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Dissemination of algorithms for decision-making aiding in the design of furniture and other products made of lignocellulosic materials in the scientific literature

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Abstract: *Dissemination of algorithms for decision-making aiding in the design of furniture and other products made of lignocellulosic materials in the scientific literature*. The issue of the proper selection of dimensions of the designed products can be supported with the use of mathematical algorithms built into CAD systems. There are many such algorithms, they have their specificity and areas of application. The article lists a dozen or so of the most popular algorithms of this type, and then checks their prevalence in the scientific literature on furniture design. The result is a point the method (group of methods) that best takes into account the specific features of lignocellulosic materials. The main conclusion is that the most popular algorithms are: the ε-constraint method, genetic algorithms and artificial immune systems. The most popular is the ε-constraint method.

Keywords: furniture and lignocellulosic materials, optimization, optimization algorithms

INTRODUCTION

Decision-making is the process of making choices from many alternatives (Polikar, 2006). An important element of the design of each product are the decisions about its geometric form, i.e. the values and proportions of the dimensions of the entire product and its individual cooperating elements. Those decisions can be made intuitively, on the basis of the applicable technological rules or it can be supported by mathematical algorithms for optimization. In the design process as well as in production, the majority of all measurement statements involves the requirements for length, width, height, depth, thickness, diameter, circumference, etc. Such a set of data is a part of a set or sequence of values and, therefore, not independent. Considering the restrictions in the scope of functionality, usability, compatibility, safety, or cost in industrial design a need arises for the selection of mathematical optimization methods to support decision-making in the dimensions of the designed elements (Yao and Carlson, 2003).

Web-based design platforms change furniture design, manufacturing, and marketing. In the case of contemporary remote design carried out by a furniture user, a non specialist appear two problems, one of them is the problem of appropriate ergonomics of furniture designed in this way, and the other – an excessive number of possible variants when choosing furniture dimension values. This creates the need to create preferred dimensional sequences that would support non-specialist designers, and which would be values resulting from a number of optimization measures taken. Creating a series of dimensions based on mathematical principles would allow to unify the situation on the furniture market.

Currently, wood and wood-based materials are widely used, and the topic of process optimization and therefore taking appropriate dimensional decisions is highly relevant (Yao and Carlson, 2003). Many engineering sectors are challenged by multiobjective optimization problems. Even if the idea behind these problems is simple and well established, the implementation of any procedure to solve them is not a trivial task. Optimization is understood as a method of determining the best (optimal) solution (searching for the extreme of a function) from the point of view of a specific criterion. In the context of products made of lignocellulosic materials, the optimization criteria may be: production time (related to the optimization of technological processes), production cost (being a certain compromise between price and quality) and customer satisfaction. In the context of furniture, and therefore a very large group of products made of lignocellulosic materials, important optimization criteria will be dimensional criteria (e.g. maximum storage area with minimum product size), production criteria (dimensional and modular repeatability), design quality criteria and, as in the case of other products, criteria related to the cost of production (Nouri and Abdul-Nour, 2019).

There are many optimization methods that are commonly used in various fields of technology. Single and multicriteria optimizations are used. Multi-criteria optimization occurs in many different areas: in product and process design, finance, aircraft design, in the chemical industry, car design, wherever optimal decisions have to be made in the presence of trade-offs between two or more conflicting goals (Siskos, 1986). An aim of multi-criteria optimization is maximizing quality and minimizing product costs by reducing the weight of the device while maximizing the strength of its individual components (Yu et al., 2015). It was decided to check the universality of undertaking optimization issues in the furniture industry by reviewing the Scopus literature database. The aim of the article was a literature query, indicating the universality of the topic presented and indicating the directions of a possible search for optimization methods that can be used in the production and design of products from lignocellulosic materials.

Due to the complexity of the issues, it was found that optimization methods should be sought among MOOP (Multi-Objective Optimization) methods (Renzi and Leali, 2016). They can be defined by like the equation below:

minimize: $f(\mathrm{x})$

subject to: $g_i(\mathrm{x}) \leq 0$, $i = 1,2,\ldots, m$

$\mathrm{h}_j(\mathrm{x}) = 0$, $\mathrm{l} = 1, 2, \ldots, l$

$x_{inf} \leq x \leq x_{sup}$, where $f(\mathrm{X}) = [f_1, f_2, f_3, \ldots, f_k]\mathrm{T} : \mathrm{X} \rightarrow \mathrm{RK}$ is a vector with the values of objective function to be minimized. X is the vector containing the design variables. X_{inf} and Xsup are the lower and upper bounds of the design variables, $g_i(\mathrm{x})$ represents the inequality constraint function and $h_j(\mathrm{x})$ the equality constraint function.

Typically, these methods are divided into four groups depending on how the decision maker (DM) articulates preferences: no-preference methods, a priori methods, a posteriori methods, and interactive methods. Among them, twelve methods were selected that are commonly used and therefore have a high potential for their implementation into the described products, including furniture. The methods tested in Scopus were: Pareto optimal, The weighted sum method, The weighted metric methods, The min-max method, The goal programming, The ε-constraint method, Nature inspired metaheuristic algorithms, Genetic algorithms, Particle swarm, Simulated annealing, Ant Colony optimization algorithm and Artificial immune systems.

In the context of optimization tasks, it is suggested to also look for methods among algorithms for solving IT tasks. An example may be the known backpack problem, which is an example of maximizing the problem of selecting items so that their total value is as large as possible and at the same time fits into the backpack (Li et al., 2020). For a set of elements with a given weight and value, select such a subset that the sum of the values is as large as possible, and the sum of the weights does not exceed the given backpack capacity (Sabba and Chikhi, 2014; Feng et al., 2018). Another example would be a simplex algorithm, hence an iterative method of solving linear programming problems by means of successive improvement (optimization) of the solution. Regarding furniture, metaheuristic methods inspired by nature seem to be particularly important. The well-known golden ratio or the Fibonacci sequence can be found, for example, in the arrangement of leaves of some leaves or in the spiral shape of a shell. Such analogies become an inspiration for the search for newer and newer optimization methods, inspired by phenomena occurring in nature. In the context of furniture, it is particularly important due to the aesthetic aspect, which recognizes that forms known in nature are commonly recognized as beautiful. Newly developed methods that are of particular interest include: Butterfly Search Algorithm, Bat Algorithm or Whale Optimization Algorithm.

MATERIALS

A query was made in Scopus by checking numerous publications in the field of furniture and, in turn, given optimization methods. A three-step search was performed. In the first stage, the number of furniture-related documents was checked (documents containing the word "furniture" in keywords section). In the second stage, it was verified how many of the documents on the furniture industry relate to optimization issues (the word "optimization" or "algorithm" in the title, summary and keywords). The third stage was the systematic search among documents on furniture, documents containing individual names of optimization methods. The methods tested in Scopus were: Pareto optimal, weighted sum method, weighted metric methods, min-max method, goal programming, ε-constraint method, Nature inspired metaheuristic algorithms, Genetic algorithms, Particle swarm, Simulated annealing, Ant Colony optimization algorithm and Artificial immune systems. In the case of a non-meaningful term, the search area was narrowed down by adding appropriate search terms.

RESULTS AND DISCUSSION

The results of the first two phases of searching the Scopus database are summarized in Table 1.

Table 1. The number of publications in the field of furniture

Query	**Results (number of publications)**
KEY (furniture)	9426
(KEY (furniture) AND TITLE-ABS-KEY (optimisation))	187
(KEY (furniture) AND TITLE-ABS-KEY (algorithm))	137
Notice: KEY = keywords	

Table 2. The searched phrase in the Scopus database and the number of searches

Search term	**Number of publications in Scopus**	**Query string**
Pareto optimal	6	(KEY (furniture) AND TITLE-ABS-KEY ("Pareto"))
Weighted sum method	2	(KEY (furniture) AND TITLE-ABS-KEY ("weighted sum"))
Weighted metric methods	0	(KEY (furniture) AND TITLE-ABS-KEY ("weighted metric"))
Min-max method	1	(KEY (furniture) AND TITLE-ABS-KEY ("min-max"))
Goal programming	9	(KEY (furniture) AND TITLE-ABS-KEY ("Goal programming"))
E-constraint method	54 (search limited to fields: computer science, engineering, mathematic, decision making, materials)	(KEY (furniture) AND TITLE-ABS-KEY ("ε-constraint method"))
Nature inspired metaheuristic algorithms	1	(KEY (furniture) AND TITLE-ABS-KEY ("Nature" AND "Metaheuristic"))
Genetic algorithms	24	(KEY (furniture) AND TITLE-ABS-KEY ("Genetic algorithms"))
Particle swarm	7	(KEY (furniture) AND TITLE-ABS-KEY ("Particle swarm"))
Simulated annealing	6	
Ant Colony optimization algorithm	1	(KEY (furniture) AND TITLE-ABS-KEY ("Ant Colony"))
Artificial immune systems	23 (search limited to fields: arts and humanities, engineering)	(KEY (furniture) AND TITLE-ABS-KEY ("Artificial immune systems"))

The results of a detailed search for the number of documents with specific optimization method names are summarized in Table 1.

Table 2 shows that three methods are particularly popular among the considered optimization methods: E-constraint method and two nature inspired: Genetic algorithms and Artificial immune systems.

CAD methodology in products design includes two areas: creative (conceptualization) and routine consisting in making construction records (Sydor, 2009). Optimization methods support the creative area. They are easy to implement in CAx systems. Besides the popular optimization methods, bionic methods are commonly used in the furniture industry, which is confirmed in the publication (Smardzewski, 2007). In addition new metaheuristic algorithms are gaining more and more attention. Taking into account the conducted query in Scopus, it can be concluded that the popular optimization methods in the field of furniture are: ε-constraint method (54 documents), Genetic algorithm (24 documents), Artificial immune systems (23 documents), The goal programming (9 documents) and Pareto method (6 documents).

In engineering problems, there is very rarely only one best solution that minimizes all target functions. Usually, there are many potentially optimal solutions. Therefore, the expected result of optimization is a set of solutions, called the productive set, which can be very large. Useful insight into the structure of the engineering problem is then obtained (Eichfelder, 2009). In our opinion, it is one of the reasons for the popularity of the ε-constraint method in the furniture industry. The use of evolutionary algorithms to find candidate solutions is widespread. Usually they supply a discrete picture of the non-dominated solutions, a Pareto set. A popular algorithm is Artificial immune system. The common feature of these solutions is offering a set of many non-trivial solutions and high versatility of use. Although it is very interesting to know the nondominated solutions, an additional criterion is needed to select one solution to be deployed.

CONCLUSIONS

1. Optimization methods are particularly useful in information systems for product design and manufacturing (CAD-CAM).
2. The popular method are the Genetic algorithm Pareto methods, however, more and more attention is paid to bionic algorithms in the field of metaheuristic optimization methods.
3. The subject of optimization methods in the furniture industry is not commonly discussed in scientific articles, as indicated by the Scopus database review.
4. It is suggested that the given processes and the selection of preferred dimensional values be optimized by using proven and commonly used optimization methods that could be adapted to the furniture environment.
5. It is suggested to search for optimization methods among popular algorithms such as Genetic algorithm Pareto, but also among newly emerging metaheuristic algorithms.

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Streszczenie: *Upowszechnienie w literaturze naukowej algorytmów wspomagających podejmowanie decyzji w projektowaniu mebli i innych wyrobów z materiałów lignocelulozowych.* Zagadnienie właściwego doboru wymiarów projektowanych wyrobów może być wspomagane za pomocą algorytmów matematycznych wbudowanych w systemy CAD. Takich algorytmów jest wiele, mają one swoją specyfikę i obszary zastosowań. W artykule wymieniono kilkanaście najpopularniejszych algorytmów tego typu, a następnie sprawdzono ich rozpowszechnienie w literaturze naukowej dotyczącej projektowania mebli. Wynikiem jest metoda punktowa (grupa metod), która najlepiej uwzględnia specyficzne cechy materiałów lignocelulozowych. Główny wniosek jest taki, że najpopularniejsze algorytmy to: metoda ε-ograniczenia, algorytmy genetyczne i sztuczne układy odpornościowe. Najpopularniejsza jest metoda z ograniczeniem ε.

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