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Invention Reasoning Scheme Based on Workshop Design Konstruktion (WDK) Artefact Models and its Application in the Patent Search*

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Patent system has an important role in engineering design process as it provides a source of ideas through patent information. On the other hand, the patent system poses potential constraints on the engineering design process, because a granted patent in force may prevent the exploitation of a technical solution. The aforementioned issues are the main reasons why the patent search should not only be performed as a search for ideas and a search for potential constraints on the innovation process, but also be taught in engineering design courses. Namely, in order to be able to carry out their future tasks in industry, engineering students need to be capable of handling patent information since it strongly influences any industrial innovation process. The existence of information, however, does not guarantee its proper usage, since patent search requires considerable knowledge and effort by the searcher to access and benefit from the information contained in patent databases. For this reason, we developed an invention representation and reasoning scheme based on engineering design artefact models in order to improve the quality of patent search process, primarily among non-experienced searchers, such as engineering students who typically use patent information as a source of ideas in engineering design and product development projects. The invention reasoning scheme contains categories adopted from the theory of technical systems, primarily the model of transformation process and the model of technical system, as well as categories from other Workshop Design Konstruktion (WDK) theories, and is aimed at supporting reasoning during the patent search process. In order to investigate the applicability of such a scheme in patent search, a case study on a small group mainly consisting of mechanical engineering students was conducted, which demonstrated that this patent search reasoning tool based on the WDK artefact models may be successfully applied in patent searches conducted by non-professional patent searchers.

Keywords: patent search; engineering design; artefact models

1. Introduction

1.1 Patent information as a type of engineering design information

Patent information is the largest single source of engineering design information existing in the world [1]. It is not only the amount of information that distinguishes patent information from other types of engineering information, but also the way in which information is organized, structured and validated [2]. Patent information is contained in patent documents that are stored and organized in patent databases freely accessible through search engines. Patent documents enter the public domain in the course of the patent granting process, which is conducted by the patenting authorities and which typically contain textual and graphical technical information. A granted patent confers its owner exclusive control over an invention as a technical solution, and thus the potential profit arising from such exclusivity as an advantage over the competition. However, an invention needs to meet the patentability criteria in order to be granted a patent. The patentability criteria include novelty, inventive step and industrial application. Novelty implies that a technical solution has not been previously publicly known, and the inventive step means that a technical solution has not been obvious on the basis of publicly known information, also referred to as state-of-the-art.

On the other hand, engineering design is an information transformation process, having as an input information about a problem, related to a certain human need, and the product's function, related to something the product is meant to do, and on the other end, as its output, information about the product's structure, namely information about what the product actually is [3]. Dym, Agogino, Eris, Frey and Leiter [4] have defined engineering design as a systematic and complex cognitive process of generating, evaluating and specifying concepts that fulfill certain objectives or needs and meet specified constraints. Consequently, patentability is a legal constraint of the engineering design process,

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which normally enters the process in its ideation phase [3] and which has to be assessed in order to prevent the unnecessary and costly development of something already known to the public. Apart from conferring its owner competitive advantage, a patent provides the public with information on the invention, which becomes publicly accessible by entering patent databases. In this way, the public is able to access information that may otherwise remain secret, and use it for further development. Therefore, the system ensures a balance between the private interest of the patent owner, by conferring the exclusivity on one hand, and the interest of the society, by providing an important source of technical information that is freely available.

The common point between the engineering design and the patent system is the invention that constitutes a technical solution to a technical problem. Since it is technical information that is being processed in the engineering design process, the input to the engineering design process may be patent information used as a source of ideas. Conversely, the patent information may pose a constraint on the engineering design process.

1.2 The patent search process

In order to access patent information, patent information retrieval (IR), also named patent search, is performed [2]. Like any other information retrieval process, the patent search is characterized by information need generation, information interaction and search task solving [5]. Since information need is defined as a gap in available knowledge, information retrieval process begins with a search request as an information need formulation which is to be analyzed and reasoned about by the searcher [5, 6]. Next, a search statement containing search concepts is formulated, which is followed by selection of search terms based on the search statement. Search terms correspond to concepts from the search statement, whereby the search terms may be identical to the concepts, or may directly correspond to them, e.g. in the case of synonyms. In addition, the search terms may be implicitly, i.e. contextually related to concepts, e.g. in the case of technical equivalents or related technical problems.

In the next step, search terms are selected and assigned to concepts, constituting an expression thereof. This is followed by transforming the search statement into a search query, as the language understandable to the search engine. Upon processing the query, documents are retrieved by the search engine. Now, the retrieved documents need to be analyzed and compared to the search statement in order to assess their relevance.

In order to reasonably formulate the search statement and to derive search terms from it, the searcher has to reason about the technical system the search request refers to [6]. Namely, these initial phases of patent search as well the final step of relevancy determining are cognitive processes, requiring knowledge about the technical system in question, as well as analytical, reasoning and decision making skills [2].

The traditional approach to patent search includes a manually generated query consisting of keywords or metadata, primarily classification codes and/or keywords, and their combinations that are created using query syntax. This is followed by automatic query processing by the search engine and manual relevance assessment of the retrieved documents, whereby automatic tools are used throughout the process for searchers support, for example for filtering and representation of results [7]. Each search engine has its own syntax for query formulation, normally including Boolean operators such as "AND", "OR" and "NOT" and truncations, such as " * ", " # " and " ? ".

Keyword based search is characterized by the usage of legal language, typically giving words broader meaning, and usage of synonyms and homonyms [2, 8]. Therefore, it requires from the searcher specific knowledge and reasoning of the language specific to a particular field of technology. However, the advantage of keyword based search is its simplicity, requiring no particular knowledge on the search engine functionality, and hence no special training for the searcher [8].

On the other hand, classification-based search is related to finding classification codes, contained in one of several available classification systems such as the International Patent Classification, corresponding to the search concepts [9]. A disadvantage of this type of search is that a classification code may not exist for a specific concept [9]. In addition, irrelevant results may be obtained when the document is incorrectly classified by the patenting authority.

Since patent search is an iterative process, a single query is practically never used. Instead, the query is changed or modified and relevancy is repeatedly assessed in every iteration step [9]. The iterative process of creating and sequentially entering different queries in a search engine is defined as search strategy [9]. Contrary to the search request analysis, which requires decisions on semantic and contextual aspects of the search statement, formulation of a search strategy involves decisions on its syntactic and logical aspects [6].

Information retrieval effectiveness is normally measured by recall and precision, whereby recall is defined as the proportion of the retrieved number of relevant documents and the total number of relevant documents in a collection, whereas precision is defined as the ratio of the number of relevant retrieved documents and the number of retrieved documents. For example, the keyword based search is characterized by low precision but high recall, primarily due to the mentioned language issues, contrary to the classification based search that results in high precision [9]. If the proper search strategy is applied, it is possible to improve both recall and precision, despite the inverse relationship between them [9]. Another, subjective measure of the search process is accessibility that is defined as effort exerted by the searcher when accessing databases [10]. At the same time, search effort, as an objective measure, can be quantified as time required for performing a search task [11] and therefore be directly linked to efficiency [6].

There are several patent search types, two of which are especially relevant for engineering education. First of all, since patentability may pose a constraint on the engineering design process, a patentability search, also termed novelty search, is conducted in order to perform patentability assessment of a technical solution under development [9]. The patentability search process can be conducted either in a formal procedure of patent granting by the patenting authorities or, apart from it, by anyone interested to check if an invention is patentable, e.g. before filing a patent application. Next, given the important role of patent information to serve as a source of ideas used in industrial innovation processes, state-of-the-art search, also termed informative search, is performed [9, 12].

Another subtype of patent search is the quick search, normally applied at the beginning of informative and patentability searches in order to decide on subsequent search tactics [9]. It is characterized by the use of precise classification codes and keywords, typically with no synonyms, by the use of "AND" operator and truncations only for plural. The quick and informative searches typically involve lower cost and effort; hence, they are aimed at high precision and lower recall, whereas patentability searches involve balance between recall and precision [9].

1.3 Importance of patent search for engineering education

Patent search is an important innovation factor that affects the engineering design process either as a constraint or a source of ideas. Furthermore, patent search is especially important for engineering students, because in order to be capable to successfully conduct the engineering design process, they need to not only understand the role of patent information in the engineering design process, but to be capable to practically use it and benefit from it. However, while information is an essential element of engineering and engineers were among the first whose search behavior was examined [10], human and cognitive factors in patent search have been dealt with by only a few authors, even though they strongly influence the final outcome of the patent search process and contribute to the patent search quality to a significant extent.

On the other hand, both the engineering design process and the patent search process are iterative and creative mental activities, highly dependent on human cognition. Consequently, they are characterized by the application of models and representations, as cognition and reasoning support tools. In addition, they both constitute information transformation processes, having as common ground knowledge on the technical systems that constitute a link between engineering design and patent search. Moreover, patent searches are typically performed in the course of the engineering design process. Yet, even though artefact modeling theories have found an application in the engineering design process as a means for aiding designers when reasoning about the developed artefact, there is no known application of technical artefact models as a support to analysis and reasoning in manual patent search.

Consequently, the aim of this paper was to support engineering students in handling patent information, from the perspective of engineering design models, as something they get acquainted with during engineering design courses. In other words, the aim was to apply knowledge that belongs to the engineering design science in order to enhance human cognition and reasoning in patent search. More specifically, the aim was to support mechanical engineering students as non-experienced patent searchers in the initial phases of manual patent search process, namely the search request analysis, search statement formulation and selection of search terms, as well as in the final phase of relevancy assessment of the retrieved results. For this purpose, we developed an invention reasoning scheme, based on engineering design artefact modeling theories. The WDK modeling theories were chosen because they may be regarded as theories of choice when it comes to the modeling of technical artefacts and technical processes in mechanical engineering, with considerable results of application in industry and education.

Given the importance of patent search for engineering design and its high dependence on the human factor, in this paper we addressed the following research questions: Firstly, we examined if the reasoning scheme was applicable as a support to human cognition and reasoning in patent search. Secondly, we examined if the developed tool improved the effectiveness and efficiency of selected phases of the patent search process, namely, search request analysis, preparation of search statement, selection of search terms required for formulating a search query and relevancy determining of retrieved results, since these phases are where human reasoning about a search subject has the highest impact on search outcome. Finally, we examined if the reasoning scheme improved the accessibility of patent information. Concerning the abovementioned research questions, we conducted a case study research on a group mainly consisting of mechanical engineering students. As a search task, the quick patentability search was chosen, because this type of search does not require specific search knowledge and skills from the searcher, as previously explained.

Apart from introduction, the paper has five sections. In section 2, the existing reasoning tools applied in automatic and manual patent searching will be presented. This will be followed by a presentation of design models and modeling theories with emphasis on an overview of the models of the WDK school including the most recent developments. In section 3, the invention reasoning scheme based on the WDK artefact models will be presented and its elements will be explained. In section 4, the research methodology for evaluating the reasoning scheme to the real search case will be presented. In section 5, the analysis of data interpretation of the findings will be discussed, followed by discussions and limitation in section 6 and conclusions and future work in section 7.

2. Literature review

2.1 Automatic patent search tools

As already mentioned, in case of manual patent search, the search request and search query are manually created, the query is automatically processed and relevance assessment is conducted manually again. Consequently, in manual patent search, the skills of the patent searcher have a predominant role [7]. However, manual patent search methods generally may involve much mental effort and may be time consuming [13].

For this reason, numerous semantic-based solutions have been developed based upon knowledge based systems (KBS), capable of performing semantic searches, automatic classification and other tasks [7]. Typically, instead of working on word meaning, they deploy the principle of word occurrence. Automatic patent information retrieval tools are generally applied to automatic extraction and visualization of invention information from a document [7, 14]. In general, such tools are mostly utilized in the patent analysis task, by applying semantic artificial intelligence technology based on different knowledge models, including ontologies, which are further based on technical artefact models and representations.

For example, Cascini and Neri [13] have developed an automatic patent IR tool that is capable of natural language processing and automatic identifying and extracting information from a patent document. In addition, it features a semantic model, based on the TRIZ engineering design method, for classification and functional analysis of an invention with the aim of invention analysis support [7]. A similar tool for automatic query formulation, search and classification of patent documents, based on TRIZ, has been developed by Nani and Regazzoni [15]. Fantoni, Apreda, Dell'Orletta and Monge [14] have developed a tool and a method based on the function-behavior-structure (FBS) model, for automatic extraction and visualization of invention information.

2.2 Manual patent search tools

While there is a number of automatic patent IR tools aimed at improving search efficiency and lowering search effort, their professional application is still questionable [16] and the patent search task is still, as a rule, performed manually, according to prescribed guidelines and manuals normally published by patenting authorities [17]. Professional searchers and patent examiners typically apply manual tools based on patent text and metadata with the support of automatic tools in some steps of the process [7].

In the case of formal assessment of patentability conducted on patent application by the patenting authorities, the search request is related to patent claims, supported by description and drawings. On the other hand, if patent search is conducted externally to the patenting process, the search request needs to be verbalized first, i.e. articulated orally or in writing.

Apart from the guidelines and procedures prescribed by the patent authorities and despite the importance of the human role in the search process, manual patent search has not been a commonly addressed research topic. Starešinić and Boh [18] are among the few researches in this field who have addressed the issue of full-text patent document searches from the perspective of end-users, stressing the human role in patent search. They have proposed rules for increasing search relevance, but without employing a specific modeling based reasoning tool.

2.2.1 The European Patent Office invention reasoning scheme

The European Patent Office (EPO) defines a structured manual patentability search as an iterative process [19, 20] that begins with an analysis of the

Table 1. The method applied by the European Patent Office for invention analysis and reasoning in patentability search—the EPO invention reasoning scheme [19, 20]

Step	Activity
1	Identify problem underlying the invention
2	Identify inventive concept
3	Identify essential features—features essential to solution of the problem
4	Identify results and effects
5	Identify related application

invention that is disclosed in patent application as search request. For the purpose of representing identified and selected information, including concepts, and its corresponding search terms, a search table is used as a tool proposed by the EPO [19, 20]. In order to support reasoning when the search request is analyzed, the EPO proposes identification of the following categories: problem underlying the invention, inventive concept leading to the solution, features essential to the solution, as well as the results and effects produced [19]. In addition, a related invention application should be identified [20]. Although the EPO prescribes this method as part of the search and examination guidelines, for the purpose of further elaboration in this paper, we represent it in a tabular way (Table 1) and name it the EPO invention reasoning scheme.

The EPO approach, as a typical manual search approach, implies that not only the initial phases of the search, including analysis, information selection and filling out a search table, but also the evaluation of retrieved documents requires reasoning and depend on human decision. Namely, each retrieved document is to be analyzed and manually compared by its technical features and evaluated for similarity against the searched invention as defined by the search statement. Hence, another tabular representation of the searched invention features and corresponding features of relevant retrieved documents has been proposed for relevancy assessment [20]

2.2.2 The essential features

Another author who has addressed the problem of human cognition in manual patent search process is Nijhof [21] who conducted a study showing that typical mistakes are made in the initial phases of the patent search process, namely during search request analysis, search statement formulation and selection of search terms. In addition, Nijhof asserts that identification of the problem, solution and technical field, as proposed by the EPO [19, 20], is not enough to understand all the aspects of an invention. For this reason, he further defines the problem underlying the question as a cause and effect relationship forming a basis for defining the object of the invention. On the other hand, the solution is considered a combination of action and subject, whereby the subject performs the action that is directed towards the cause. Furthermore, it has been emphasized that the invention, as a solution, is directed towards the cause of the problem and not towards the effects that characterize the problem, whereby the effects are defined as manifestations or symptoms of the problem. For example, if an object is to have clean clothes, the solution related to washing with soap would consist of soap as the subject and washing as the action.

As a consequence, Nijhof [21] proposes the so-called essential features as the aspects of technical subjects which correspond to the following concepts: action, direct object of the action (the cause), subject, object of the invention and technical field. Namely, the essential features need to be identified before the search terms are selected and the query formulated based upon them.

2.2.3 The invention diagram template

Another tool to support reasoning and decision making during patent search has been proposed by Hunt, Nguyen and Rodgers [12]. The tool, named the invention diagram template, aims at being exhaustive in capturing all the terms that could be associated with an invention. In a similar manner as in the EPO approach, it is utilized in the first phases of document analysis and identification of subject features. A search request is created and subject features are identified by using the so-called problem-solution approach. The invention is analyzed and structured with respect to the problem it solves, its structure ("what the invention is") and its function ("what the invention does"). On the basis of these categories, as guidelines, the relevant keywords and terms are brainstormed for subsequent generation of search queries and retrieving of documents.

Moreover, Hunt, Nguyen and Rodgers [12] have proposed another tool, namely the hierarchical decision tree, as an invention feature map for relevancy assessment. It is a graphical representation of the invention features with their relationships, derived from the patent document. Additionally, a worksheet can be used, in the same way as in the EPO approach, to list the relevant subject features and link them with the retrieved document sections [12]. The worksheet can be created by converting the feature map into a feature matrix; therefore, an overview of the invention and the state-of-the art documents is enabled for the purposes of comparison and relevancy assessment.

2.3 Design models and modeling theories

Modeling of technical systems is considered the core activity of engineering design, whereby a model is considered a designer's interpretation of the product [22]. By reproducing the properties of an object [23], models support designers' cognition during the engineering design process [24]. There is a number of technical artefact models proposed for use in the engineering design process dealt with by the technical artefact oriented theories or model-based theories [24, 25]. Artefact models are used in engineering design methods to assist designers either manually or automatically in reasoning about a technical artefact being developed. Contrary to computer models, manual models are informal, less complete and accurate, since their purpose is not to be processed by a computer, but to create associations to knowledge and support reasoning and thinking [26]. On the other hand, automatic models are more formal, and normally represent ontology based structured design knowledge [e.g. 27].

Functional models are a type of technical artefact models that focus primarily on artefacts' functionality [28]. Despite their purpose of cognition support, a literature study on functional models has revealed that practitioners are less likely to use them due to their complexity, difficulty, as well as unclear benefits of their application [29]. Likewise, Eckert, Ruckpaul, Alink and Albers [30] and Eckert [31] have conducted empirical research studies on building functional models and their practical application in industry, pointing to many problems in the practical application of functional models, including the reluctant use of models in industry, which may come from the fact that models are, in general, complicated and require much effort to learn and apply [31]. In addition, it has been found that in despite of the importance of analyzing previously existing solutions for new product development, primarily as a source of ideas, the analysis of technical systems has not been systematically taught at universities [30].

For the abovementioned reasons, Eckert [31] has proposed several requirements for functional product models with respect to the needs of the designer, stating that models are to be comprehensive, without much learning effort and with immediate benefit seen from their use. Namely, the models need to be "easy to learn and easy to apply". In addition, the benefit for model builders must be clear, so as to motivate them to build the model, whereas in the case of less intuitive models, requiring more understanding, learning material is to be provided.

2.4 Workshop Design Konstruktion (WDK) technical artefact models

Workshop Design-Konstruktion (WDK) was established in 1978 by Vladimir Hubka, Umberto Pighini from the University La Sapienca, Rome and Mogens Myrup Andrasen from the Danish Technical University, as an informal international association gathering researchers in the field of engineering design [32]. In 2000, the association evolved into a formal association of engineering design researchers, named the Design Society.

2.4.1 Theory of technical systems

The theory of technical systems that has been put forward by Hubka and his collaborator Eder [33] may be considered a fundamental theory of the WDK school. The central model of the theory is the model of transformation system, featuring an operator acting on an operand and exerting an effect on it, thereby causing its transformation. The operand may refer to material, energy or information, whereas the operator may be a human and/or a technical system. In addition, an effect may be exerted on the operand by the active environment. The way the effect is exerted on the operand by the operator is defined by the technology. The output of the transformation of the operand satisfies a certain human need, leading to fulfillment of the purpose of the system.

The theory of technical systems has provided an important contribution to the technical artefact modeling because, unlike other artefact oriented theories, it makes distinction between two transformation processes. One that is related to the activity performed with the technical product by the user and the other related to the activity within the technical product itself, resulting in separation of the product and the use activity [33, 34]. Furthermore, the transformation system is acknowledged for linking technology, as the way the use activity is realized, e.g. writing technology, and the goal of activity, i.e. the need satisfaction, e.g. a written message [34].

Hubka and Eder [33] laid particular emphasis on the distinction between technical processes in general and those happening inside the technical system, resulting in a model of technical system. Namely, the technical system constitutes an execution system within a transformation system. It is characterized by its internal transformation, i.e. conversion of material, energy or information. With respect to the technical system, three structures have been identified: function, organ and component structure, constituting representations of the same technical system at a different level of abstraction. The three structures that are carried by the technical system consist of functions, organs and constructional parts respectively. Prior to exerting an output effect, the technical system is subject to the external effects of other technical systems, the humans or the active environment [33].

In addition, Hubka and Eder [33] have put forward the theory of properties of technical systems used to further explain technical systems, stating that engineering design is a process of establishing values of the properties. The properties are grouped into external properties, related to the use of the technical system, and internal properties that are related to the system itself. A specific class of internal properties, named elementary design properties, includes those properties that are defined directly by the designer and that influence all other properties. These include structure, form, size, material, surface finish, tolerances, and method of manufacture of a part.

Hubka and Eder [33] have considered function a property of the technical system, describing it as an ability of the technical system to fulfill its purpose by transforming the input into output under certain conditions. The organs are defined as means for realizing the functions by exerting the effects. The conversion of the operand within the technical system is characterized by the mode of action, defining how the inputs to the technical system are transformed into effects as its outputs. The mode of action is associated with the specific physical principle enabling the internal conversion, analogous to the technology defining the physical principle at a higher level of the general transformation process.

2.4.2 Danish Technical University branch of the WDK

The theory of technical systems strongly influenced the Danish Technical University (DTU) branch of the WDK [25]. One of the branch's representatives who laid particular emphasis on the practical and pedagogical application of the theory of technical systems was Tjalve [35]. In elaborating the elementary design properties, Tjalve named them basic properties. He selected and put forward the four basic properties of the technical artefact, namely those related to each element, including form, material, dimensions and surface finish, as well as a fifth basic property, namely the structure, related to the spatial arrangement of individual elements. The basic properties constitute those properties that are manipulated by the designer during the engineering design process. Hence, they tend to completely define a product, whereas all other properties depend on them in a causal way. In contrast to Hubka and Eder [33], Tjalve reduced the number of basic properties by excluding tolerances and method of manufacturing.

In addition, Tjalve [35] has emphasized the difference between functional and non-functional relationships among the elements. With this respect, functional relationships are characterized by the functional or working surfaces having an active function during use, such as the seat of a chair. Moreover, there are two types of functional surfaces: inner functional surfaces interacting with another element of the system and outer functional surfaces interacting with the environment, for instance, the surface of a handle. The functional surfaces are characterized by the following basic properties: the number and spatial arrangement which are qualitative parameters and the form and dimensions as quantitative parameters, whereas the non-functional relationship between the elements does not affect their functionality.

Andreasen is another founder of the WDK, who has further developed the theory of technical systems by putting forward the theory of domains [24]. The first version of the theory of domains recognized, in like manner as Hubka and Eder [33], four domains of an artefact, namely the transformation domain, the function domain, the organ domain and the part domain, corresponding to Hubka's process structure, function structure, organ structure and constructional structure [24].

The theory of domains [24] has provided another refinement to the theory of technical systems by making a distinction between characteristics that are structural and properties that are behavioral in nature. In other words, characteristics are determined during the design and properties describe the behavior of a product, whereby behavior is commonly defined as evolution of the physical state of a technical system.

Furthermore, the theory of domains interprets function as being behavioral and not structural in nature, hence considering it a property and not a characteristic of the system [24]. As a consequence, the function structure doesn't exist; instead, the organ domain comprises functions that are used to designate organs [24] leading to refinement of the theory of domains by omitting the function domain.

The theory of domains also uses and further explains the concept of working elements, referred to as "wirk' elements, originating from the German design theory [25]. Namely, by means of the wirk elements, the organs, characterized by certain mode of action, create effects exerted on their surroundings [24]. As an illustration, the wirk elements of a gear wheel constitute gear as an organ creating the effect of transmitting torque and rotation. The parts constitute individual physical entities that can be assembled together to constitute an organ, whereby a single part may contribute to the realization of several organs and may feature one or more wirk elements [24].

According to the most recent refinement of the theory of domains, the transformation domain has been named activity domain, putting forward the activity performed with a technical product in order to satisfy a certain need [36]. The theory has emphasized that a product can either be transformed as an operand, or it can serve as an operator performing the transformation. The latter is typically related to consumer technical products, specific for their interaction with users. In that respect, the theory has introduced another model, the link model that provides a link between the product's activity and the users' activity with the product [34, 36]. Moreover, in relation to the use activity, the theory introduces use function as a result created by the use activity [34, 36]. The use function is considered the most important function satisfying a certain need, solving a problem or fulfilling a task. Hence, it represents what the operator intends to do with a product in order to achieve the wanted result.

In contrast to the activity domain related to use function, the organ domain is characterized by wirk function [36]. The wirk function is defined as an effect created by an organ, which is based on the mode of action as a way of interaction, initiated by external stimuli, between the organ and its surroundings or with another organ [34, 36]. Consequently, the wirk function has been related to what the product is to do, namely to its operation, independently of its use [36]. For instance, a pencil's wirk function is its ability to deposit material on a surface, enabled by the friction between paper and pencil, whereas the use function is to create a written message, as the activity's result.

To summarize, according to the theory of domains, a product is a system of organs, whereby each organ consists of one or more parts. Organs and parts are related by wirk elements and corresponding wirk functions as the active effects they generate [36]. Their mutual interaction as well as their interaction with the surroundings is enabled through effects they produce on the basis of external stimuli and their mode of action [36].

What the latest version of the theory of domains [34, 36] has indicated is that it is not only the organs as structural elements that carry functions, but functions are carried by the activities as well, when the product is activated and being used. Hence, in order to activate the use function, users' interaction with the product needs to exist. Namely, only when subject to use in the use activity, the product demonstrates certain behavior. In other words, an organ has to be stimulated from outside to create a certain effect—the wirk function [36]. Consequently, the theory of domains has implied that the activation of use functions occurs only with the activation of wirk functions by the user. For instance, the use function of an electrical drill is to bore holes. The wirk functions are "to create rotation" and "to create pressure" [34]. Furthermore, it has been noticed that most products do not perform transformation, but only contribute it, implying that most of the technical systems feature static structures that, for instance, have a function to hold, to support etc., with no internal transformation, although there is a static interaction between the structures [34].

In addition, even though the theory of domains [34] does not consider function a property, it assigns functional and other properties to both the product and the activity. Functional properties determine the quality of a function. Unlike functions, functional properties are metric (qualitative or quantitative), with a value that is changed over time and corresponding to the state change of the product, whereby the product may have an operand or an operator role when the activity is performed [34]. Consequently, functional properties can be used for product evaluation. For example, a thermometer's function "to show temperature" carries precision as a function property. Aside from the functional properties, there are other properties, typically related to the product's lifecycle phases, which may be assigned to both the activity and the product [34].

Another product modeling theory of the WDK school with a focus on product structure is the theory of structuring. It considers product structure by the way its elements are related, as seen from an expedient angle [37]. Accordingly, the theory has introduced two different types of structures built into a product [37]. First, a product may carry superimposed functional structures related to the product itself and its primary purpose and use. For instance, a lamp holds at least three superimposed functional structures serving as light source, static support and heat transmission. In addition, a product holds superimposed product life-oriented structures, determined by its life phases such as production, service and recycling. For instance, a means for changing toner in a copying machine is activated only during machine servicing, and is normally not activated during the use of the product. Consequently, product properties may be assigned to products and activities with respect to their functions as well as to the life cycle phases, such as production, assembly, storage, packing, transport, repair, cleaning and disposal [37].

3. The invention reasoning scheme based on the WDK artefact models

The developed invention reasoning scheme, based on the WDK artefact models, is aimed at the support of reasoning and analysis of the search request, formulation of the search statement and selection of the search terms that are used to formulate a search query. In addition, it is aimed at the support of relevancy determining after conducting the search. The scheme features three main groups related to the activity, the technical system and the properties of the technical system (Table 2).

The first group, containing categories 1 to 8, is related to the activity performed with an artefact, including: the activity itself, the use function as the result of the activity, the operand—the object of the activity, the operator—the technical system and the technology as the way the effect is exerted on the operand by the operator. In addition, the first group includes the active environment as represented by the effects it creates on the operand, the mode of action defined as the physical principle determining how inputs to the technical systems are transformed into effects exerted on the operand. Finally, it defines the main wirk function, determining the main effect created by a technical system, and thereby defining what the technical system as an operator is to do. The categories of the first group were adopted from the model of transformation system and the model of technical system of Hubka and Eder [33], which has been modified by Howard and Andreasen [34] and Andreasen, Howard and Bruun [36] by introducing the activity, corresponding to Hubka's transformation process.

The second group (categories 9–10) is related to the organic structure of the technical system as the operator. It represents artefact elements functionally and structurally interrelated with wirk elements, the structural characteristics of wirk elements and the structural characteristics of parts that constitute organs. These elements were adopted from the theory of domains [24] and the work of Tjalve [35]. As previously explained, wirk elements are crucial for understanding the interrelation between structure and function, and thus for understanding what any technical system is, and what it should do. Therefore, the number and relative arrangement of organs, parts and wirk surfaces are to be identified with their sub-functions. In addition, for each part, its form, material and dimensions are to be determined. Since the characteristics are geometric and material by nature, they can be graphically represented with respect to the organs and parts of a technical system, as well as its environment, with corresponding wirk elements and their sub-functions.

The third group (categories 11–12) is related to the functional properties and other properties of the technical system. The elements of the third group were adopted from the theory of domains [24] and the theory of structuring distinguishing between properties and characteristics, as well as from recent developments of the theory of domains [34, 36] distinguishing between those properties related to the artefact's function and the properties related to the other lifecycle phases of the artefact as recognized by the theory of structuring [37]. Functional properties are defined as the measurable quality of the use and wirk functions, whereas other properties are defined as the measurable quality of activity and technical system with respect to lifecycle phases: production, assembly, storage, packing, transport, repair, cleaning and disposal.

There are several reasons for choosing the WDK artefact models as a basis for the reasoning scheme that serves as a support tool in manual patent search performed by engineering students as non-experienced searchers. First, the theory of technical systems has been widely accepted by the engineering design research and education community as the

Table 2. The invention reasoning scheme based on the WDK artefact models. The 12 categories are shown in the first column, with corresponding descriptions in the second column

	Category	Explanation
1	Activity	Activity performed with the product on a certain object
2	Use Function/Purpose	Result of the use activity in order to satisfy a need/solve a problem/fulfill a task
3	Technology	The way the effect is exerted on an operand by the operator
4	Operand I/O	An object the activity is performed on
5	Operator	The technical system performing an activity with or without the aid of humans
6	Active environment	The effects exerted by the environment
7	Mode of action	Physical principle defining how the inputs to the technical systems are transformed into the effects exerted on an operand
8	Main wirk function	What the technical system is to do/the main effect created by a technical system
9	Organs/Parts/Wirk surfaces/Wirk sub-functions	Number and relative arrangement of the organs/parts/wirk surfaces/their sub-functions
10	Parts' characteristics	Form, material, dimensions
11	Functional properties	The measurable quality of the use and wirk functions
12	Other properties	The measurable quality of the activity and the technical system with respect to lifecycle phases: production, assembly, storage, packing, transport, repair, cleaning and disposal

preferred artefact-oriented theory and further elaborated for application in engineering design education by Hubka's collaborator Tjalve [25].

Moreover, recent research conducted by Weber [38] indicates that the theory of technical systems approach is the most comprehensive, having identified all three elements as relevant for the artefact concepts and theories. Namely, the theory comprises the general transformation process model, the model of technical system structures and the concept of technical system properties. In addition, a recently conducted research [39] on different functional modeling approaches across engineering disciplines has demonstrated that the commonly applied Pahl-Beitz approach [40] and the approach of WDK school representatives Hubka and Eder [33] and Tjalve [35] are the two dominant approaches for design modeling in mechanical engineering. Furthermore, the WDK approach has been identified as more general and comprehensive compared to the Pahl-Beitz approach, because it is characterized by the transformation process changing the state of the operand carried out completely externally to the technical artefact, compared to the Pahl-Beitz approach that doesn't take into consideration processes external to the technical systems. The WDK approach particularly considers both humans and technical systems as operators creating effects enabling the external processes to take place.

In a similar manner, the theory of domains [25, 34] has been successfully applied in design engineering education. Furthermore, the link model, as the most recent advancement of the theory of domains, has been intended for designers, researchers and engineering students as an education means serving as an aid for developing their reasoning abilities in design synthesis of technical systems [34].

4. Research methodology

4.1 Case study settings

In order to prove the applicability of the developed invention reasoning scheme in manual patent search, the case study method was employed. More specifically, in our study, we conducted an experimental protocol analysis and a questionnaire based interview in a small but homogenous group including five graduate students of the Faculty of Mechanical Engineering, University of Belgrade, and one research associate. The experiment, which was conducted at the premises of the Faculty of Mechanical Engineering, University of Belgrade, was observed by the first and the third author. As a source of patent documents, the Espacenet [41], free online available search tool of the European Patent Office was chosen for the keyword based search of abstracts. As a search task, the quick patentability search was chosen, since it does not require particular knowledge and skills on patent search and therefore can be performed by non-professional searchers. During the experiment, quantitative data were collected in a protocol analysis in order to measure the efficiency and effectiveness of a patent search. All the measurements were performed with the EPO reasoning scheme first, followed by measurements performed with the WDK models based reasoning scheme.

Since precision, as an effectiveness measure, is defined as the number of relevant documents in a set of retrieved documents, it was measured by counting the number of relevant documents in a set of retrieved documents, based on a previously formulated search query. Recall, which is the second most common measure of patent search effectiveness, defined as the ratio of relevant documents retrieved and the total number of relevant documents, was not used as it was much more difficult to obtain. Namely, it was difficult to establish how many relevant documents exist in the vast database like Espacenet, comprising nearly 100 millions of patent documents. Moreover, for quick patentability and informative searches, high precision is required and not high recall, as already discussed.

In addition to the precision, the efficiency of a patent search was measured according to the methodology adopted from Azzopardi, Joho and Vanderbauwhede [11]. Accordingly, we measured the time required for preparation of a search statement and the time for relevancy assessment of the retrieved results. The times obtained in this way are inversely proportional to efficiency and directly proportional to the objective, measurable search effort. In addition, we measured the number of generated search terms as another efficiency measure of the initial phases of patent search, whereby the number is directly proportional to efficiency and inversely proportional to search effort.

Finally, with the questionnaire based interview it was investigated how the application of the scheme affects the accessibility of patent information. Although accessibility is a measure inversely proportional to search effort and consequently similar to efficiency, it may, unlike efficiency, be considered a subjective measure, depending on the participants' subjective perception of the search effort made when accessing patent information [10].

4.2 Search request

The search request was based on a patent document [42] relating to a system and a method for protecting the head of a user in case of an abnormal movement, such as a fall or a collision, i.e. to an airbag foldable

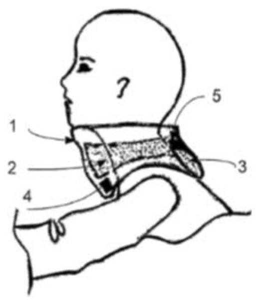

Fig. 1. Search request related to a drawing from the patent document showing the airbag in a folded state [42].

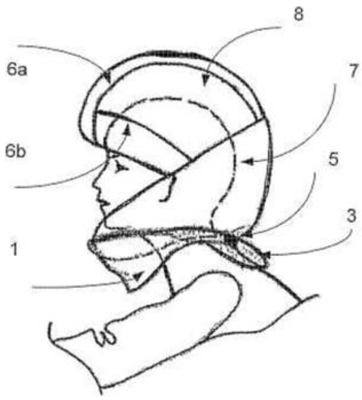

Fig. 2. Search request related to a drawing from the patent application showing the airbag in an activated state [42].

into a collar acting as a helmet, typically intended for cyclists.

Instead of providing the participants with details from the patent document such as the following abstract [42]:

> "The system comprises an apparel (1), an airbag (2), an inflator (3), and a trigger. The airbag includes a first part (7) for surrounding the neck and back head portion of the user after inflation, and a second part (8) for forming a hood surrounding the skull of the user after inflation. The first part (7) and second part (8) are folded and arranged in the apparel (1) before inflation. The apparel is arranged around the neck of the user, like for example a collar or a scarf.",

the participants were provided with pictures from the document and oral explanations in order to prevent direct extraction of search terms from the patent document text. The participants were asked to analyze the pictures and reason about the invention based on the pictures and oral explanations only. The collar airbag was selected as a typical product whose behavior changes over time, having interaction with the user as well as a certain degree of automatization.

4.3 An example of search statements based on the reasoning scheme

Although not shown to the participants during the experiment, an example of possible search statements derived from the scheme was shown in Table 3 in order to illustrate how search statements containing search concepts can be created by means of the scheme. It also served during the experiment as a reasoning aid for the observers in monitoring the selection of relevant search terms and for relevancy assessment. The 12 categories of the invention reasoning scheme and corresponding search statement examples are shown in Table 3 that was obtained by adding another column, with examples of search statements, to the Table 2. Even though, in this specific case, several categories including active environment (category 6), parts' characteristics (category 10), functional properties (category 11) and other properties (12) could not be derived from the search request, possible solutions are shown in Table 3 for illustrative purposes. On the other hand, categories 4 and 5, related to the operator and operand, are always involved in a transformation process and consequently should always be present in the scheme. Although, according to the example, the system of airbags was considered the operator, whereas the operand was the body part, other elements of the system may be selected as operators and operands. Namely, within the same technical activity there may be various possible operators and operands, depending on the system view and the corresponding search request. For example, the operator may be the actuator activating the airbags, in which case the airbags would be the operand. The example shown illustrates how the scheme creates associations and enables reasoning in order to derive search statements from search requests in a systematic way, thereby forming a basis for query formulation. In summary, the search statement formulation depends on the perception of the searcher and various relevant search statements are generally possible.

4.4 The experiment

Prior to performing a quick keyword based patentability search in the Espacenet patent database [41], the participants were given an introductory presentation on patent search in general, since the participants had no previous experience in this field. This was followed by conducting measurements of precision and efficiency according to a measurement program. The measurement program included applying the EPO invention reasoning scheme, with subsequent application of the invention reasoning scheme based on the WDK artefact models as the contrasting case. Before the program was conducted, in each case an introductory presentation on the corresponding invention reasoning scheme and short briefing notes were given.

The measurement program in each case included analysis of the search request according to the

Table 3. Examples of search statements derived from the search request added to the corresponding categories of the reasoning scheme shown in Table 2

	Category	Explanation	Example of search statement
1	Activity	Activity performed with the product on a certain object	Airbags inflating around a body part
2	Use Function/ Purpose	Result of the use activity in order to satisfy a need/solve a problem/fulfill a task	To protect body head and neck in an accident
3	Technology	The way the effect is exerted on an operand by the operator	Cushioning of a body part
4	Operand I/O	An object the activity is performed on	Uncushioned body part/cushioned body part
5	Operator	Technical system performing an activity with or without the aid of humans	Two serial airbags
6	Active environment	The effects exerted by the environment	Not mentioned in the search request, but can be related to outside temperature, atmospheric pressure etc.
7	Mode of action	Physical principle defining how the inputs to the technical systems are transformed into the effects exerted on an operand	Air stream triggered by motion
8	Main wirk function	What the technical system is to do/the main effect created by a technical system	To inflate the airbags
9	Organs/Parts/Wirk surfaces/(Wirk sub-functions)	Number and relative arrangement of the organs/parts/wirk surfaces/their sub-functions	Neck and head airbags, acting on sides and back of neck and head
10	Parts characteristics	Form, material, dimensions	Not mentioned in the search request, but may be related to special kind of material, special pattern of fabric
11	Functional properties	The measurable quality of the use and wirk functions	Not mentioned in the search request, but may be related to impact energy absorption capacity, response time etc.
12	Other properties	The measurable quality of activity and technical system with respect to the lifecycle phases: production, assembly, storage, packing, transport, repair, cleaning and disposal.	Not mentioned in the search request, but may be related to shape manufacturability, material manufacturability, properties such as easy to clean, recyclable fabric etc.

selected scheme, preparation of the search statement, selection of keywords and query formulation, followed by query processing, retrieval of documents, and relevancy analysis. The experiment duration in each case was limited to 45 minutes. Essentially, in the first phase, search statements and corresponding keywords were written down in English or in Serbian, and translated into English by the participants in an experimental protocol. The time for preparation of a search statement was measured and the generated keywords were counted. Only "AND" operator, keywords in singular and the truncation for plural (*) were used to decrease variability in query formulation as much as possible. The keywords were entered in the field "Title or abstract" provided by the "Advanced search" option in Espacenet. In the next phase, the retrieved documents were analyzed and assessed for relevancy using each reasoning scheme and time was measured. Finally, the record of relevant retrieved documents was taken, whereby the documents considered relevant were those featuring a helmet with an airbag for protection against falls. These two features defined the relevance criteria since they belong to the same field of application and represent two main features of the search request that is basically related to the helmet with an airbag.

4.5 The interview

In order to collect quantitative data, an interview among the participants was conducted after the experiment took place. The aim of the interview was to determine the accessibility of patent information when applying the two invention reasoning schemes. Consequently, during the interview the following research question was asked: Which of the two reasoning schemes was more helpful in accessing relevant patent information?

5. Analysis and interpretation of the results

5.1 Analysis and interpretation of the experimental results

Quantitative data collected in the experiment by conducting searches with the EPO reasoning scheme are shown in Table 4, and the data collected when searches were performed with the WDK models based reasoning scheme are shown in Table 5. The measured data represent how each of the reasoning schemes affects precision and efficiency of the patent search.

The data particularly demonstrated that the search precision increased when the WDK models based reasoning scheme was applied. Namely, in this case precision was raised by more than 100%, from 31% to 63%, meaning that the participants found more relevant documents when applying the WDK models based scheme. Moreover, when applying the WDK based reasoning scheme, one participant found the exact document searched. Furthermore, efficiency expressed as the time required for preparation of the search statement was raised by around 30%, from 5.3 (5 min 20 s) per participant to 3.7 (3 min 40 s) per participant when the WDK based scheme was used, meaning that the participants required less time to analyze the search request and prepare a search statement with the WDK based scheme.

On the other hand, results showed that efficiency, expressed by the number of generated search terms, and efficiency of relevancy determining, expressed by the time spent in reviewing the documents, were slightly lower when the WDK models based scheme was applied, compared to results obtained with the EPO invention reasoning scheme, meaning that the application of the EPO reasoning scheme led to lower search effort. Namely, slightly less time was spent in reviewing the documents and the number of selected search words was higher when the EPO reasoning scheme was applied. However, the time spent in reviewing the documents dropped from 4.3 min (4 min 20 s) per participant to 5.2 (5 min 12 s) per participant, which can be considered insignificant given the increase in participants' fatigue as the experiment progressed. The same interpretation was applied concerning the number of selected search terms, where the average number of selected search terms dropped from 5.8 per participant to 4.5 per participant when the WDK based reasoning scheme was applied.

To conclude, the results obtained from the experiment showed that the WDK based scheme generally increased both precision and efficiency of the patent search, compared to the case when the EPO reasoning scheme was applied. Namely, the WDK based

Table 4. Experimental results related to the precision and efficiency of patent search obtained with the EPO invention reasoning scheme

	Search precision	**Search effort (efficiency)**		
Participant	**Number of relevant documents in a set of retrieved documents [%]**	**Time required for preparation of search statement [min]**	**Number of selected search terms**	**Time spent reviewing the retrieved documents [min]**
1	/	6	15	6
2	20	6	4	2
3	100	5	5	9
4	6	5	4	2
5	4	5	4	2
6	27	5	3	5
Minimum*	4	5	3	2
Average*	31**	5.3	5.8	4.3
Maximum*	100	6	15	9

* Per participant.

Table 5. Experimental results related to the precision and efficiency of patent search obtained with the invention reasoning scheme based on WDK artefact models

	Search precision	**Search effort (efficiency)**		
Participant	**Number of relevant documents in a set of retrieved documents [%]**	**Time required for preparation of search statement [min]**	**Number of selected search terms (keywords)**	**Time spent reviewing the retrieved documents [min]**
1	/	4	8	2
2	12.5	2	3	2
3	100	5	5	2
4	100	3	4	8
5	91	4	3	9
6	12.5	4	4	8
Minimum*	12.5	2	3	2
Average*	**63****	3.7	4.5	5.2
Maximum*	100	5	8	9

* Per participant.

scheme enabled finding more relevant documents. In addition, it required considerably less effort in terms of time required for preparation of the search statement. On the other hand, search effort measured by the number of selected search terms and in terms of time required for relevancy assessment remained nearly the same.

5.2 Analysis and interpretation of the interview results

In the interview, it was investigated how the application of each scheme in patent searching affects the accessibility of patent information. Since accessibility is a subjective measure of the search effort exerted by a searcher during the patent search, the participants were asked to answer which of the two reasoning schemes was more helpful in accessing relevant patent information. Most of the participants commented on the efficiency and effectiveness of each scheme, such as "the second method is more efficient" and "the second method enables finding more relevant results", which were actually measured by the experiment, so only two responses were chosen as relevant, as they described the method irrespective of its performance: "The second method requires more thinking" and "I consider the second method to enable classification and systematization of keywords". Therefore, the WDK based reasoning scheme was perceived as more demanding, requiring more effort from the searcher when reasoning about the invention to be searched. Although the obtained results may indicate ambiguity in terms of search effort measured during the experiment and the search effort perceived and recorded during the interview, there is a difference in the objective search effort related to efficiency, as measured in terms of time and selected search terms, and subjective search effort, as perceived by the searcher. The reason for this contradiction may be that the improved reasoning scheme involves effort to learn, but once learned, it leads to rather better efficiency.

6. Discussions and limitations

Concerning the purpose of engineering education to educate engineers to design [4], engineering students need to be prepared to understand the context and complexity of engineering design and to acquire skills and competences in order to be fully capable of performing future tasks in industry [43]. A context they especially need to be aware of is patent information, because it is an important innovation factor influencing any industrial innovation process either as a source of ideas or as a constraint on the process. The only way to address the patent information is through patent search. However, the existence of information does not guarantee that it will be properly exploited. Namely, the patent search requires knowledge and effort from the searcher to access the information contained in the patent databases.

For this reason, in this paper we developed an invention reasoning scheme based on the Workshop Design Konstruktion (WDK) artefact models and investigated its applicability as support for reasoning in the patent search. Namely, we examined if the search for a technical solution in patent databases can be conducted with the means that are used in engineering design and that have been successfully applied in industry and education. In other words, we investigated whether technical solutions can be searched in the same way as they are reasoned about during their design. Therefore, a case study was conducted to investigate if the created invention reasoning scheme is applicable in supporting engineering students in reasoning during patent searches. More specifically, the aim of this study was to examine whether the reasoning scheme improves the effectiveness and efficiency of patent search, as well as to investigate how the scheme affects the accessibility of patent information. This was verified in the case study comprising an experiment and an interview conducted among six participants, including five mechanical engineering students and one researcher. The experiment was designed to test the reasoning about the same search request in two contrasting cases. In the first case, the existing invention reasoning scheme of the European Patent Office was applied, whereas in the second case, the Workshop Design Konstruktion (WDK) models based reasoning scheme was used. In addition, in the framework of the case study, the participants were interviewed on accessibility, as a measure of effort put in by the searchers when applying each of the reasoning schemes in quick patentability searches.

In the area of the case study experiment, it was determined that both the precision and efficiency of search generally increased when the WDK based invention reasoning scheme was applied, as compared to the existing scheme. Therefore, essential findings from the experiment showed that application of the WDK models based reasoning scheme leads to more effective searches, since it enabled finding more relevant documents. In addition, it involves less effort in terms of the time required to perform a search task. This is in line with the recognized value of design theories and methodologies in engineering education, which not only provide support in acquiring fundamental knowledge, but also enable organization of the product development related knowledge [44].

However, in the area of the interview among the engineering design students, the results revealed that accessibility as a subjective measure of the effort the searcher has to invest in order to access the information source and conduct the search is decreased when the WDK based invention reasoning scheme is applied. The collected answers have led to the conclusion that patent searching by means of the WDK based invention reasoning requires more thinking and analyzing, and thereby more mental effort, which may be expected in a mental activity such as engineering design modeling [31].

A few limitations of the proposed scheme are discussed next. Firstly, the scheme was applied in simple, quick patentability searches, meaning that only reduced keyword queries were generated, consisting of "AND" operator and truncation for plural, without the usage of synonyms. While this type of search is rarely used alone, and a single query is practically never used, the purpose of using this type of query in the case study was to decrease the variability in query formulation. However, application of different query syntax and multiple queries, for example as part of a search strategy, may render different results regarding the applicability of the scheme. Moreover, the scheme was not tested for reasoning in the classification based search, typically applied in patentability and informative searches. Secondly, the measurement was restricted to precision, whereas recall, as the ratio of retrieved relevant documents and total number of relevant documents in the searched database, was not measured. Thirdly, although the group was little, it was homogeneous, where participants had similar levels of domain specific knowledge, and almost no knowledge about patent searching skills and methods. However, the applicability of the scheme was not tested among more experienced engineers with or without specific patent search knowledge and skills. Finally, even though the scheme has proven applicable, it does not guarantee that a complete search can be conducted. It rather serves as a tool for increasing search efficiency and effectiveness, and it cannot substitute experience and adequate training in patent search.

7. Conclusions and future work

This paper presents an invention reasoning scheme based on WDK artefact models for application in the initial and final phases of manual patent search process performed by engineering students. Namely, efforts have been made to analyze artefact modeling theories of the WDK school in order to create a knowledge representation scheme containing categories that serve as a support for search request analysis, preparation of search statements and selection of search terms so as to create a search query and for assessing relevancy of retrieved results. The applicability of the scheme has been proven by conducting a case study related to an innovative consumer product. The case study has demonstrated that the scheme increases both the effectiveness and efficiency of patent search as common patent quality factors, thereby increasing the capability of students in searching patent databases in comparison to the existing scheme. Consequently, the case study has proved that the scheme can support students in accessing patent information that may be used either as a source of ideas or for patentability assessment in engineering design projects. On the other hand, the scheme requires effort to be learnt and applied, which however is not considered an obstacle for engineering students who are normally familiar with engineering design models and methods.

A future case study may be performed among other interested parties, such as experienced researchers or engineers in industry, in order to investigate whether the reasoning scheme improves the reasoning of experts and if it is suitable for educating practitioners as well. In addition, future research may be directed towards investigating the scheme's applicability in formulating complex queries. Further studies may also be required for measuring recall as another measure of search effectiveness, which can be done by limiting the total number of documents potentially searched by creating a pre-defined set of patent documents to be searched. As a consequence, by using both common search effectiveness measures, the applicability of the scheme would be additionally supported. In addition, while the focus of this paper was the application of artefact models in patent search, it may point to the possibility of further and wider application of engineering artefact representation and modeling, not only in the field of patent search, but in other fields of patent law and patent and innovation management. Namely, since the engineering design science provides domain knowledge about technical systems, it might also be applied in drafting patent applications and in similar tasks common to the patenting process. Consequently, the tool originating from engineering design research would give rise to more effective management of inventions as industrial innovations.

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