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Computer Aided Material Selection in Design Process

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***Abstract*— The selection of proper materials for different components is one of the most challenging tasks in engineer's activity. The traditional approach to the selection of materials required looking through the literature and material safty data sheets.With the development of information technology, engineering work has also changed. It involves not only arduous browsing catalogues and guides but also defining queries in database applications. This approach greatly accelerated the process of selection of materials, but it did not eliminate all the problems associated with obtaining information from large data sets. This paper presents the developed Web Material Selector application designed for computer-aided materials selection. The WMS allows to work with very large databases through the use of a professional tool to manage complex data structures. At the same time the application is designed to optimize the search process, what significantly reduces the number of materials whose properties a designer should carefully consider.**

I. Introduction

IT is estimated that there are more than 80 000 materials on the market, each of which is described by a series of properties: mechanical, physical, chemical, economic, etc. These numbers show how difficult task was put before an engineer who must made the best choice of the optimal material from which the given item will be made The traditional approach to the selection of materials for specific applications required looking through the literature and material safty data sheets.

Realising the potential for analysis and searching large data sets offered by modern database management systems, to some extent facilitates the work of structural engineers. However, existing solutions do not eliminate all the problems associated with obtaining information from large data sets. On the one hand, the engineer would have the greatest database, which will enable the analysis of the broadest range of materials properties. On the other hand, when searching large databases, the number of materials that meet the very stringent criteria (on the assumption that the element does not operate in extreme conditions) is very high, which hampers the decision process and extended the selection of the best material. The solution to these problems may be to design a new algorithm for the selection of materials in the design process, using the methods of artificial intelligence in the data classification and multi-criteria decision-making models. The main function of this algorithm will reduce and prioritize the search results to databases in such a way that making the decision on the selection of the material as easy as possible.

II. Methodology for the Selection of Materials

Rules for the selection of materials in engineering design has been described in detail in the works of Dobrzański [1] and Ashby [2].The authors defined a complex decision-making process that requires good knowledge of the widely understood materials science and related areas. The procedure of an engineer depends to a large extent on the features that the projected element will meet and the type of project (original, adaptive, alternative). Fig. 1 shows the general scheme of the process of selection of materials.

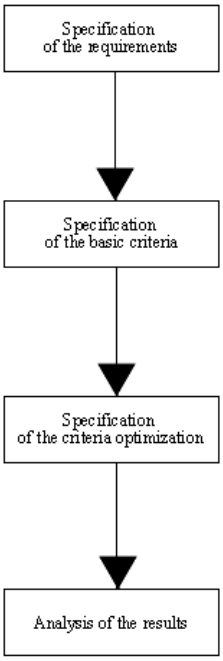

Fig. 1 Methodology for the selection of materials

In the first stage there are a reconnaissance of design and constructional assumptions and analysis of material requirements. In the next step, the basic criteria are formulated. They are strict conditions that allow us to assess whether the given material can be used in the present analyzed case or whether it should be unconditionally rejected. The result of the analysis of the material base in terms of the basic criteria is to obtain the space of solutions, ie the set of materials that may be used in a given project.

In the next step optimization criteria (functional) are described. These criteria are not strict conditions but they only define the value of the objective function, thus indicating the direction to be pursued. The analysis of the space of solutions, taking into account these criteria, allows to organize the list of pre-selected materials. The order of materials on the list is dependent on the optimization algorithms used in the process. If there are a lot of materials that meet the basic criteria, as a result of optimization, the worst materials that meet the specified criteria can also be removed from the list. The last step in the process of designing involves a detailed analysis of materials ranked as a space of solutions in terms of the possibility of using a given material in a specific project. Here assessment, apart from properties, includes so. local conditions, making the selection of the best material from dependent on the owned equipment, the availability of material on the market, confidence in providers, etc.

The vast amount of materials and a lot of properties which are used to describe them justify the attempts at working out computer systems supporting the process of material selection.

III. Systems Architecture of WMS

The few currently existing solutions of computer-aided materials selection have a number of constraints. The flagship program Cambridge Engineering Selector based on the idea of Ashby has a very general approach to the material data that only allows pre-selection. However, applications developed under the leadership of Dobrzański are equipped with much more extensive and accurate database but supporting the process of selection is limited only by the multi-criteria search of these databases.

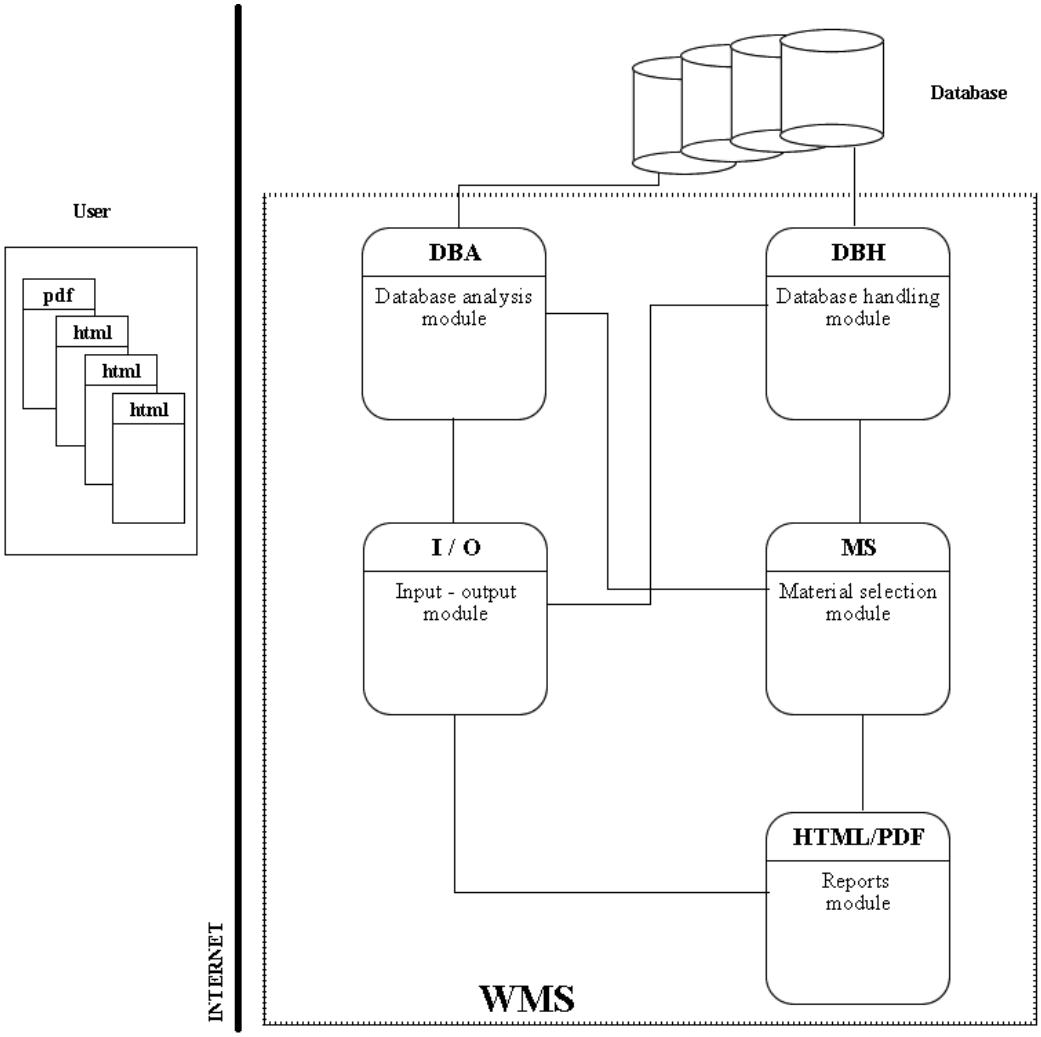

Fig. 2 Multi-layer system architecture of WMS

Originally the WMS program was supposed to eliminate these restrictions. It should support accurate material data for the largest possible number of materials, enable multi-criteria search of database and use optimization algorithms supporting the choice of the best materials. Additionally, in line with current trends in computing, it was decided to create a multi-user network applications with the ability of Internet service and the use of professional database management system of the company IBM. To be able to create a complete documentation of the process of material selection a print option of reports should be introduced.

WMS application designed for computer-aided materials selection is placed on the servers of Rzeszów University of Technology. It was established in accordance with the standard J2EE(Java Enterprise Edition) that defines the rules for creating applications in the Java programming language based on multi-layered architecture. Users gain access to the application using a web browser.

The system has a structure typical of an expert system where the machine is separated from the applicant database (Fig. 2). Entering the data related to the material sought takes place through dynamically generated web pages. Selection of appropriate criteria is determined by a database connected to the system, from which a web page is generated through analysis module and the input-output module.

For proper operation of the program it is required to establish a connection to a database of materials, for demonstration purposes there are two sample databases available. The first database "Plastics" contains information on over 500 plastics and polymer matrix composites. These materials can be found in the commercial offer of five leading manufacturers of plastic products. The second database shows the properties of the materials belonging to the group of stainless steels. It contains information on 300 materials (about 100 kinds in various forms of delivery and subjected to different heat treatment processes) and their properties. The program also offers the possibility to create their own databases, so that users can create their own database of materials.

The application service is very intuitive and is done using a web browser. It provides three basic modes of operation:

- Browsing a database;
- Editing and creating a database;
- Computer-aided materials selection.

The action of this last option is illustrated in Fig. 3. After choosing the appropriate database and the option "Selection of materials" in the menu we can determine information about the executed project. This option allows to enter information concerning the name, description, and additional design elements (such as graphics, calculation, charts); it enables to create a full documentation of the process of material selection.

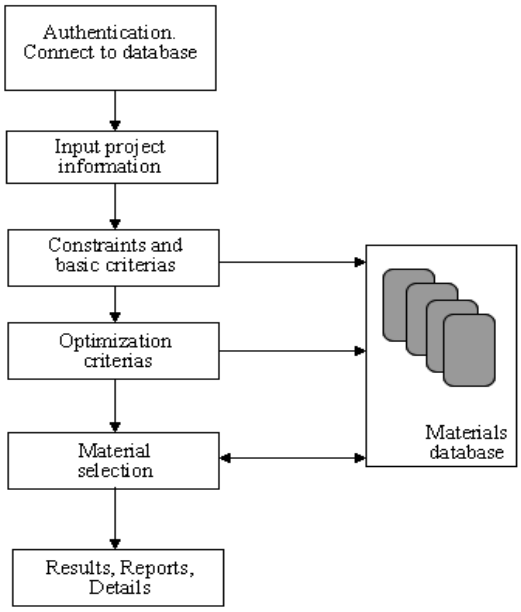

Fig. 3 Selection of materials in the WMS program

The process of selection of materials is done by defining the basic criteria, and thus choosing the right properties, relationships, and entering the boundary value. You can enter up to 10 criteria, and determine the relationship between them. From the declared database the program searches for materials meeting the specified criteria that will provide a solutions space. Then we introduce the optimization criteria determining the property, the purpose (min, max), and the priority of the given criterion (in the range of 1 - 10, where 10 is the highest priority). Using the defined data and information contained in the database the program prioritizes the space of solutions. The ranked list of materials is displayed on the screen (Fig. 4).

At this point, it is possible to view detailed information about a particular material and generate a report of the process of material selection as a PDF file.

WMS is a flexible tool for the selection of materials, the criteria are defined on the basis of the property in the database so that they can be closely matched to the needs of users.The program works with any database created using an appropriate WMS program options or compatible with the documentation supplied with the tool.

IV. Optimization Algorithm

Simple searching the database based on the basic criteria in the presence of a large number of materials and not restrictive criteria brings about choosing a variety of materials.

In recent years there has been many attempts to develop effective an way to find the optimal material from materials that meet the basic criteria. Most of these solutions are MCDM methods[3-6] - multi-criteria decision-making methods, but a statistical method was also developed [7] and a solution based on fuzzy logic [8,9].

Fig. 4 The screen of WMS program - the results of searching the best material

To facilitate the selection of materials, an own MCDM method was implemented in the program - a simplified method for optimization. This method gives results similar to methods developed by other authors but computationally it is much easier what - in the presence of the large data sets - significantly reduces system's uptime

The starting point of the method is a matrix of size m x n (Fig. 5), where n is the number of materials that meet the basic criteria, and m is the number of optimization criteria. In the first step we calculate the arithmetic mean (xj) and the standard deviation (sigma j) for each criterion. Then we determine the value of the assessment factor Cji for each material.The final grade is the sum of the products of factor Cji and weights Pj corresponding to the priorities set by the user at the introduction of optimization criteria.

$$CK_i = \sum_{i=1,\,j=1}^{n,\,m} C_{ij} * P_j$$

If in the given criterion materials with smaller properties match design assumptions better (that is the objective function aims to minimize), for example, the material sought should be as light as possible so the smaller the density of the material the better it matches the assumption, then Pj of such a criterion is negative.

The last step involves sorting ascending the table of materials on the basis of final assessments and the possible rejection of the materials that meet the specified criteria the worst.

V. Summary

To improve the process of selection of materials we need solutions that fully use possibilities of information technology. One of such solutions is the Web Material Selector. This is a free, web-based application supporting the selection of materials, enabling multi-criteria search of the database of material. An additionally implemented optimization algorithm arrange according to preset criteria and limits the number of alternative solutions that should be analyzed in detail in the final phase of the materials selection. The program also makes it possible to create complete documentation of the process of material selection.

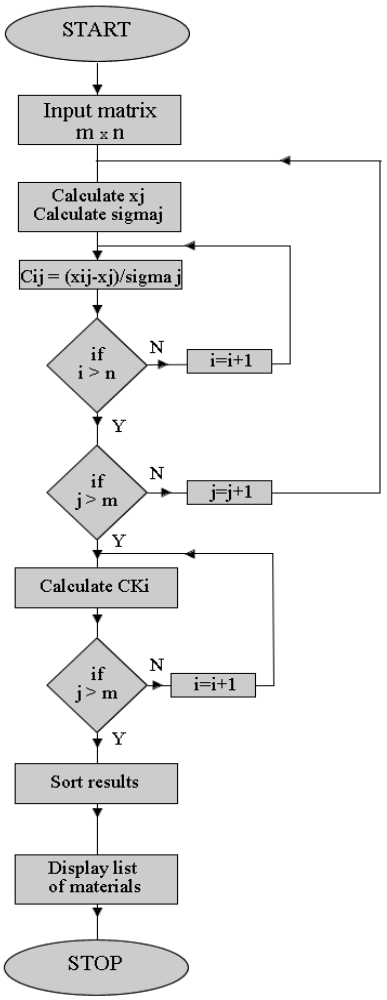

Fig. 4 Algorithm of the simplified optimization method

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