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MICROSYSTEM DESIGN-KNOWLEDGE MANAGEMENT WITH KNOWLEDGE-NETWORKS

Jorge Antonio López-Garibay, Hansgeorg Binz
Institute for Engineering Design and Industrial Design, Universität Stuttgart, Germany

ABSTRACT
Knowledge management represents an opportunity to stimulate systematic design. This paper offers a method to develop a design-knowledge management tool for microsystem engineering inspired by *bionic software* and based upon industrial practice. On the assumption that in opposition to the role of computers in the information society, the knowledge society will emphasise the central position of people within product development, the authors took a broader definition of knowledge than the notion coined by artificial intelligence and embraced a knowledge-based orientation towards product innovation. Then, with the premise of turning artificial intelligence into intelligence augmentation, established knowledge-representations were analysed to determine which one can best handle and depict complex interdisciplinary heterogeneous knowledge entities and their interrelations while supporting the transformations of the concept-knowledge theory of design, as it is required in microsystems engineering. A scenario of the application is provided. The depicted solution can be extended to the development of other integrated engineering systems, for instance, mechatronic systems and microelectromechanical systems.

Keywords: Microsystems, knowledge management, knowledge-networks, product innovation

1 INTRODUCTION
The origin of economic growth is design-knowledge. With practically the same natural resources the human race has always had, higher standards of living have been achieved because of the constant expansion of human knowledge about product design, the process of rearranging physical objects into structures that add value. However, the perception of design-knowledge as source of economic progress is recent. Historically, due to the fact that the conception of a product influences the need for information, capital, energy, labour and physical resources for its realisation, societies temporarily focused on the management of some of these factors and in that way typified their economies. In the industrial society, for instance, capital and labour were preponderant. Businesses competed with one another based upon price reduction. In the dotcom economy, information was the driving force. These eras brought rationalisation and digitisation respectively. With them, design cycles became shorter and product technologies outdated faster. Enterprises experienced a rapid competition and strove to create market advantages with differentiated products. In the knowledge society, the value of a new product will be determined mainly by the knowledge invested in its development. The struggle for competitive advantages will be won by managing knowledge and firms will compete with one another by augmenting product characteristics, for example variety, quality, function, and introducing innovations. For this reason, design-knowledge is becoming more important as orientation of the product innovation process. This trend is particularly evident in the systematic development of microsystems, a knowledge-intensive engineering field that today concerns the design of science-based products.
Microsystems are sets of micrometer-sized three-dimensional components that can synergistically handle non-electrical and electrical signals to perform sensing, processing other actuating functions. Microsystems constitute an ideal link between the physical world and microelectronics, which can only process electrical signals. Because of miniaturisation, microsystems are characterised by enhanced engineering functionalities, for instance, lower weight, better thermal performance, higher natural frequencies, greater dimensional stability, superior motion accuracy, higher velocities and finer measure precision. Indeed, owing to these features, many brand new products are unfeasible without

microsystems, for example, biomedical, lifestyle and mechatronic devices. Furthermore, by means of microsystems, it is possible to integrate decision-making, adaptability and innovative design solutions into technical products that enable the extension of well-known functions and their shift towards different implementation forms, for example mechanical, electrical, software. The latter is the key to successful development of novel "intelligent" designs and thus a factor for gaining competitive advantages. Nevertheless, microsystems are, as engineering integrated systems, interdisciplinary, heterogeneous and complex. Interdisciplinarity influences the communication between developers.
Heterogeneity often compels to distribute the development process among teams that belong to various departments and even different companies and complexity makes the total system behaviour more difficult to describe and simulate. Furthermore, systematic designers may be confronted with the fact that microsystems must often be designed without ample awareness of the product's overall function and its requirements. Sometimes there is even no known effect to accomplish the function [1]. Moreover, the design concept is highly dependent on given microstructuring techniques while the embodiment relies upon the available manufacturing technologies.
The informational competencies of the information society like the abilities to search and compose information did not bring significant change to engineering design. The development of design-knowledge management could stimulate systematic design. Knowledge management recognizes value in originality, innovation, adaptability, intelligence and learning, while information management occupies itself with documents, CAD drawings, spreadsheets and program code. Design-knowledge management is people-oriented, gathers common design problems and their solutions, and supports learning in a design community. It deals with intellectual capital, competitive advantage and innovation.
Regarding the forthcoming era of knowledge, the question arises how knowledge management could be brought into microsystem engineering design.
The objective of this paper is to present an original approach to knowledge-management in microsystem engineering design, going beyond ordinary knowledge-management technologies that are usually integrated in CAD, CAM, CAE and PLM software such as databases, computer libraries and design catalogues, which are usually conceived for non-interdisciplinary engineering domains. The authors describe the problem of design-knowledge integration, evidence the need for a knowledge management tool to support microsystem designers in re-integrating heterogeneous knowledge into products, and present a model of the impact that such a tool could have on design time, cost and quality of new products. Then they explain what knowledge-networks are and propose to use them in solving the problem. Finally, the writers tell how design-knowledge management tools based upon knowledge-networks can be realised and present their own development for managing a digital, heterogeneous knowledge-repository within innovative microsystem design processes. Figure 1 shows a model of the theoretical reference and the contribution of this article.

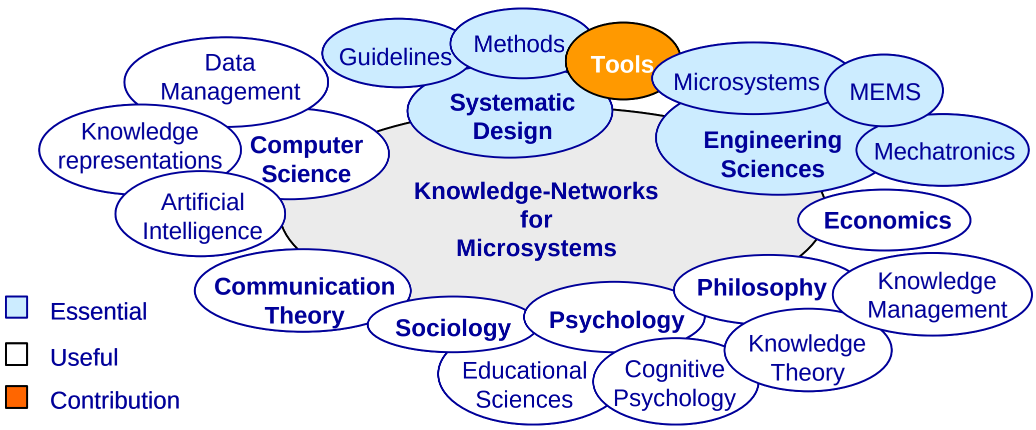

Figure1. Theoretical reference and contribution model of this paper

2 RESEARCH METHODOLOGY

This work aimed at developing a support tool to enrich systematic design and, consequently, followed a prescriptive research approach according to the design research methodology proposed by Blessing and Chakrabarti [2].

It was assumed that, in opposition to the fundamental role of computers that the information society longed for, in the knowledge society, the central position of people within product development will be emphasised. Sound evidences for this supposition are, on the one hand, the by far not fulfilled expectation of design automation and expert systems completing conceptual design tasks, and on the other hand, the growing trend towards replacing old paradigms of artificial intelligence by a model, in which more intelligent systems are created by merging man and machine. The resulting *bionic software* is a tool that encourages both computers and humans to deliver better results than either can do alone [3]. In other words, bionic refers to the integration of living beings into technical systems as components to perform system functions. This view is ahead of considering people only as users. The premise is to turn artificial intelligence into intelligence augmentation. In fact, the bionic aspect is critical to many of the most successful web applications, for example Google's crawl, Amazon's Mechanical Turk and Web 2.0 applications for harnessing the collective intelligence. Without the system administrators feeding and updating the applications at the other end of the user's Internet connection the system stops working.

Subsequently, a definition of knowledge broader than the concept coined by artificial intelligence research during the information era was taken as starting point. Spinner and Wilson provided an ample, anthropological notion that does not depend on the capabilities of computer technologies [4], [5]. This characterisation is consistent with the assumption and the premise of the paragraph above.

Accordingly, Paschen's process of knowledge development was adopted as orientation of the product innovation process, from knowledge differentiation to re-integration into novel products by designers. It reflects the ideal approach to the development of integrated engineering systems without being utopian [6]. It can consequently be extended to microsystems.

Already having an orientation, the concept-knowledge theory of design gave the theoretical support for knowledge integration into innovative microsystems [7]. According to its explanation of the design process, on the one hand, knowledge can be turned into concepts by means of disjunction, partition and validation, and on the other hand, through creative inclusion and partition, concepts can be transformed into new concepts (design problems) or into knowledge (innovations). In addition, unlike classical systematic design [8], this theory offers insights into science based products like Microsystems.

Then, established knowledge-representations were analysed to determine which one, while supporting the concept-knowledge theory of design, can best handle and depict complex, interdisciplinary, heterogeneous knowledge entities and their interrelations, as it is required in microsystems.

Finally, a design-knowledge management tool based upon knowledge networks was developed in accordance with the method proposed later in this article, to be applied in the provided scenario.

3 THE NOTION OF HETEROGENEOUS DESIGN-KNOWLEDGE

Since the mathematical description of information by Shannon and Weaver (communication theory) and after Wiener recognized it as fundamental element in addition to energy and matter because of its technical potential for control and simulation (cybernetics), the notion of knowledge has been increasingly understood as information. The proliferation of the digital computer and the development of codifications by computer science accentuated this trend.

Information is widely understood as interpretable data that can be transferred to different media and processed with electronic circuits. Information becomes knowledge, when an individual takes it up, places it in the context of its experience, combines it with its pre-existent knowledge and is able to generate new knowledge out of it. Consequently, knowledge can be formulated as the product of information, experience, skill and mental attitude [9]:

$$K = I \times E \times S \times A \qquad (1)$$

The understanding of knowledge as information made it possible to gain insights into knowledge representations and their applications. However, the strictly physical notion of information, namely occurrence probability of events (entropy), does not provide any meaningful orientation that product developers could follow towards creative productivity, as it is required in designing and inventing.

Differentiations and extensions of knowledge types and forms have been richly discussed in the literature, see for example Table 1. These have contributed to gain insights into the economy of knowledge, for instance, recognising the difference between tacit and encoded knowledge aids to incorporate geography in knowledge dynamics: thinking only about encoded knowledge, it is difficult to envision any barriers to the straightforward propagation of new ideas through the Internet in digitised form. To the contrary, tacit knowledge does not have unproblematic mobility. It is embedded in the minds of individuals and in the routines of organisations. More fundamentally, a base of tacit knowledge is a pre-requisite for using any bit of encoded knowledge. This means in practice that knowledge creation tends to be localised, for example in certain firms or particular cities, and that simply having access to codified information does not imply having knowledge. A very significant economic aspect of knowledge is its competitive behaviour. Unlike ordinary goods and services, knowledge has increasing returns (continuously declining marginal costs), that is: the next unit of output can be produced even more cheaply than the last. As the leading producer faces permanently declining costs, having the largest market share produces the highest profits [10]. Whoever has the leading position in the market can maintain and extend it. Eventually, it is likely that a single firm will dominate or monopolize the market. Think about Microsoft and Intel with their knowledge-intensive products, for example.

Table 1. Example of Knowledge types [11]

Knowledge Types	**Author examples**
Embodied knowledge	Hayek (1945), Nonaka/Takeuchi (1995)
Procedural knowledge	Ryle (1958), von Krogh/Ross (1996)
Embedded knowledge	Berger/Luckmann (1966), Collins (1993)
Tacit knowledge	Polanyi (1966), Nonaka/Takeuchi (1995)
Embrained knowledge	Argyris/Schön (1978), Blackler (1995)
Event knowledge	Bell (1985), von Krogh/Ross (1996)
Encoded knowledge	Zuboff (1988), Blackler (1995)

In contrast to knowledge differentiation, today integration of heterogeneous knowledge is becoming more important and a distinct perspective on knowledge is needed. Spinner became aware in his “Architecture of the Information Society” (1988) that the entire knowledge terminology referred to the concept coined by computer science, fundamentally being knowledge content-related data [4]. He got back to basics and pointed out that it was data, the other way round, what should be preferably understood as technically stored knowledge, no matter what the content was. As a result, information was encoded knowledge of all possible contents. In this context, Wilson postulated (1998) that knowledge was a collective term for heterogeneous knowledge entities that could be interrelated [5]. This meant an historical trend change in which differentiations of knowledge forms are integrable.
This kind of integration takes place in interdisciplinary heterogeneous fields, for example biomedicine, mechatronics and microsystem engineering. The main representative is microelectronics.
With this perspective, Paschen’s process for the development of human knowledge can be taken as orientation for innovative design through heterogeneous knowledge integration [6]:

- In the beginning, potential knowledge exists integrated in all things (phenomena, materials, living beings).
- This knowledge is dissected in the long historical development of codification means as if it was anatomical, and after some elements are excluded or every time more differentiated, knowledge is stored and increasingly specialised conveyed.
- However, highly specialised differentiation makes junctions (biochemistry, social-psychology), integration sciences (ecology), joint projects (atomic bomb, moon landing), new ways of thinking (interdisciplinarity) and expansions (art as knowledge) necessary.
- Therefore, the excluded heterogeneous knowledge elements must be intelligently reintegrated with increasingly effective control resources in order to preserve the global quality.
- With the digitalisation of knowledge, excluded heterogeneous knowledge elements can be re-implanted in things. For this, it is required an extension of the definition of knowledge to all human experience fields, in order to safeguard the human quality of the products.

Embracing this knowledge development process, from the differentiation of phenomena to the reintegration in microsystems, a knowledge management tool is needed to support microsystem designers in re-integrating heterogeneous knowledge into products. Figure 2 shows a system analysis model of the impact that this tool could have on design time, cost and quality of new products.

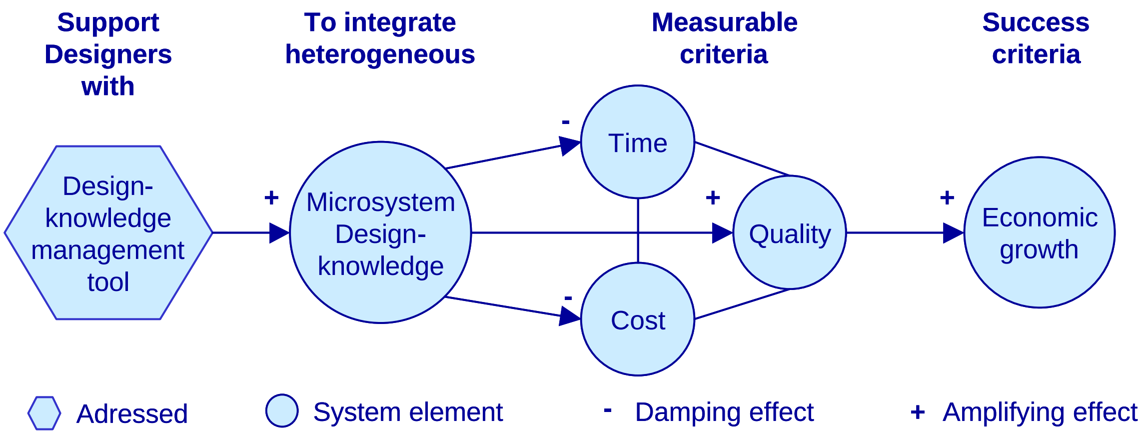

Figure 2. Impact model of the design-knowledge management tool

4 KNOWLEDGE-NETWORKS

A Knowledge-network is a knowledge representation technology [12] consisting in a dynamic computer graph formed by nodes and links. Nodes represent notions and links stand for relations between notions. A Knowledge-network can be understood in terms of five distinct roles it plays:

- It is fundamentally a surrogate, a replacement of real objects that enables an entity to determine consequences by reasoning rather than direct interacting with them. Replaced objects can be concrete and abstract notions. Entities can be intelligent beings and technical systems that artificially reason.
- It is a set of ontological commitments, guidance in deciding what and how to attend in order to manage complexity.
- It is a fragmentary theory of intelligent reasoning, implicit in its conception of intelligent inference, the set of inferences it sanctions and the set of inferences it recommends.
- It is a medium for pragmatically efficient computation. It provides guidance on how to organize information and facilitate making inferences.
- It is a medium of expression by which entities can communicate.

A knowledge-network enables a computer to make knowledge operational. It should guarantee that externalised designer competences would be recorded and made available for the future.

The basic unit of a knowledge-network is a word or natural language concept that is related to other concepts. Depending on the represented knowledge domain, the number of relations between concepts can be in the order of thousands.

Figure 3 shows an example of a knowledge-network. It illustrates how concrete and abstract concepts can be connected through different relationships. The example can be read as following: microsystem design-knowledge includes operations (as defined in [13]), which can be calculation procedures or rules. There are design, function, junction and variation rules. Variation rules comprise a set of laws for varying embodiments, function structures and so forth. The interrelation list can be infinitely enlarged.

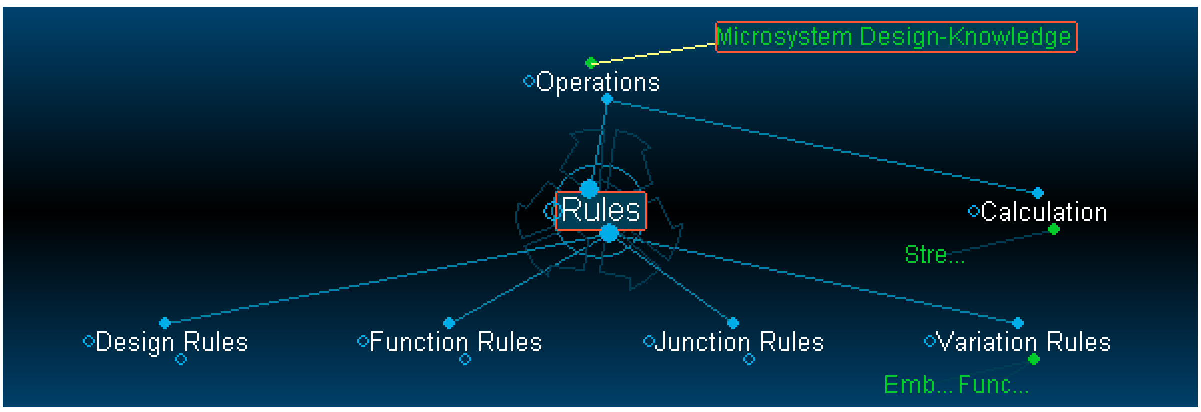

Figure 3. Example of a knowledge-network

The performance of knowledge-networks resembles the human cognitive process: after learning a concept, a person can remember it (retrieve it from memory), relate it with other concepts or compare it. Therefore, the functionalities of Knowledge-networks are similar to the human long memory. The advantage relies upon the higher efficiency of computers by managing huge amounts of knowledge.
A knowledge-network is not a data structure but a knowledge structure. Knowledge networks function as linked metainformation, what allows the integration of any content without considering its media. The capacity to handle heterogeneous content and multimedia is a significant difference between knowledge-networks and classic homogeneous databanks. Network nodes can be related to text documents, spreadsheets, images, audio, videos, macros, applications, web links, and other file formats. Figure 4 shows the relationship between network nodes and files by means of file format icons to the left of the node labels.

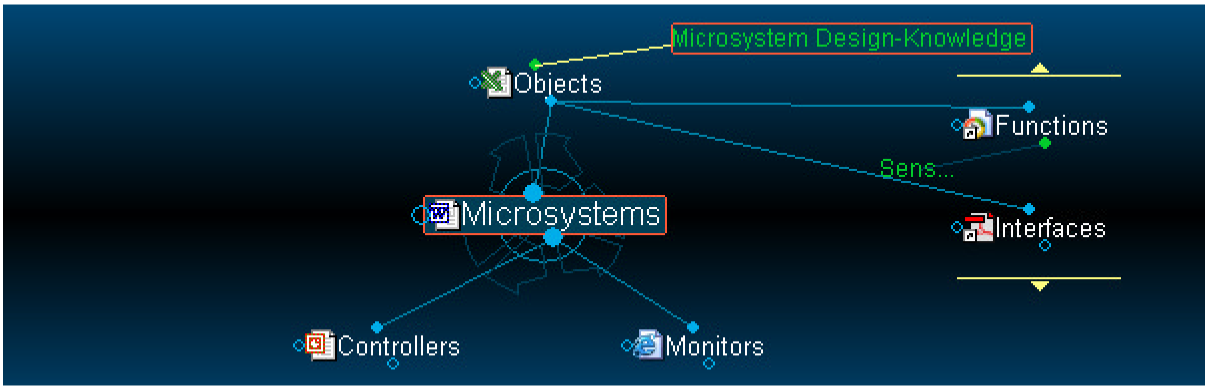

Figure 4. Heterogeneous content managed by a knowledge-network

Furthermore, knowledge-networks manage concepts and their terms separately. It is possible in this manner to represent the same content in different languages or access it through synonyms, what provides intelligent search functionality (semantic search).
Knowledge-networks enable the user to graphically interact. This lets the knowledge searcher substitute the keyword typing in a search engine for explorations. Exploration is a relevant search tool when the search objective is undefined, as it is often the case by designing science based products. Exploring concepts, designers interlace webs of greater complexity, until new ideas are associatively built. Leaping from node to node stimulates creativity. New ideas can and should be added to the network to achieve knowledge expansion.
Unlike semantic nets, knowledge-networks have non-directed links between nodes and the types of relationships they symbolise are not restricted to semantic associations.
Knowledge-networks have the advantage of being easier to handle and maintain than other formal representations like propositions and rules.

5 APPLICATION ENVIRONMENT

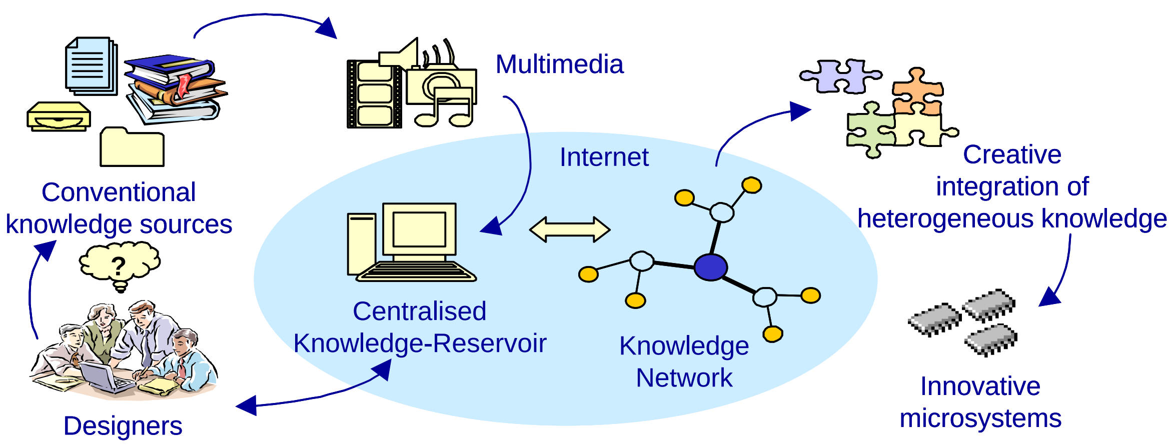

Figure 5. Application Scenario

The scenario, depicted in Figure 5, represents the application environment for which the design-knowledge management tool was conceived: Not all designers have the same research needs. Their knowledge requirement depends upon variables like education, experience, industrial branch, project and product development phase. In addition, people do not reason all alike. However, the personnel in a design department normally have to refer to the same sources when looking for knowledge, for instance colleagues, documentation of past projects, databases, design catalogues, expert systems. Not to hinder creativity, it is crucial to provide them with multiple seek possibilities that adapt to their ways of thinking. It is also important, in order to enhance productivity, to centralize in digital form all the knowledge sources in a single knowledge-repository.
Let such a design-knowledge management tool be ubiquitous by placing it in a computer network so that it can be accessed through the Internet. Then, a graphical user interface can be added that enables the user, to query, navigate, browse and explore through stored design objects, solutions and processes. This content is represented by means of words interrelated to one another with lines in a mesh resembling a net, so that clicking on a term brings it to the centre of the screen, driving for example text, sound and video to the user. At this moment, the selected term is surrounded automatically with links to related knowledge. In this case, one can say that design-knowledge is being managed with knowledge-networks. The relational interface simulates the associative learning process of people and thus, fosters creativity and innovation. When innovations arise, this also means new knowledge has been build, the designers themselves as system components incorporate it in the knowledge-network. The knowledge is expanded.

6 DEVELOPMENT OF KNOWLEDGE-NETWORKS FOR MICROSYSTEMS

A knowledge-network was developed to manage a microsystem knowledge-repository based upon design catalogues [1]. The knowledge management tool was particularly conceived to implement a V-model-based interdisciplinary microsystem design methodology elaborated at the Institute for Engineering Design and Industrial Design [14]. It is also compatible with traditional design methodologies, all of which make use of knowledge repositories [1].
Relying upon the research results, this paper presents a method for developing knowledge-networks. Figure 6 shows the general approach, which is detailed in the following paragraphs.

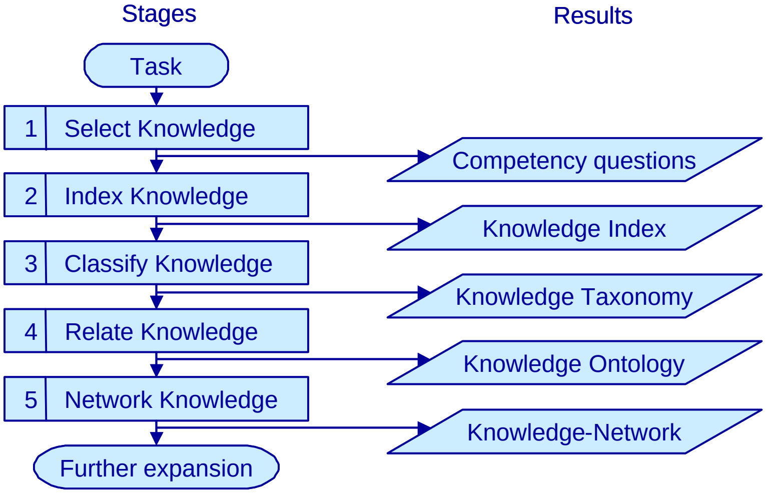

Figure 6. General approach to the development of knowledge-networks

6.1 Knowledge Selection

Knowledge-networks should free designers from solving repetitive problems, also called competency questions. They provide good guidance on what relevant knowledge a network should include, because despite its constant expansion, the network must be fed with basic knowledge in the beginning. Several competency questions have been discussed in the literature, see for example [15], [16], or must be directly investigated. The Institute for Engineering Design and Industrial Design surveyed six research institutions and industrial enterprises in the field of microsystems [14]. With the answers to the question on what the main problems are by designing new products, a catalogue of competency questions, elaborated with the available literature, was completed. Table 2 summarises some problem areas.

Table 2. Summary of competency questions

Question	Knowledge-Field
When an existing product has miniaturisation potential, which technology is the adequate?	Miniaturisation
What materials are suitable for structuring Microsystems?	Materials
What are the qualitative differences between the available micromanufacturing technologies?	Manufacturing
How are Microsystems assembled?	Packaging
How is a good procedure for the development of microsystems?	Design methods
How much system integration is optimal?	System integration
Which are the product requirements for a particular application?	Product development

6.2 Knowledge Systematisation

The power of knowledge-networks relies upon a systematic structure in which knowledge is indexed, classified and ontologically interrelated. There are several heuristics for structuring knowledge-networks. Approaches can be automatic, semi-automatic or manual. At least an index, a taxonomy and an ontology are needed to structure knowledge for systematic use in a knowledge-network. For naming notions in different languages or referring to them with synonyms, a thesaurus is also required.

6.2.1 Knowledge Index

An index refers to controlled vocabulary for representing the selected knowledge in a sort of keyword catalogue. Indexing enables common understanding between agents and constitutes the base on which computer knowledge processing can be supported. Statistical analysis of frequent words in a representative number of papers and text books can help to find which terms are relevant in a knowledge domain. By the development of a search engine Zhang, Troy und Bourgoin calculated the word frecuency in 30,000 paper abstracts of 20 journals and congress procedures on microsystem engineering [17]. They elaborated a top-level index consisting of 10 terms according to which it is possible to classify microsystem literature by researcher, affiliation and topic. However, they underline the fact that the top-level topic to which an article belongs is most often not mentioned in the document. That is the reason why for the objective of the present paper, namely a much more complex knowledge management tool, 12 text books in two different original publication languages were additionally scanned by means of optical character recognition (OCR) and then statistically indexed with help of database filters. Textbooks are always explicit about top-level topics. The resulting list of 1,948 non-trivial unique microsystem engineering concepts reflexes relevant concepts in the knowledge field of microsystems. Table 3 shows the first 10 most frequent terms obtained and compares it with the cited work.

Table 3. First 10 index terms of microsystem design-knowledge

Term	Frequency factor	Zhang et al (ranking not available)
Sensors	1.00	MEMS
Silicon	0.48	Devices
Processes	0.36	Materials
MEMS	0.35	Modelling
Microsystems	0.32	Design
Materials	0.31	Fabrication
Manufacturing	0.28	Characterisation
Applications	0.27	Packaging
Devices	0.27	Applications
Design	0.26	Interface electronics

6.2.2 Knowledge Taxonomy

The more orderly knowledge is organised, the faster users can find it. People develop a sense of where a particular notion in the knowledge-network is and which related notions surround it. Order promotes learning. A taxonomy provides hierarchical order for knowledge in the network. Therefore, the index obtained as explained in the section above was classified through combination of two different approaches, semi-automatic classification and domain expert intellectual tuning. The semi-automatic classification was performed with Protégé 3.2.1, a free, open source ontology editor and knowledge acquisition system [18]. Figure 7 shows the result.

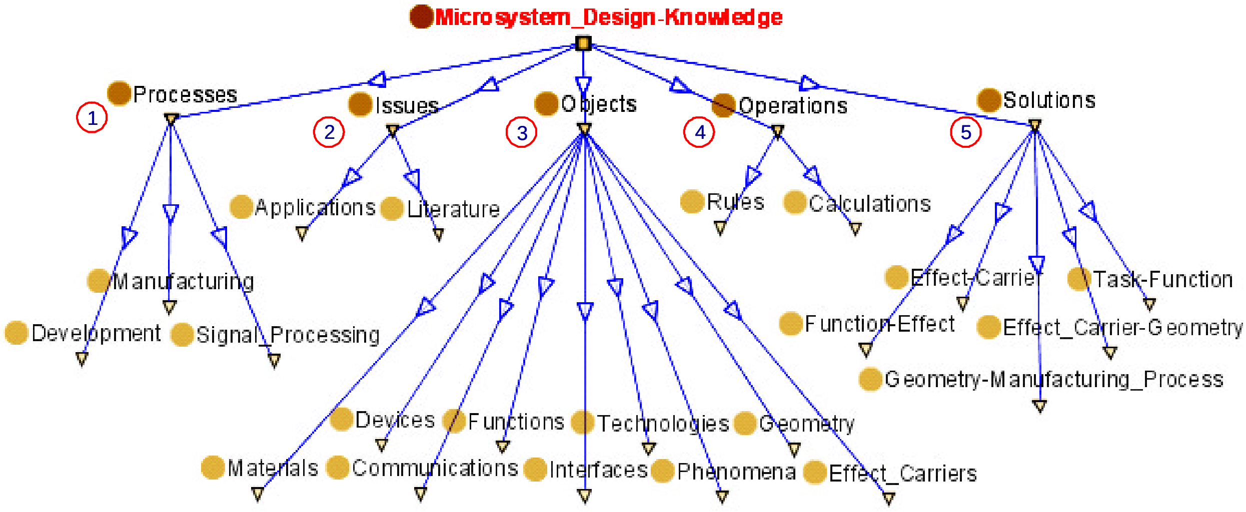

Figure 7. Top-level taxonomy of microsystem design-knowledge

It is important to note that the originality of this classification relies upon the correspondence between the top-level classes 3, 4, 5 and the well established methodology of design catalogues, which has been adapted to the design of Microsystems and extended adding classes 1 and 2 [19].

6.2.3 Knowledge Ontology

When the terminology in a knowledge-network is already controlled and classified, terms can be related to one another by means of an ontology. Relations between notions are a pre-requisite for creativity and innovation. An ontology is a machine readable formal description of notions and relationships that are important in a knowledge domain. Ontologies have been adopted by business and scientific communities to share, reuse and process domain knowledge. They are central to applications such as scientific knowledge portals, information management and integration systems, e-commerce and semantic web services. This part of the work was elaborated with the Protégé-OWL editor [18]. The Web Ontology Language (OWL) is the most recent development of the World Wide Web Consortium in standard ontology languages for the Semantic Web. The advantage of an OWL ontology is that the formal semantics specifies how to derive logical consequences, for instance, non-explicit facts entailed in the ontology. Figure 8 shows a partial representation of the ontological relationships between microdevices.

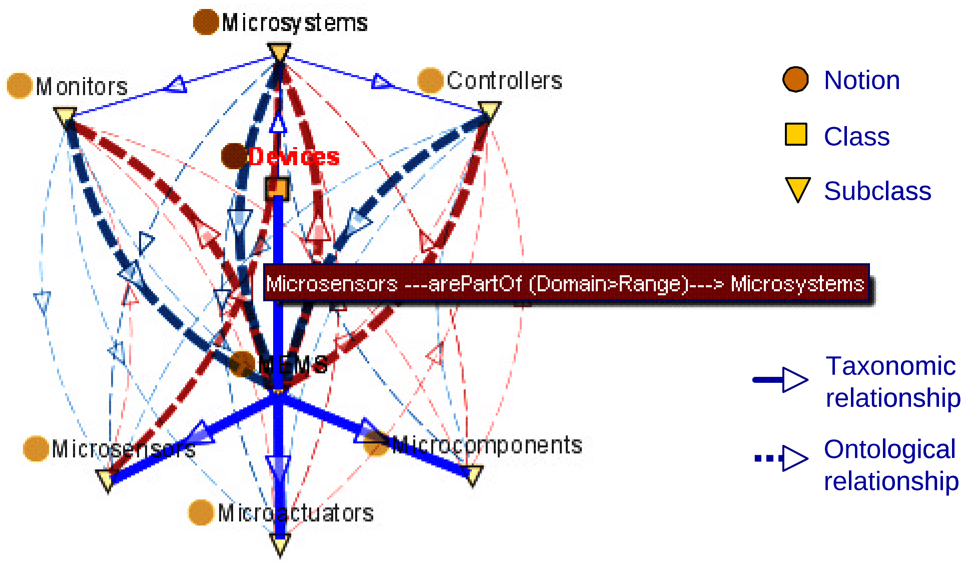

Figure 8. Partial representation of the microsystem ontology obtained with Protégé-OWL

Clicking on the keywords (classes) highlights their relationships. Positioning the cursor on a highlighted relationship activates a pop-up description. For this example, MEMS was clicked and the software automatically emphasised its relations to other classes through thicker lines. Other relationships are represented by means of thin lines. All lines have arrows that show the direction in which the relationships take place. Full lines stand for class-subclass relationships. For instance, microsensors are a subclass of MEMS. Dotted lines depict non-hierarchical relations, such as the domain-range relationship in the pop-up description “microsensors are part of microsystems”.

6.3 Knowledge-Network

The last step in the development of a knowledge-network is making the ontology operational. In this research project, the commercial package PersonalBrain 3.03 was selected for the realisation of the microsystem design-knowledge management tool [20]. The software is capable of basic knowledge-network representation and management functions and features different search and interaction facilities such as navigation, exploration, browsing, querying, history keeping and statistics. The software also handles any file format. In addition, the knowledge-network can be exported in Extensible Markup Language. This ensures the machine readability of the content, for example for Internet applications.

7 EXAMPLE APPLICATION

The design of suspended electrostatic structures for microsystems, *object* (1) in Figure 9, is a common problem in the development of microsensors, *object* (2), and includes the embodiment of beams, plates and electrostatic gaps and anchors, *objects* (3), (4), (5), (6) respectively. The task requires a background knowledge of the underlying physics, primarily elastostatics, kinematics, air damping, and electrostatics. This knowledge is encompassed in a deeper ontology-level, in form of *operation* Structural_Analysis (7). In case of designing a beam (3), there are two options: *solution* Cantilever_Beams (8) or *solution* Built-in_Beams (9).

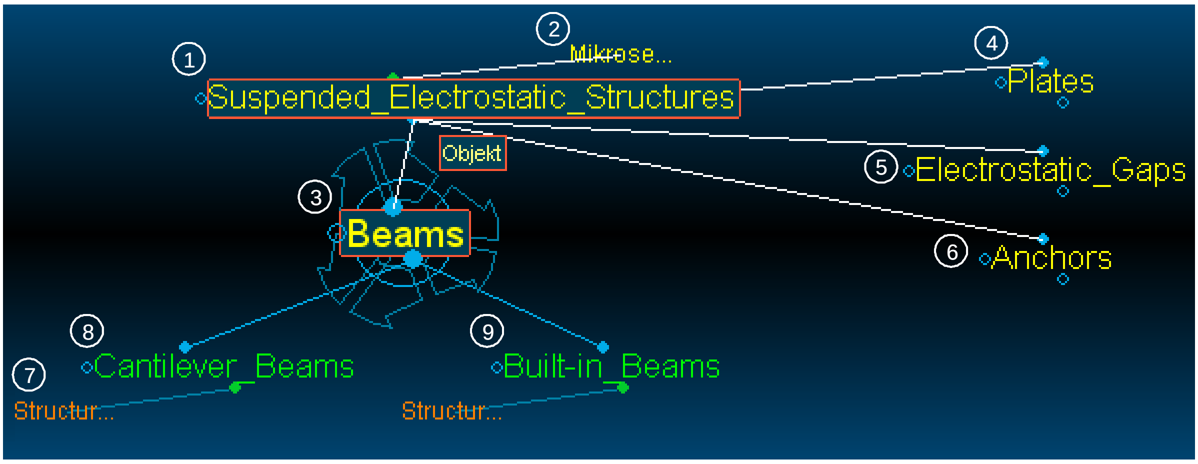

Figure 9. Knowledge-network about beams as suspended electrostatic structures

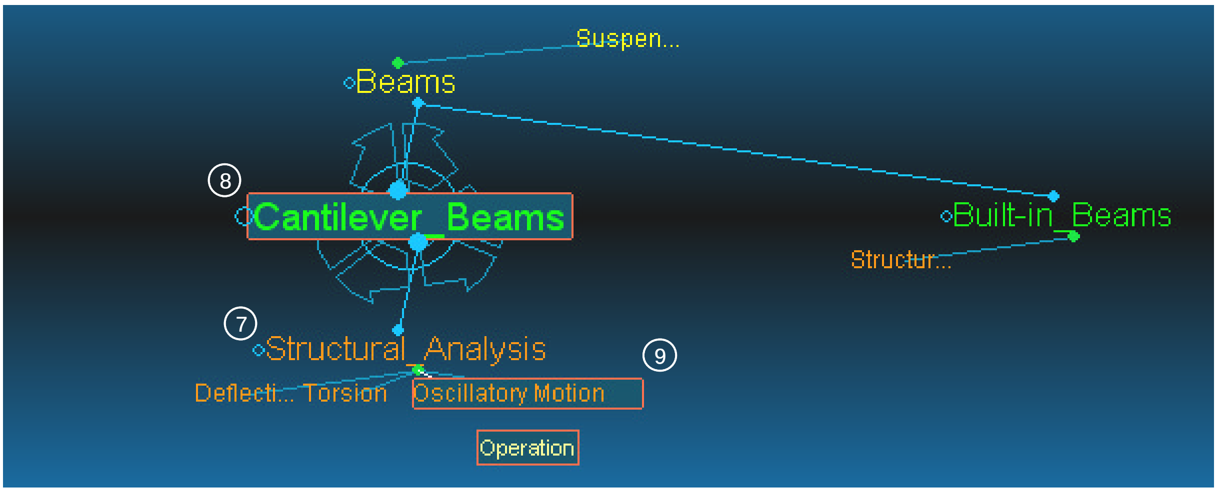

Figure 10. Knowledge-network about cantilever beams

Being interested in a cantilever beam, for example, clicking on node (8) will reconfigure the network like shown in Figure 10.
If the task were to analyse (7) the oscillatory motion (9) of the cantilever beam (8), node 9 of the knowledge-network in Figure 10 should be clicked. The network will be reconfigured again and knowledge about oscillatory motion analysis of cantilever beams is shown in a Web page, figure 11.

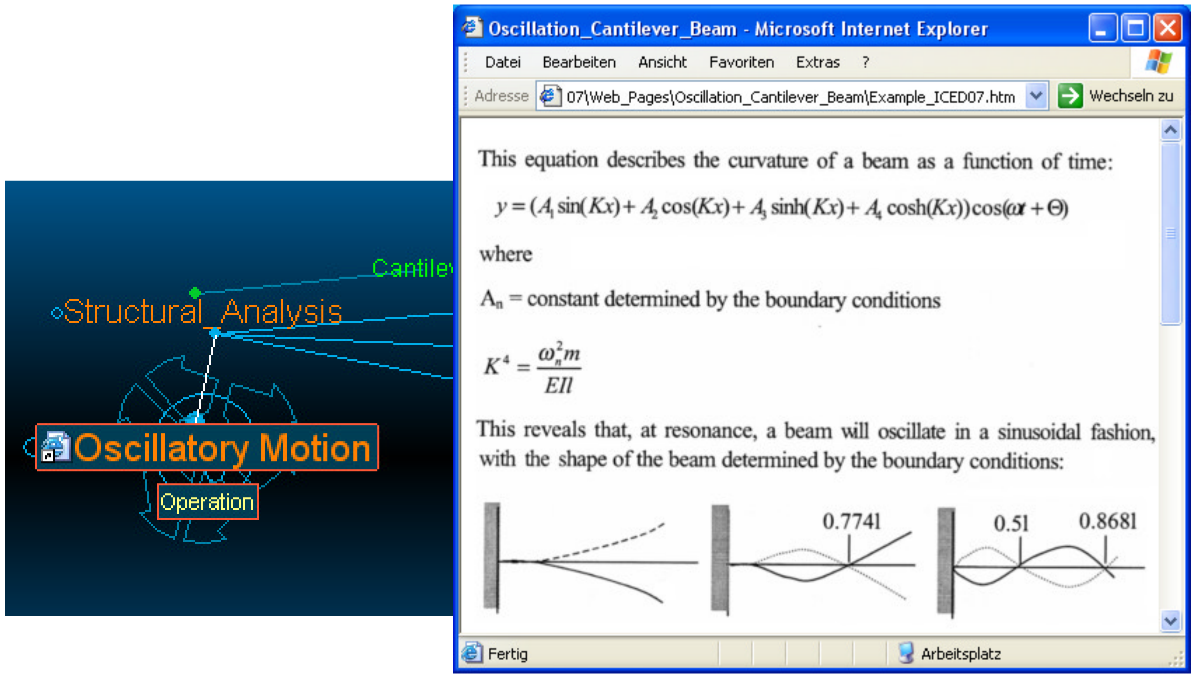

Figure 11. Knowledge-network about cantilever beams

8 CONCLUSIONS

In the knowledge society, knowledge level theories of design and the improvement of design-knowledge management will open new possibilities for economic growth by means of product innovation. That is the reason why a different perspective on knowledge is required.
Instead of knowledge differentiation, integration of heterogeneous knowledge should be pursued. This kind of integration takes place in interdisciplinary heterogeneous engineering fields.
Microsystem design is an interdisciplinary engineering field with high innovative potential. Therefore, a design-knowledge management tool is needed in this area.
Knowledge integration has a physical consequence in products with better performance, improved quality or innovative functions and a non-physical outcome in embedded knowledge within the software and control routines of the products themselves. Therefore, knowledge integrations represent new possibilities for the development of autonomous (also called intelligent) products and processes. This trend will be characterised by anthropologisation (the human being as central object) in opposition to computerisation.
Anthropologisation can improve design-knowledge management tools. This means consideration of the human cognitive processes, for instance the ability to think associatively, explore spaces and memorise visually.
The tool presented here is a *bionic system* in the sense that it integrates people as components in a tool to enable both computers and humans to perform better than either can do alone.
The solution tool can be extended to the development of other interdisciplinary, heterogeneous, complex, integrated engineering systems such as mechatronic systems and microelectromechanical systems.

ACKNOWLEDGEMENTS

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Contact: Jorge Antonio López-Garibay
Institute for Engineering Design and Industrial Design
Universität Stuttgart
Pfaffenwaldring 9
D-70569 Stuttgart
Germany
Phone: +49 (0)711 685 66043 / 66055
Fax: +49 (0)711 685 66219
e-mail: jorge.lopez@iktd.uni-stuttgart.de
URL: www.iktd.uni-stuttgart.de