving them a due consideration right from the onset of the product development process is the key to being competitive.

Knowledge is central in creative processes. The available body of tacit, implicit and emergent knowledge is vital for creativity. Really creative individuals in all professions – be in engineering design, performing arts such as music and theatre, etc. – normally spend many years acquiring and refining their knowledge. In the context of enabling creativity, it is important to distinguish the term 'knowledge' from the terms 'information' and 'data'. These three terms are closely related but the literature, in general, holds that they have very different meanings.

The general consensus in the literature, which is also the understanding adopted in this special issue, is that 'data' are symbolic surrogates used to represent factual information (e.g., raw numbers from measurements or statistics, etc.). 'Information' is taken to mean the processed data. Information gives the meaning of data and serves as a basis for knowledge. Information is obtained through interpretations, abstractions or associations of data. 'Knowledge', by contrast, is a result of experience with data and information, or simply putting the data and information into action, refer, e.g., to Blumenthal (1969), Burch et al. (1979), Dretske (1981), McMahon and Lowe (2002) and Wilson (1987). Knowledge is obtained in different ways, for instance, through formal instructions and learning, through building experience, by developing relevant technical skills, through activities such as brainstorming, and through empirical exploration and rational comprehension (see e.g., Horváth, 2004). Problem-solving knowledge includes not only data and information, but also what can be deduced or inferred from experience and reasoning with data and information. Many researchers, however, tend to use the terms knowledge and information interchangeably (Wang and Noe, 2010). This includes some of the authors whose papers are included in this special issue.

### *2.2 Types and sources of knowledge*

Creative product development requires different types and sets of inspirational background knowledge that come from different sources. These chunks of knowledge can be categorised in different ways. One way of classifying knowledge is on the basis of the possibility to document and to share knowledge, namely if it is explicit or tacit knowledge (Collins, 2010; Huang and Yanga, 2009; Nov and Jones, 2005; Davies, 2004; Koskinen et al., 2003; Gurteen, 1998). Explicit knowledge is the type of knowledge that can be articulated or represented formally (for instance, in the form of words, numbers, graphical representations, scientific formulae, product specifications, manuals, universal principles, and so forth) and shared systematically. In contrast with explicit knowledge, tacit knowledge is the type of knowledge that is highly personal and hard to represent in a formal way and therefore difficult to communicate. These include personal imaginations, insights, perceptions, inspirations and feelings, which are typically deeply rooted in 'hard-to-pin-down' things such as individual actions, experiences, ideas, values, beliefs, emotions, skills or crafts.

Another way to categorise knowledge is on the basis of the origins of knowledge. In this respect, knowledge is classified as 'generated' knowledge (e.g., knowledge from in-house R&D activities, knowledge learnt by doing, knowledge inputs from a local cluster, knowledge from well-educated in-house workforce, knowledge embedded within the organisation's members, tools, technology or tasks, and so forth) or 'transferred knowledge' (i.e., knowledge input from outside the firm, unit or enterprise; knowledge from R&D activities carried out by other organisations, suppliers, or from customers, and so forth) (Frenza and Ietto-Gillies, 2009; Foss and Pedersen, 2002; Argote and Ingram, 2000). Furthermore, knowledge can also be classified according to the ways people obtain this knowledge, or according to the ways of knowing as 'dualism received', 'subjective', 'procedural', or 'built or constructed knowledge' (Huang and Yanga, 2009; Lakkaraju, 2008; Goodman, 2001; Belenky et al., 1986). 'Dualism received' knowledge is the type of knowledge obtained mainly through instructions or teaching individuals. Knowledge is gained through gathering data and information and committing it to memory. 'Subjective' knowledge is gained by observing or experiencing, and gradually discovering how to apply facts and information, whereas 'procedural' knowledge is gained through seeing the complexity in problems or issues and by discovering the need for systematic analysis. In this case, knowledge is generated by building up skills for dealing with complexity (for instance, by thinking about several factors or views; looking at a situation from different perspectives; using systematic methods of analysis; gathering evidence; seeing strengths and limitations, simulating processes, and so forth). With regard to 'constructed' knowledge, people gain knowledge through critical and creative combination and application of facts and experiences. This involves learning how to explore complexities fully, creating a world view (i.e., a view from which commitments will ultimately be made) and taking a stand. Also, an obvious way to classify knowledge is that based on application areas or professions, where knowledge is classified, for instance, as design knowledge, ergonomics knowledge and so forth (Szykman et al., 2000; Horváth, 2004; Zeng and Yao, 2009). Usually knowledge of factors influencing product designs is crucial in ensuring quality and acceptability of eventual products. Some of these factors are discussed in the subsequent section.

### *2.3 Influence of knowledge*

It is widely acknowledged that success in engineering product development activities is highly dependent on the knowledge of the involved engineers (Mital, 1995; Jokinen, 1997). Like in other fields or professions, specialised body of background engineering-oriented knowledge is vital for product developers. This includes knowledge about ergonomics, functionality, manufacturability, maintainability, assemblability, cost, materials, reliability, safety, aesthetics and environments (Mital, 1995; Jokinen, 1997; Horváth, 2004). Often these highly interconnected factors and many others are taken into consideration, and a large amount of information is typically used to make designs work. Since many products are designed and destined for human use, ergonomics understanding of how to accommodate human performance and safety of users normally plays a major role. The type and number of functions a product has to perform (i.e., functionality of a product), which in most cases derives from both rational reasoning about possible physical performance and from intuitive reasoning about the opportunities and conjectures, will inevitably influence eventual design.

Manufacturability naturally plays a major role when designing a product because virtually all products are manufactured through multiple manufacturing processes and by using various techniques. Therefore, the availability of manufacturing resources such as machine tools, tools and fixtures often strongly influences the manifestation of the final product. Maintainability is also an important factor because no one expects to develop a product that will continue to function acceptably forever. Often components fail or must be replaced when their useful life is over. The need to disassemble components influences how they should be joined. With regard to cost, the potential customers are usually prepared to pay a certain price for the product. Cost incurred to bring a product to the market including such costs as of the materials and labour required to manufacture the product should be taken into consideration. The availability of materials certainly has an influence on the final design of a product. Building high levels of reliability into components and products is one of the most critical aspects of design in today's manufacturing arena, where quality has a direct influence on competitive advantage. Usually, a wide range of product safety rules and standards apply depending on the nature of the product. Design safety concepts such as redundancy have become familiar means to achieve overall product safety goals and product developers often perform significant safety testing to ensure that the product complies with applicable standards for safety.

Furthermore, the aesthetics requirements for products including, for instance, shape or form preferences may, for instance, determine the layout of the internal elements of the product such as circuits or other internal mechanisms. In short, most products are often designed to look stylish. The outside appearance of a product can also easily influence the technology inside it. Similarly, consumer preferences for product aesthetics can also alter the techniques through which product is manufactured. And as for the environment, nowadays many people are concerned about their environment and the damages a product may cause to the environment. When designing a product, it is increasingly becoming necessary to ensure, for instance, that the materials selected can be recycled or the product itself can be manufactured from recycled materials.

Apart from depending on different types of requirements-related knowledge such as those mentioned earlier, which are certainly important design knowledge, it is also important to note that success in engineering product development activities also depends on other kinds of knowledge such as the evaluation knowledge and synthesis knowledge – see, e.g., Zeng and Yao (2009).

In the light of the discussion in this subsection, it is certainly evident that product developers are faced with a real challenge of handling of the complexity brought about by the need to ensure that all highly interconnected factors influencing product development are taken into consideration, including also the challenge of handling the associated background knowledge. Currently, various methods and techniques incorporated in information systems are increasingly being used to support knowledge processing and sharing. However, as shown in the subsequent section, new approaches and techniques for processing, integrating and availing knowledge are continuously being developed as attempts to deal with existing challenges.

## 3 Techniques and challenges for assimilating knowledge and supporting creativity in product development processes

As pointed out earlier, creativity depends on the individual's knowledge of concepts and ability to combine and apply knowledge to create new ideas, perspectives or solutions. Without a deep understanding of the required concepts, crafts or skills; product developers cannot draw from their recollection and create new ideas, perspectives or solutions. It is difficult to imagine how the product developers can be creative and be able to develop solutions, ideas, theories or new products without having the requisite background knowledge. Apart from depending on their individual background knowledge, product developers in many industrial organisations are also increasingly being supported by various concepts, formal methods and sophisticated tools in acquisition, representation, sharing and transfer of knowledge. Many new concepts, approaches and insights are also continuously emerging. The following subsections briefly examine the advancements and issues related to knowledge acquisition, representation, transfer, sharing and exchange.

### *3.1 Acquisition and representation of knowledge*

Many studies in the existing literature suggest that the level of knowledge acquired has direct effect on the level of firm's performance and creativity (Soo et al., 2007). 'Knowledge acquisition' can be described as the process of gathering knowledge about a specific domain, usually from an expert, and incorporating the acquired knowledge into a computer-based tool (Kim and Courtney, 1988). It involves defining a domain problem, designing architectures, building a knowledge base, and testing and refining the resulting application. Methods such as interviews (i.e., structured, prompted and unstructured), observation (i.e., inferring knowledge from behaviour while doing tasks), induction (i.e., generating heuristics algorithmically from judgements) and prototype review (Welbank, 1990) are typically used to gather knowledge.

Gathered knowledge can be represented in different ways, stored, and later on retrieved from an information system and reused. A view commonly held in the existing literature is that information systems support knowledge creation and sharing in organisations, and that creative work is closely related and reliant on knowledge sharing and use. Some decades ago, non-computerised methods such as paper-based methods were predominantly used to represent or to access knowledge. Nowadays, numerous computer-based information systems are available; some of which are characteristically equipped with sophisticated algorithms.

Performance of an information system usually depends on how well knowledge is organised and represented in it. Knowledge can be presented pictorially, symbolically, linguistically, virtually and algorithmically (Owen and Horváth, 2002). Various techniques for knowledge representation and sharing have been developed. Most of the prevailing techniques involve using various representation formalisms such as predicate logic, databases, natural languages, scripts, decision trees, frames, ontology, semantic networks and production rules – which is the widely used scheme – see, e.g., Brachman and Levesque (2004), Davis et al. (1993), Chen (2008) and Wang et al. (2009). Numerous works on knowledge representation in the existing literature focus on the application of different representation formalisms to represent specific domain knowledge.

### *3.2 Knowledge transfer, sharing and exchange*

Knowledge transfer, sharing or exchange is vital among members of product development teams and it is widely argued that adoption of formal knowledge management strategies in organisations provide the basis for competitive advantage (Argote and Ingram, 2000; Pumareja and Sikkel, 2005). 'Knowledge sharing' is an activity that involves providing information and know-how to help others and to support collaboration in problems solving or in the development of new ideas or solutions (Wang and Noe, 2010; Hendriks, 1999). It can occur in different ways, for instance, through written correspondence, face-to-face communications, through networking with other experts, by explaining things, e.g., in formal presentations or lectures, or through documenting knowledge. Shared knowledge in product development is particularly vital because it offers different viewpoints on possible solutions to problems. Failure to share knowledge can lead to adverse consequences such as lack of participation or resistance to ideas or solution proposals. 'Knowledge exchange' by contrast includes knowledge sharing and knowledge seeking, but this term is used synonymously with knowledge sharing in some literature. 'Knowledge transfer', which refers to movement of knowledge between different groups, units, departments, divisions, or organisations rather than among individuals (Wang and Noe, 2010; Argote and Ingram, 2000), is another important aspect of knowledge and it involves both sharing and acquisition of knowledge. The common modes of knowledge transfer include lectures, directives, Socratic questioning, learning by doing (e.g., through guided practice, experimentations, observations, etc.) and rules of thumb.

Some ICT tools are routinely used to support knowledge transfer, sharing and exchange in different ways, for instance by removing barriers (e.g., through using various groupware applications), by providing access to information (e.g., by using intelligent agents and document management systems to tap into the knowledge contained in documents), by improving processes (e.g., by using case-based reasoning or expert systems to assist knowledge sharing by extracting knowledge), or by locating knowledge carriers (e.g., using automated knowledge maps) – see, e.g., Hendriks (1999), Turban and Aronson (1998) and Pumareja and Sikkel (2005). Intranets and the internet are also prominent ICT tools for facilitating knowledge transfer, sharing and exchange.

### *3.3 Challenges ahead*

Some studies have recently indicated that most of the existing knowledge-based systems cannot sufficiently address knowledge representation, storage, transfer, sharing and exchange challenges and do not comprehensively support users – see, e.g., Chen (2010). In particular, in the light of the discussion in Section 2.3, handling of the complexity brought about by the interconnections of factors influencing product design as well as handling of the complexity and heterogeneity of background knowledge required in product development are some of the main challenges that still require further research. More effective strategies and methods that can help to improve knowledge representation, transfer, sharing and exchange and to support creativity in organisations need to be developed and put to use. Organisations and researchers still face and need to overcome numerous and highly diverse infrastructural and strategic challenges. These include, for instance, the challenges of overcoming limitations of existing ontologies for organising knowledge; developing more effective infrastructure and technologies for knowledge acquisition, representation, transfer, sharing and exchange; developing computationally efficient and scalable algorithms, e.g., efficient reasoning algorithms, managing documentations and trash efficiently; integrating knowledge bases or databases and planning systems; ensuring interoperability between dissimilar platforms or applications; developing effective navigational tools and many others. The papers included in this special issue deal with some of these challenges.

## 4 About this special issue

The issue of how to support creativity in design and in other product development processes has vigorously been dealt with by many researchers (Goel, 1995; Cross, 1997; Bonnardel and Marmeche, 2004). The papers included in this special issue on ‘Knowledge Inclusion in Creative Processes’ present novel concepts, methods and techniques for handling and integrating knowledge in creative processes. Thematically, this special issue deals with two broad subject matters, which are:

- implementation of dedicated computer-based tools for handling knowledge in product development processes
- development of some concepts for knowledge handling and for supporting creativity.

Two papers deal with the former theme and the rest with the latter theme. The first one written by Muzzupappa, M., Barbieri, L. and Bruno, F. and titled '*Integration of topology optimisation tools and knowledge management into the virtual Product Development Process of automotive components*' presents a methodology in which a CAD system, a multi-body simulator and a topological optimisation tool are synergically employed to support the design of a suspension component. The methodology they propose defines some guidelines and introduces two knowledge-based interfaces. The authors claim that this methodology facilitates the integration of topological optimisation of the component within a standard design process. The results of the application of the proposed methodology show, they argue, that the integrated design approach can efficiently support the selection of the optimum concept of a mechanical component with complex dynamic behaviour.

The second contribution authored by Vroom, R.W. and Olieman, A.M. titled '*Sharing relevant knowledge within product development*' deals with the challenge of knowledge codification. They introduce a web-based tool for industrial design engineers, dubbed WikID, that they have developed to facilitate finding industrial design information on the World Wide Web. The major challenge they dealt with was the one posed by the necessity of providing freedom for the WikID authors to edit articles and, at the same time, achieving a consensus on the contents. The authors have investigated the 'design relevance' through a literature study and have also conducted interviews with experts and subsequently defined the scope of contents in terms of products, disciplines and design aspects. In addition, they have developed article-writing guidelines to help users decide on design relevance of their articles. The authors argue that design relevance is not a property of information, but of the situation where users' expectations are met.

Six papers focus on the development of various concepts for handing knowledge and for supporting creativity. The first one written by Albers, A., Schmalenbach, H. and Lohmeyer, Q. titled '*Ontology development for knowledge representation*' asserts that problem solving in creative processes is strongly connected to high information demands and permanent information processing. The authors claim that cooperative working, especially within knowledge-based activities, needs to be supported by promising approaches. They argue that ontologies – typically used to represent a common comprehension model of a knowledge domain – are particularly well suited for realisation of comprehensive communication and IT-based applications for domain-specific knowledge. On the basis of existing methodologies, the authors propose an approach for ontology development that focuses on comprehensive integration of validation activities into the steps of ontology development processes and use a real-world ontology development example to illustrate their approach. They claim that integration of validation activities, which allows continuous validation, improves the ontology development process, and that frequent communication with all participants of the development process improves the common comprehension and allows evolution of an explicit shared vocabulary within a heterogeneous group of experts of a delimited knowledge domain.

The next paper authored by Del Frate, L., Franssen, M. and Vermaas, P.E. and titled '*Towards a trans-disciplinary concept of failure for Integrated Product Development*' deals with the issue of sharing and communication of knowledge about failure phenomena in the design phase of the product development process. They argue that knowledge about failure is typically spread among a number of engineering disciplines and specialisations, and that this leads to multiple definitions, which they claim might affect communication as well as the product that is being designed. The authors advocate the idea of having transdisciplinary definitions and attempt to identify definitions that could improve communication. They first identified four criteria that they used as the basis for deciding on the suitability of a definition and conducted a literature survey to find candidate definitions. The authors analysed these definitions' compliance with criteria and propose a tentative transdisciplinary definition that meets all four criteria. They argue that this transdisciplinary definition will assist communication and knowledge sharing.

The paper written by Polverini, D., Graziosi, S. and Mandorli, F. titled '*A step-based framework to combine creativity, project management and technical development in industrial innovation*' argues that since the assessment of the novelty, feasibility and value of new product ideas is highly subjective and uncertain, it is hard for companies to successfully apply their innovation strategies and to come up with a final product that concurrently and successfully embodies both customers' needs and company requirements. The authors further argue that the implementation of selected formal approaches in specific stages of the innovation process may reduce uncertainty, especially in idea generation, design, managerial and decision-making activities without forcing the innovation process into a more rigid and constrained path. They, therefore, propose a multi-step design and managerial framework based on well-known existing and emerging methods and techniques to help firms achieve greater success in developing new products. The authors use a case study to demonstrate the effectiveness of their framework.

Wynn, D.C., Eckert, C. and Clarkson, P.J. in their paper titled '*Simulating intertwined design processes that have similar structures: a case study of a small company that creates made-to-order fashion products*' present an approach for analysing a creative design process and a case study of a simple customisation environment to show how simulation of interdependent design and production processes can be used to explore the circumstances under which accepting a new order for customised products is more likely to create unacceptable delays to other schedules. The authors argue that resource limitations create dependencies between projects in companies that handle multiple development projects and that draw on the same limited resources at the same time, especially the companies that run many customisation projects concurrently in which existing product designs are changed to meet particular needs. Furthermore, they argue that accepting a new order for the design and production of customised products can have knock-on consequences by jeopardising the timely delivery of other projects. They claim that (simulation-based) techniques similar to those used in their study could be used to study processes in complex engineering domains, and argue that the case study used is not only a proxy for a 'complex' situation, but also shows that less-structured processes can be simulated and analysed.

Kreimeyer, M. in the paper titled '*Aggregate views to manage complex dependency models*' addresses the challenge of dealing with large dependency models that often are hard to analyse or work with. The author proposes an approach to compute reduced models (of fewer domains and relationship-types than the original ones) out of larger ones that comprise several domains. It is argued that engineered systems are often modelled as dependency models that typically consist of different coexisting classes of entities (domains) and relations (relationship types). These models can be used to study various structural aspects such as relationships and constellation of entities, design, and how to improve the behaviour of a system. Kreimeyer further argues that such models are often too complex to use and that in certain instances it is necessary to generate more condensed models to see the dependencies of different entities and make them accessible to different algorithms or analysis methods, e.g., 'Design Structure Matrix' based analysis methods. On the basis of the existing works in various disciplines, the author proposes three different strategies: path searching, attribution and superposition. For each of the three strategies, the resulting aggregate models are reviewed, and principles to working with the resulting aggregate relationship types are determined. The author proclaims that aggregation enables the application of common analysis methodology and algorithms for dependency models.

The last paper written by Fargnoli, M., De Minicis, M. and Di Gravio, G. titled '*Knowledge Management integration in Occupational Health and Safety systems in the construction industry*' asserts that knowledge management has an important role in increasing company know-how and improving knowledge updating and sharing processes. The authors have conducted a study aimed at collecting and classifying all safety requirements and specific problems for the construction sector to provide a specific knowledge management tool. They have developed a specific knowledge management framework to support companies in managing safety issues. They claim that the developed framework represents a dynamic risk management approach for safety compliance and improvement, which reduces company's efforts and costs, improves knowledge transfer process within the company, allows companies to safely manage the selection and maintenance of machines and equipments, and supports training of workers and increases diffusion of safety procedures throughout the company. A prototype system has been developed and applied to real-world case studies. They argue that these studies brought to light the effectiveness of their system in providing a complete overview of all safety issues related to the most common work activities.

Lastly, we would like to sincerely thank all authors for their valuable contributions. Without their efforts and support, this special issue would not have been compiled. We also extend our sincere thanks and gratitude to all reviewers for the efforts and time they spent in reviewing initial drafts of manuscripts. Their comments and suggestions have undoubtedly enhanced the quality of this special issue and improved it to its present form.

## References

Amabile, T.M. (1983) *The Social Psychology of Creativity*, Springer-Verlag, New York, p.78.

Argote, L. and Ingram, P. (2000) 'Knowledge transfer: a basis for competitive advantage in firms', *Organizational Behavior and Human Decision Processes*, Vol. 82, No. 1, pp.150–169.

Belenky, M., Clinchy, B., Goldberger, M. and Jill Tarule, J. (1986) *Women's Ways of Knowing*, HarperCollins, New York.

Blumenthal, S.C. (1969) *Management of Information Systems: A Framework for Planning and Development*, Prentice-Hall, Englewood Cliffs, NJ, USA.

Bonnardel, N. and Marmeche, E. (2004) 'Evocation processes by novice and expert designers: towards stimulating analogical thinking', *Creativity and Innovation Management*, Vol. 13, No. 3, pp.176–186.

Brachman, R.J. and Levesque, H.J. (2004) *Knowledge Representation and Reasoning, Morgan Kaufmann*, San Francisco, CA, USA.

Burch, J.G., Strater, F.R. and Grudnitski, G. (1979) *Information Systems: Theory and Practice*, John Wiley and Sons, New York, NY, USA.

Chen, T. (2008) 'Knowledge sharing in virtual enterprises via an ontology-based access control approach', *Computers in Industry*, Vol. 59, No. 5, pp.502–519.

Chen, Y. (2010) 'Development of a method for ontology-based empirical knowledge representation and reasoning', *Decision Support Systems*, Vol. 50, No. 1, pp.1–20.

Christiaans, H.H.C.M. (1992) *Creativity in Design: The Role of Domain Knowledge in Designing*, PhD Thesis, Delft University of Technology, Netherlands.

Collins, H. (2010) *Tacit and Explicit Knowledge*, The University of Chicago Press, Chicago, IL, USA.

Cross, N. (1997) 'Creativity in design: analyzing and modeling the creative leap', *Leonardo*, Vol. 30, No. 4, pp.311–317.

Davies M. (2004) 'Knowledge (explicit and implicit): philosophical aspects', *International Encyclopedia of the Social & Behavioral Sciences*, pp.8126–8132.

Davis, R., Shrobe, H. and Szolovits, P. (1993) 'What is a knowledge representation?', *AI Magazine*, Vol. 14, No. 1, pp.17–33.

Dretske, F. (1981) *Knowledge and Flow of Information*, MIT Press, Cambridge, MA, USA.

Edmonds, E. and Candy, L. (2002) 'Creativity art practice, and knowledge', *Communications of the ACM*, Vol. 45, No. 10, pp.91–95.

Foss, N.J. and Pedersen, T. (2002) 'Transferring knowledge in MNCs: The role of sources of subsidiary knowledge and organizational context', *Journal of Int. Management*, Vol. 8, pp.49–67.

Frenza, M. and Ietto-Gillies, G. (2009) 'The impact on innovation performance of different sources of knowledge: evidence from the UK Community Innovation Survey', *Research Policy*, Vol. 38, pp.1125–1135.

Goel, V. (1995) *Sketches of Thought*, MIT Press, Cambridge, MA, USA.

Goodman, D. (2001) *Promoting Diversity and Social Justice: Educating People from Privileged Groups*, Sage Publications, Inc., London, UK, p.53.

Gurteen, D. (1998) 'Knowledge management and creativity', *Journal of Knowledge Management*, Vol. 2, No. 1, pp.25–37.

Hendriks, P. (1999) 'Why share knowledge? The influence of ICT on the motivation for knowledge sharing', *Knowledge and Process Management*, Vol. 6, No. 2, pp.91–100.

Holt, K. (1988) *Production Innovation Management*, Butterworths & Co (Publishers), Ltd., London, England, UK.

Horváth, I. (2004) 'A treatise on order in engineering design research', *Research in Engineering Design*, Vol. 15, pp.155–181.

Huang, S. and Yanga, C. (2009) 'Designing a semantic bliki system to support different types of knowledge and adaptive learning', *Computers & Education*, Vol. 53, No. 3, pp.701–712.

Jansson, D.G. and Smith, S.M. (1991) 'Design fixation', *Design Studies*, Vo1. 12, pp.3–11.

Jokinen, P.A. (1997) 'Sharing engineering design knowledge and delivering proven practices in engineering organizations', *ISA Transactions*, Vol. 36, No. 4, pp.257–266.

Kim, J. and Courtney, J.F. (1988) 'A survey of knowledge acquisition techniques and their relevance to managerial problem domains', *Decision Support Systems*, Vol. 4, No. 3, pp.269–284.

Koskinen, K.U., Pihlanto, P. and Vanharanta, H. (2003) 'Tacit knowledge acquisition and sharing in a project work context', *Int. Journal of Project Management*, Vol. 21, pp.281–290.

Lakkaraju, S.K. (2008) *Synchronising Subjective Knowledge and Knowledge Management Systems in Organisations*, PhD Thesis, University of Western Sydney, Sydney, New South Wales, Australia.

McMahon, C. and Lowe, A. (2002) 'Opportunities and challenges of knowledge management', *Proceedings of the 4th Tool and Methods for Competitive Engineering (TMCE) Conference*, 22–26 April, Wuhan, China, pp.21–34.

Mital, A. (1995) 'Is the background knowledge of ergonomists important if ergonomics is to succeed within a simultaneous engineering (SE) environment?', *Int. Journal of Industrial Ergonomics*, Vol. 16, Nos. 4–6, pp.441–450.

Nov, O. and Jones, M. (2005) 'Creativity, knowledge and is: a critical view', *System Sciences, Proceedings of the 38th Annual Hawaii Int. Conference on Systems Science – HICSS '05*, January, pp.44b–44b.

Owen, R. and Horváth, I. (2002) 'Towards product-related knowledge asset warehousing in enterprises', *Proceedings of the 4th Tool and Methods for Competitive Engineering (TMCE) Conference*, 22–26 April, Wuhan, China, pp.155–170.

Pumareja, D.T. and Sikkel, K. (2005) 'The role of dissonance in knowledge exchange: a case study of a knowledge management system implementation', *Proceedings of the 38th Hawaii Int. Conference on System Sciences*, 3–6 January, Big Island, HI, USA.

Purcell, A.T. and Gero, J.S. (1996) 'Design and other types of fixation', *Design Studies, Special Issue: Design Cognition and Computation*, Vol. 17, No. 4, pp.363–383.

Rosenau, M.D., Griffin, A., Castellion, G.A. and Anschuetz, N.F. (1996) *The PDMA Handbook of New Product Development*, John Wiley & Sons, Inc., New York, NY, USA.

Soo, C.W., Devinney, T.M. and Midgley, D.F. (2007) 'External knowledge acquisition, creativity and learning in organisational problem solving', *Int. Journal of Technology Management*, Vol. 38, Nos. 1–2, pp.137–159.

Szykman, S., Sriram, R.D., Bochenek, C., Racz, J.W. and Senfaute, J. (2000) 'Design repositories: engineering design's new knowledge base', *Intelligent Systems and their Applications*, IEEE Vol. 15, No. 3, pp.48–55.

Turban, E. and Aronson, J.E. (1998) *Decision Support Systems and Intelligent Systems*, 5th ed., Prentice Hall, Upper Saddle River.

Ulrich, K. and Eppinger, S. (1999) *Product Design and Development*, 2nd ed., McGraw-Hill/Irwin.

Wang, S. and Noe, R.A. (2010) 'Knowledge sharing: a review and directions for future research', *Human Resource Management Review*, Vol. 20, No. 2, pp.115–131.

Wang, T.I., Hsieh, T.C., Tsai, K.H., Chiu, T.K. and Lee, M.C. (2009) 'Partially constructed knowledge for semantic query', *Expert Systems with Applications*, Vol. 36, No. 6, pp.10168–10179.

Welbank, M. (1990) 'An overview of knowledge acquisition methods', *Interacting with Computers*, Vol. 2, No. 1, pp.83–91.

Wilson, P. (1987) 'Information modeling', *IEEE Computer Graphics*, Vol. 7, No. 12, pp.65–67.

Zeng, Y. and Yao, S. (2009) 'Understanding design activities through computer simulation', *Advanced Engineering Informatics*, Vol. 23, No. 3, pp.294–308.