Egyetemi doktori (PhD) értekezés tézisei

Decision-Making Models for Optimal Engineering Design and their Applications

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Abstract

The task of solving optimal engineering design problems is considered as a demanding decision-making process where the real-life industrial problems typically have to be considered from very different perspectives. In this context the most logical approach to achieving the best solution, at the presence of multiple design criteria and numerous design variables, has been the task of performing scientific optimization to produce potential solutions for further decision-making. Accordingly multiple criteria decision-making approaches to optimal engineering design problems, via employing efficient, robust, global and multi-objective optimization algorithms, have brought a significant and competitive advantage to the optimal design. However most of these approaches, due to the characteristics of the real-life problems, often associated with the usage, dimensionality, and high computational cost of the objective evaluations, have not been practical and widely acceptable in engineering design community. Here the difficulties and further requirements of utilizing the optimization approaches in optimal engineering design are discussed with a more emphasis on challenges to complex geometries, dimensionality, and multiple criteria nature of the real-life engineering design problems. As a response to the considered challenges, performing the optimizations approaches in the framework of an integrated design environment is proposed as the key success to win industry.

Further this research the metamodels in general approaches to optimal engineering design, are seen as the essential but not sufficient tools to enhance creating the efficient global

optimization approaches in dealing with dimensionality. In fact by extension the dimension of multiple criteria decision-making problems which has been mostly due to the increasing number of variables, optimization objectives, and decision criteria, presenting a decision-maker with numerous representative solutions on a multidimensional Pareto-optimal set can not be practical in engineering applications. Accordingly for better dealing with the ever increasing dimensionality a supplementary decision-support system to enhance the metamodels is proposed. As the result an improved decision procedure is formed according to the limited human memory and his data processing capabilities. In this context the research further contributes in shifting from generating the Pareto-optimal solutions, to the reactive and interactive construction of a sequence of solutions, where the decision-maker is the learning component in the decision-making loop. To doing so the conventional evolutionary and interactive optimization and decision-making algorithms are updated by reactive search methodology, empowered with the advanced visualization techniques, in the framework of an integrated design environment.

1 Summary of contributions

Due to highly expensive numerical analyses in engineering and process simulations [1], [2], for an optimal design, decision-makers (DMs) have been urged to extract as much information as possible from a limited number of test runs. A vast number of statistical and optimization algorithms exist to extract the most relevant qualitative information from a database of experiments in order to support the decisions in real-life optimal engineering design where a number of objectives in multiple design criteria from very different perspectives are to be considered simultaneously [3]. Besides, the multiobjective optimization (MOO) algorithms [4], [5], offer a significant competitive advantage in different fields of optimal engineering design where the conflicting objectives are simultaneously considered leading to an overall insight into the problems.

The critical survey of Stewart [6] on the status of multiple criteria decision-making along with our state of the art surveys on the existing algorithms, which are included in this thesis [1], [2], [7], [8], [9], [10], report the needs for further improvements in today's ever increasing complexities in order to be able to efficiently deal with real-life applications. As a respond to the reported needs, this thesis preliminary propose a supplementary decision-support system based on classification [11] to identify the most relevant variables in the optimal design problems, in particular, in shape optimization for complex geometries, leading to a smaller and manageable design space. Although the examined case studies are proposed in dealing with geometrical and shape optimization problems originally, however the feedback from industries and multicriteria decision-making (MCDM) research community [12], [13], [14], and [15], indicate that the proposed methodology is also suitable for general applications to optimal engineering design. The citations and revisions of our initial proposed methodology [11] in a number of publications including Elsevier [13] and Springer [14], [15] have motivated the further investigations, researches and publications [16], [17], [18], [19], on this realm.

The thesis's further contributions to shape optimization for complex geometries e.g., [20], [21], and [22], include the development of a design strategy for general optimal engineering design problems on the basis of Non-uniform rational B-spline (NURBS) parameterization [23], [24]. Here the existing methodologies [25], [26], [27], [28] are improved in terms of integration, optimization algorithms used, complex geometrical modeling methodology and parametrization. The considered applications and case studies utilizing the proposed method would cover a wide range of optimal design problems in hydrodynamics [29], [30], [31], aerodynamics [32], [34], built environments [33], [34], and thermal-fluid structural design [1], [35]. The obtained results, communicated via the above-mentioned publications are promising.

However in the way more challenging real-life applications such as optimal design of composite textiles [36] where the detailed-complex geometry parametrization, big data and increasing the number of criteria in decision-making become the design's new issues the strategy would demand for the further improvements. For this reason in the improved design strategy the former NURBS-based shape parametrization method is enhanced with a novel methodology called generative algorithms [37], [78]. Furthermore in order to deal with big data and the increasing number of design criteria, the optimization and decision-making algorithm has been empowered by reactive search optimization methodologies and brain-computer optimization [39], [43], [38], [42]. The methodology, case studies, and results have been communicated via a number of publications [40], [41], [42], [43], [44], [45], [46], [47]. Moreover the final workflow integrated with materials selection [49], [50], [51], [52], [53] has been approved and recommended by the Europe's leading computer aided engineering (CAE) design company to the industry [52]. Furthermore the method has been continuously improved to fulfilling the needs of new fields of applications e.g., computer vision [48].

Worth mentioning that in the real-life applications an optimal design strategy receives the contributions of many different departments and multiple criteria trying to meet conflicting requirements of a design simultaneously. In this context because of the emphasis on human-technology interactions this thesis overlaps with other disciplines, particularly with business intelligence and enterprise decision management in which we should have also considered them as well in a number of research works and publications [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], which in fact are not include in this thesis.

The contributions of the thesis with the corresponding publications are the following:

1. Section one, two and three including state of art surveys on global optimization, multi-objective optimization, and MCDM [1], [2], [7], [8], [9], [10].
2. Section three proposing a design strategy for general applications to engineering optimal shape design in the framework of an integrated design environment [1], [29], [30], [31], [32], [34], [34], [35].
3. Section four proposing a supplementary decision-support system to metamodels based on classification to identify the most relevant variables in the optimal design problems [11], [16], [17], [18], [19].
4. Section five including further improvements on optimal design strategy utilizing reactive search optimization methodology in the framework of an integrated design environment [40], [41], [42], [43], [44], [45], [46], [47], [48].
5. Section five including the concept of design integration with materials selection [49], [50], [51], [52], [53].

2 Introduction

In today's highly competitive market environments, engineering designs must be optimized if they are to succeed in accomplishing objectives while satisfying constraints. Considering further multiple criteria, additionally the product development lead-time, cost and performance must be optimized to ensure affordable and speedy reaction to the changing market needs. Thus, a deep understanding of the computational tools used for multiobjective optimization [4], MCDM [5], and simulation-based optimal design [77], is critical for supporting the engineering decision-making processes. Drawing on current researches, state of the art surveys, best-practice methodologies and developing tools illustrated by case studies, this thesis provides an overview to optimal engineering design as well as simulation-based numerical design optimization with a more emphasis on challenges to complex geometries [64], big data [65], decision-making [66] and multiple criteria nature [6] of the real-life engineering design problems.

MCDM, global and multi-objective optimization

In an optimal engineering design environment solving the MCDM problem is considered as a combined task of optimization and decision-making. In fact as the process of MCDM is much expanded most MOO problems in different disciplines can be classified on its basis.

The task of optimization in engineering design is considered as a very important and in the same time complicated task for engineers to deal with. The problems of this type are mostly nonconvex, nonlinear and computationally expensive, including numerous variables and several conflicting objectives [5]. Solving the design optimization problems as such, which are mostly referred to black-box optimization problems [67], [68], is not a simple task. The black-box optimization problems with multiple objectives can be solved in several different ways. However the characteristics of these problems suggest that we should use global, multiobjective, robust, and efficient approaches to tackle the difficulties caused by several local optima, several conflicting objectives, and high computational cost of the objective evaluations. Meanwhile engineers prefer to utilize the efficient, easy to use, global and multiobjective approaches [67], [68] in order to solve these problems accurately and effectively.

Interactive, evolutionary and response surface approaches to multi-objective optimization problems

Understanding the true nature of a particular problem followed by algorithms selection task, are considered vital for effective modeling approach to the optimal engineering design [4], [5]. For this reason in this thesis a huge amount of efforts have been spent on identification the characteristics of each family of problems and the potential corresponding algorithms. Among all algorithms to MCDM, interactive [70], evolutionary [4] and response surface [3] methods have been of our particular interests. A classification of the MOO methods including their recently improved algorithms have been well presented in the thesis as a summary to a number of our published state of the art surveys and case studies, e.g., [1], [2], [7], [8], [9], [10]. Although considering shape optimization problems where the aesthetics criterion is a common objective evaluation function in the optimal design tasks the interactive approaches have been found to be more effective as they are capable of supporting the DM actively in finding the preferred Pareto optimal solution by continuously involving the preferences in the solution process to better guide the search.

Nevertheless prior to selecting a proper algorithm for a particular problem, utilizing a decision-support system with the ability to reduce the design space would help decreasing the complexities as well as providing the ability for understanding the true nature of the problem.

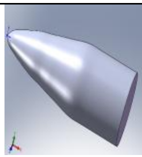
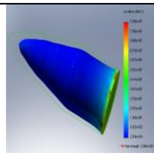
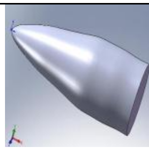
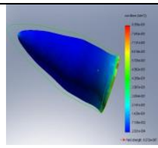
Optimization research communities have developed numerous approaches to global and multi-objective optimization so far including response surface methodologies, interactive, and evolutionary algorithms which are mainly surveyed in [3], [4], [5], [6], [7], [69], and [77]. However most of these approaches, due to the difficulties often associated with the usage and also a number of particular requirements mostly associated with increasing the design space which we have discussed them in details in e.g., [16], [17], [18], [19], haven't been really applicable in real-life engineering optimization problems within the industry. As a response to this issue our thesis identifies the most effective tools for supporting the process of engineering optimization and optimal design, within the existing global and multiobjective optimization approaches.

3 Reducing the design space

Hypothesis 1 *Reducing the design space is beneficial in understanding the true nature of a particular optimal design problem. In this context the classification task of data mining could effectively rank the design variables and identify the most relevant ones to the design objectives leading to extract more information from the optimization variables and objectives in an efficient way.*

Increasing the size of MCDM models, in terms of objectives' and variables' dimension have become more demanding, as the models have to be capable of dealing with higher computation cost, noises and uncertainties. According to [2], [3], [8], [9], [10], where the applications of meta-modeling optimization methods in industrial optimization problems are discussed, some of the major difficulties and challenges in real-life engineering design problems counted as; (1) involvement of the multicriteria and numerous objective functions, (2) the black-box function form of criteria which cannot be explicitly given in terms of design variables, and (3) there is a huge number of non-ranked and non-organized input variables to be considered. In fact often in modeling the optimal engineering design problems, the value of objective functions is not clearly defined in terms of design variables. Instead it is obtained by some numerical analyses such as finite element structural analyses [31], [49], fluid mechanics analysis [29], [30], thermodynamic analyses [1], [35], and chemical process simulations and reactions [2], [7]. These analyses for obtaining a single value for an objective function are often time consuming and most expensive. Considering the high computation costs the number of CAE evaluations are indeed subjected to minimization.

Table I. Part of the dataset considered in [17]; including computer-aided design (CAD) model, geometrical variables and numerical analyses

Variables Configuration V1-V30	**CAD Model**	**Displacement Distribution**	**Objective /target variables**
0,0.84,0.99,0.84,0.62,0.26, 0,-0.20,-0.40,-0.36,-0.70,- 0.58, 0,0.59,0.78,0.56,0.30,0,- 0.21,-0.24,-0.38, 0,1,1.2,1,0.8,0.4,0.2,0,- 0.4,-0.48, 0.6,-0.8,-0.72,			O1=c O2=c O3=b
0.62,-0.81,-0.70, 0,0.86,0.1,0.82,0.60,0.25,0 .01,-0.20,-0.39,-0.39,- 0.70,-0.58, 0,0.58,0.76,0.57,0.32,0,- 0.21,-0.23,-0.37, 0,1.1,1.21,.9,0.82,0.42,0.1 8,.1,-0.41,-0.46,-			O1=b O2=c O3=a

As a response to the considered challenges our proposed methodology which is described in [16] would help in reduction of the MOO and also robust optimal design search space which indeed would lead to the need for a fewer number of CAE evaluations. For the reason of reducing the number of analyses as few as possible our methodology works as a supporting tool to the meta-models [3], [8] and interactive MOO [7], [70].

The methodology is based on the classification task of data mining which investigates the effect of each design variable on the design objectives. In this method the target categorical variables could be defined according to the result value of numerical analyses performed by any of the CAE codes.

In our first work [11] the workflow and the correspondence algorithm were initially proposed. Yet the citations and revisions of the initial proposed methodology in a number of publications including Elsevier [13] and Springer [14], [15], had motivated the further investigations, and as the result in the followed publications i.e., [16], [17], [18] and [19] along with examining different case studies the proposed strategy has been continuously improved.

Result 1 *The classification task of data mining has been introduced as an effective option for identifying the most effective variables of the MOO problem in a MCDM system. A classification algorithm was utilized analyzing the effect of each design variable to the identified objectives. The number of the optimization variables has been managed very effectively and reduced in the given case studies i.e., [16], [17], [18], and [19]. The achieved preprocessing results as the reduced number of variables would speed up the process of optimization due to the delivered smaller design space. Data mining tools have been found to be effective in this regard. It is evidenced that the growing complexity of MCDM problems could be handled by a preprocessing task utilizing data mining classification. The modified methodology is demonstrated successfully in the framework. The promising results are the proofs for the achievement of a simple, fast, and affordable process to industries.*

4 Shape optimization for complex geometries

Hypothesis 2 *Manipulating the NURBS curve and surface parameterization with the optimization algorithms via computer-aided design packages could be considered as an effective optimal design strategy for developing the concepts with complex geometries.*

In this thesis shape optimization basically is referred to changing the external borders of the mechanical components where the geometry is defined in terms of surface and curve parameters allowing more freedom to manipulate. Shape optimization for complex geometries is an interesting and popular branch of optimal engineering design where variables and constraints are characterized on the basis of geometrical definitions e.g., dimensions, distances, curvature and aesthetic. According to the theories, approximations, and computation of shape optimization [26], with a powerful parameterization process over geometrical models, optimization the complex geometries can be conducted using standard optimization methods including either direct or indirect design methods whether gradient-based methods or global search approaches. Such parameterization is very important in CAE simulation-based design where goal functions are usually complex functions evaluated using numerical models e.g. CFD and FEA.

Toward approaching the framework of a general strategy for developing complex shapes in the engineering design our study brings together techniques that have their origins in the field of optimization and new tools of geometrical innovation.

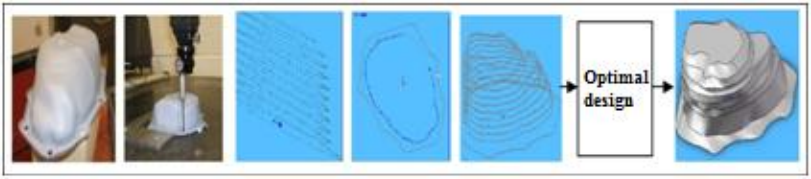


Figure 1. Shape optimization for complex geometries; the workflow

The major achievement in parameterization has been the theory of Bezier curves and surfaces which later was combined with splines as an earlier version of NURBS [26]. The use of evolutionary tools for optimizing the existing shapes by Splining is the most effective design optimization technique to be widely used in different industries e.g., [25], [27], [28]. Our surveys [20], [21] and [22], along with Renner and Ekart's [71], are devoted to this subject where the integrated Splined geometry with evolutionary tools form the basis of an evolutionary design process. In this methodology the optimal design is seen as a complex optimization task, in which the parameters describing the best quality design are searched. Yet the process has been limited only to optimal design of the simple geometries. In this context proposing NURBS [23], [24] parameterization, as a standard description method of surfaces in CAD software in industry, because of its efficient computational implementation with numerical stability and simple formulation providing smooth shape changes which are highly suited for the parameterization of a design allows obtaining versatile new shapes while maintaining a reliable control over admissible geometries.

In terms of optimization and making the final decisions according to the design preferences in an engineering optimal shape design strategy, the DMs often cannot formulate all of their objectives and preferences at the beginning. Instead they would rather learn during the process. This fact would employ lots of uncertainty and inconsistency. The uncertainty is even increased when further objective evaluation functions such as beauty are involved, as described in [22], [40], [42], and [43]. Consequently interactive approaches have been trying to overcome some of these difficulties by keeping the user in the loop of the optimization process and progressively focusing on the most relevant areas of the search directed by DM.

With utilizing the latest achievement in computational geometric design and optimization in this thesis the current techniques of parameterization, and the overall strategy, have been improved in terms of (1) manipulating the initial geometry (2) implementation and (3) integration with advanced optimization tools. Our proposed strategy, described in [20], [21], [22], is formed on the basis of NURBS integrated with evolutionary [4] and interactive MOO tools [70]. These optimization algorithms constitute a class of search algorithms especially suited for solving complex geometrical optimization problems. This provides new possibilities in dealing with complex geometries which were virtually unthinkable before.

Strategy; the research, development and successful case studies on MCDM and MOO algorithms for engineering optimal design are numerous [4], [5], [6], [26], [43], [66], [69], [70]. However the expansion and progress of applicability and popularity of these algorithms within engineering design communities have been very slow. In fact an algorithm can be widely utilized when only it is implemented within an integrated design environment of an optimization package where its ease of use, and its further integration requirements are well customized. Here the idea behind the design strategy is "the idea of integration". It is assumed that with an effective integration of the today's already existing resources of CAD, CAE, and optimization, promising results can be achieved. Consequently the improvement on geometrical parameterization techniques, and benefiting from advanced interfaces of commercial optimization packages would be essential. This ideology of design is introduced as the future trend for engineering optimal design. In the considered case studies instead of getting to the details of the optimization algorithms utilized, the focus would be on the level of integration and the potential advancement we could expect from the novel coupling of CAD, CAE, and optimization for the future designs.

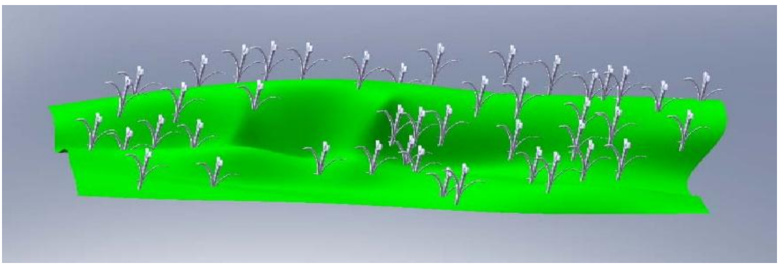


Figure 2. Optimal design of the built environments [33], [34]; the initial geometry of a built environment.

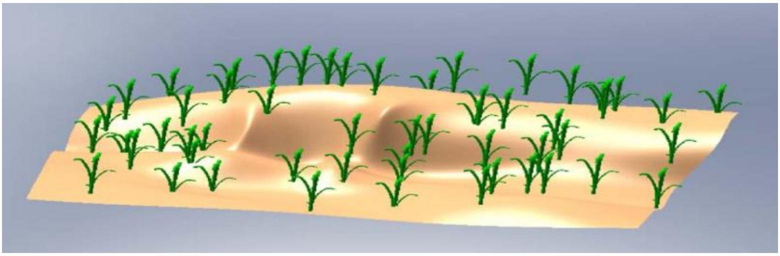


Figure 3. Optimal design of the built environments [33], [34]; an optimal configuration

Result 2 *The applicability of the proposed NURBS parametrization integrated with MOO algorithms have been shown in a series of case studies within different fields of optimal engineering design. The applications include aerodynamic optimal design [29], [30], [31], thermal-fluid structural optimization [35], hydrodynamic design [32], [34] and optimal design of built environments [33], [34]. The published case studies include further details on coupling with the other potential finite element analyses in ANSYS, involving other CAD systems, optimization algorithms, decision-making, postprocessing, and reporting [32].*

5 Further improvements on the optimal design strategy

Motivation A typical NURBS model involves far more control points than are needed for the geometrical modeling which needlessly complicates fairing and form finding. A new surface representation, which eliminates the superfluous rows and columns of control points that are unavoidable in NURBS will be a great deal of support. In fact the recent advancements in computational design has the potential to deliver the capability of accessing to a controlled process of complex geometry parameterization and generating vast space of possible solutions and exploring them.

Hypothesis 3 *Enhancing the NURBS-based parametrization of the initial proposed optimal design strategy with generative algorithms [37], [78], can improve the overall performance of the strategy in dealing with geometrical complexity of the fine products.*

Utilizing the novel parameterization methodology of generative algorithms for modeling, generative and reasoning allows optimization-analyses and parametric systems to be perfectly integrated. This means achieving an integrated infrastructure which would be a developed and more convenient version of the earlier studies which is capable of supporting optimal changes in geometry. The proposed generative algorithms as an associative parametric modeling system automates the optimal design process and accelerates the design iterations. Our updated optimal design strategy [44], [49], [50] delivers significant advantages as it speedy models geometry, generates forms, captures and manages complex geometric relationships and rapidly explores a broad range of design alternatives in less time.

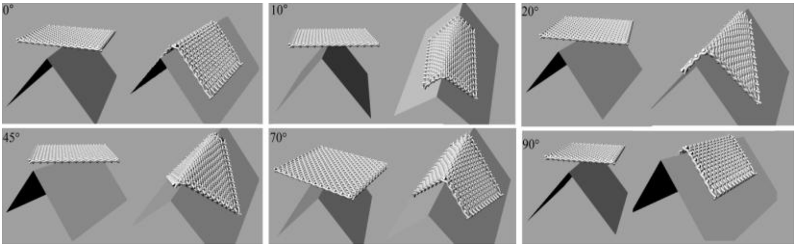


Figure 4. Draping simulation in textile composites [49], [50] considering a number of draping degrees

Result 3 *The former strategy is updated by enhancing the manual NURBS parameterization method with generative algorithms. The new approach empowered by computational methods, can direct creativity to deliver freer forms and assemblies via quick exploration of a broad range of alternatives for even the most complex geometry. Our research delivered an unrivaled creative flexibility, in order to achieve the results which have been virtually not valid before e.g., draping process simulation in textile composites [49], [50].*

Hypothesis 4 *Utilizing reactive search and brain–computer optimization algorithms [38], [39], [42], [43], instead of conventional algorithms e.g., evolutionary multi-objective optimization and interactive multi-objective optimization can improve the overall performance of the updated strategy in dealing with increasing the number of design criteria and big data.*

A MOO algorithm controlling the geometrical parameters is the core interface to the CAD, numerical analyses and DMs which are integrated to development process of shapes. However to make informed decisions in the optimal design strategies on the basis of generative algorithms the proposed methodology hasn't been integrated with a suitable optimization tool capable of increasing the number of design criteria and big data. In fact in developing a MCDM design environment relying only on evolutionary design components, in today's ever-increasing complexity when often numerous design objectives are involved, is not sufficient. Applied optimization to optimal design provides a number of efficient MOO algorithms which facilitate a DM to consider more than one conflicting goals at the time. However the reality of applied decision-making in optimal design has to consider plenty of priorities and drawbacks to both interactive and non-interactive optimization approaches used in the initial strategy.

Although the mathematical representative set of the decision-making model is often created however providing a human DM with numerous representative solutions on a multi-dimensional Pareto front is way complicated and not practical [43]. This is because the typical DM cannot deal with more than a very limited number of information items at a time [72]. Above facts, as also mentioned in [42], and later in [38] demand a shift from building a set of Pareto front, to the interactive construction of a sequence of solutions, so called brain-computer optimization [39],[43], where the DM is the learning component in the optimization loop, a component characterized by limited rationality and advanced question-answering capabilities. This has been the reason for the systematic use of machine learning techniques for online learning schemes in the optimization process [43], [44], [45], [46], [47].

The methodology has been described in [40], [41], [42] and [44], and since then it has been continuously improved to fulfilling the needs of other fields of applications e.g., computer vision [48].

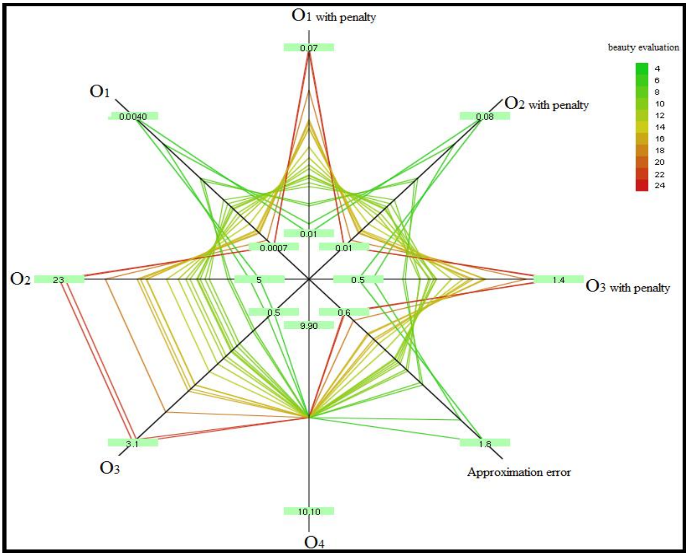


Figure 5. Case study; considering four objectives in addition to beauty evaluation function in a multi-dimensional graph [48]

Result 4 *In order to improve the performance of optimal design strategy a decision-making procedure has been proposed according to the human memory and his data processing capabilities. The* *optimization module has been upgraded with the aid of reactive search optimization. In fact the initial optimal design strategy was significantly improved in terms of MOO and decision-making in dealing with increasing number of criteria and considering objectives such as beauty allowing for an exploration of a broader field for possible solutions to a design problem. The description of the new concept of design strategy, the ability to introduce automatic changes in complex shapes, case studies and the impact on global design performance are presented in [40], [41], [42], [43], [44], [48].*

6 Integration of the optimal design strategy with materials selection

Hypothesis 5 *Considering shape optimization and materials selection simultaneously by including the materials characteristics into the geometry parameters with the further aids of reactive search optimization, data mining, and visualization can perform an optimal combination of geometry and material so that the effect of changing materials properties on the geometry of a component design can be directly evaluated.*

The area of design decision-making for simultaneous consideration of the geometrical solution and materials selection, which is in fact needed at the early design stage is relatively weak. Although the importance of integrating materials selection and product design has been often emphasized [73]. Yet The engineering designer often assumes a material before optimizing the geometry. Clearly this approach does not guarantee the optimal combination of geometry and material [74]. The usage of multi-objective optimization, combined numerical analyses and MCDM approaches for structural materials selection problems are well reviewed in [76]. In the proposed method of this thesis, previously published in [49], [50] and [51], the materials properties are directly transmitted into geometry parameters so that the effects of changing materials properties on the geometry and dimension of a component design and overall product performance can be directly evaluated. In developing the methodology the aspects of modeling, data mining and visualization the data related to materials selection are considered where the interesting patterns are automatically extracted from our raw data-set. Furthermore in our following publications [44], [45], [46], [47], [53], utilization the multi-objective optimization and decision-making, with a particular emphasis on supporting flexible visualization is discussed where the advanced visual analytical interfaces are involved to support the DM interactively.

Result 5 *The methodology was used in the case study of optimal design of textile composite structures [49], [50], where a wide variety of material combinations, reinforcements, geometries, and architectures in the specific case of mechanical modeling of draping raised the need for utilizing such tool. Although the applicability of the proposed workflow can be customized for different problems and usage contexts in industry.*

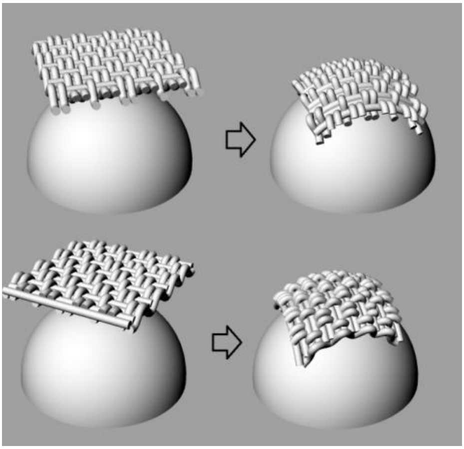


Figure 6. Mechanical simulation of draping process including a combined mechanical modeling of compression, bend, stretch, and shear shown from two different draping angles; considering geometry and materials selection simultaneously.

The preliminary tests of the optimal design-integrated materials selection strategy in the concrete context of designing the multiple dome shapes, have shown the effectiveness of the approach in rapidly reaching a design preferred by the DM. The results have been published in the simulation based engineering & science magazine [52] where the strategy has been approved and recommended to the industry by the Europe's leader and key partner in design process innovation; ENGINSOFT [52].

7 Conclusions

Performing the process of optimal engineering design within the integrated design environment of an optimization package where the ease of use, and the further coupling and integration requirements are well customized can effectively fill the gap between optimization approaches and optimal engineering design in industry. The benefits further include that the optimization algorithms whether evolutionary or interactive's can easier be enhanced by metamodels, and the optimization results can be better communicated to the decision-maker via effective graphical user interfaces, and finally the decision-support tools can make the decision-making task more convenient for engineers. In fact with an ideal integration of the today's already existing resources of CAD, CAE, and optimization tools achieving the promising results can be more convenient for engineers. Pursuing the proposed design strategy in this thesis has shown promising results in shape optimization applications. Furthermore consideration of the different combinations of CAD, CAE and optimizer in order to find the ideal combination of tools for a particular engineering design application, in this case; fluid dynamics optimal design, has been easier facilitated.

Concerning the dimensionality which is often the case in optimal engineering design; it is discussed that in today's ever increasing design complexity, by extension the dimension of MCDM problems which is mostly due to increasing the number of variables, optimization objectives, and decision criteria, presenting a decision-maker with numerous representative solutions on a multidimensional Pareto-optimal frontier is way complicated and not practical indeed. In this thesis in order to deal with the dimensionality firstly a supplementary decision-support system on the basis of classification task of data mining is proposed. This technique has been shown to be effective in reducing the design space by ranking the importance of the design variables according to the objectives. The considered case studies in shape optimization have proved the simplicity and the effectiveness of the proposed technique in the real-life industrial application. Secondly, as a potential replacement to evolutionary and interactive algorithms, for today's large-scale optimal engineering design problems, the reactive search optimization strategy in the framework of an integrated design environment is proposed where the brain-computer interactions and advanced multidimensional visualization tools can well deal with dimensionality and computational costs in tough decision-making tasks. Consequently the promising achieved results from solving a number of demanding case studies have shown the effectiveness of the approach in dealing with dimensionality.

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