MULTIPLE CRITERIA DECISION MAKING INTEGRATED WITH MECHANICAL MODELING OF DRAPING FOR MATERIAL SELECTION OF TEXTILE COMPOSITES

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Abstract

For the optimal design of composites, with the aid of advancement of interdisciplinary and data analysis tools, a series of criteria including mechanical, electrical, chemical, cost, life cycle assessment and environmental aspects are now able to be simultaneously considered. As one of the most efficient approach, the MCDM applications can provide the ability to formulate and systematically compare different alternatives against the large sets of design criteria. However, the mechanical behavior of woven textiles during the draping process has not been yet fully integrated to the optimal design approaches of MCDM algorithms.

In this article the criteria of mechanical behavior of the woven textile during the draping and the further involved simulations and analysis are included in the process of the optimal design and decision making. For this reason an advanced software architecture for interactive optimization and MCDM is utilized. In this software the identified challenges of utilizing MCDM are improved via connecting the data mining/visualization and optimization through the user interaction.

1 Introduction

In the integrated engineering design process and optimal design, the material selection for the composite can determine the durability, cost, and manufacturability of final products [1,2]. The process of material selection begins with indentifying multiple criteria properties of mechanical, electrical, chemical, thermal, environmental and life cycle costs of candidate materials [3]. However, the mechanical behavior of woven textiles during the draping processes has not been yet fully integrated to the MCDM algorithms.

1.1 MCDM for Material selection

When multiple criteria from different disciplines are to be satisfied in a material selection problem, often because of the criteria conflicts the complexities are increased. Many applications and algorithms of MCDM [3] have been previously presented to deal with decision conflicts often seen among design criteria in material selection. However many drawbacks and challenges are identified associated with the applicability [6].

2 Draping

The manufacturing of woven reinforced composites requires a forming stage so called draping in which the preforms take the required shapes. The main deformation mechanisms during forming of woven reinforced composites are compression, bend, stretch, and shear which cause changes in orientation of the fibers. Since fiber reorientation influences the overall performance it would be an important factor that along with the other criteria, should it be taken into account.

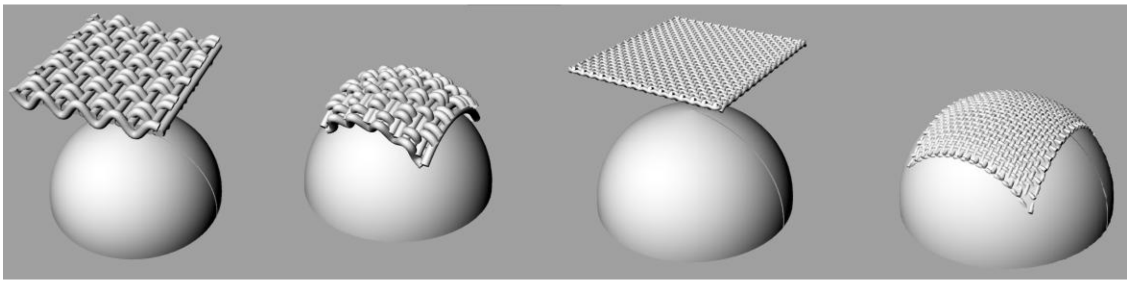

Figure 1. Simulation of the draping process

2.1 Mechanical modeling and simulation of the draping

The mechanical models of drape with a much higher computation cost, comparing to the kinematic models, offer the benefit of representing the non-linear material behavior. Moreover the mechanical simulation, as the most promising technique, gives a real-life prediction of the fiber reorientation.

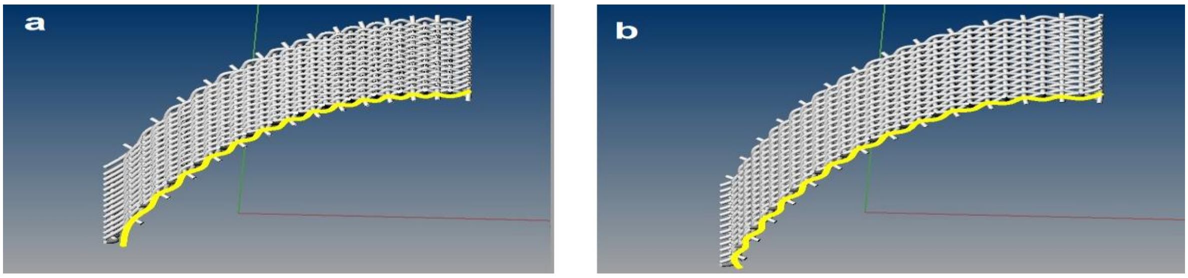

Figure 2. A combination of four different simulation criteria including the compression, bend, stretch, and shear form the draping a) Mechanical modeling of the bending; the behavior of textile under its weight is simulated by manipulating the related geometrical model within the CAGD package. b) Geometrical model

2.2 Geometrical modeling and simulation of the woven textiles

Beside of all presented approaches to the geometrical modeling of woven textiles so far [7], the Spline-based methods have been the most effective technique [7]. In fact, the Spline-based geometrical representation of a real-life model of any type of the flat-shaped woven textile, are done with implementing the related computer aided geometrical design (CAGD) code. However the mathematical representation of a woven multiple-dome shaped, in the practical scale, could not be computationally valid.

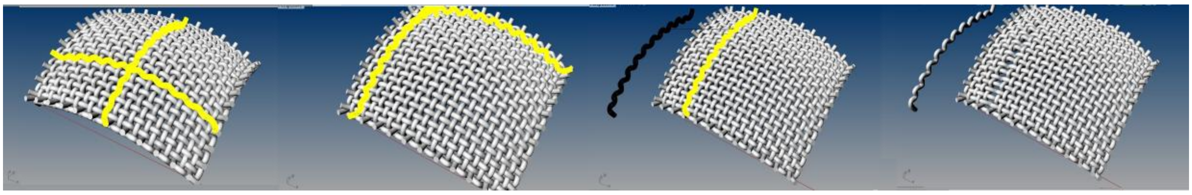

Figure 3. Geometrical modeling of double dome utilizing the Khabazi [11] algorithm.

In order to handle the computational complexity of geometrical modeling the multiple-dome woven shapes, utilizing the NURBS-based CAGD packages are essential. Khabazi [10] introduced a *generative algorithm* for creating these complex geometries. His improved algorithm is capable of producing the whole mechanism of deformation with combining all details of compressed, bended stretched and sheared properties. It is assumed that if the mechanical behavior of a particular woven fabric of a particular type and material is identified then the final geometrical model of the draping could be very accurately approximated. In this technique the defined mechanical mechanisms of a particular material, in this case glass fiber [8], are translated into a geometrical logic form integrated with the NURBS-based CAGD package through a process called *scripting* [10].

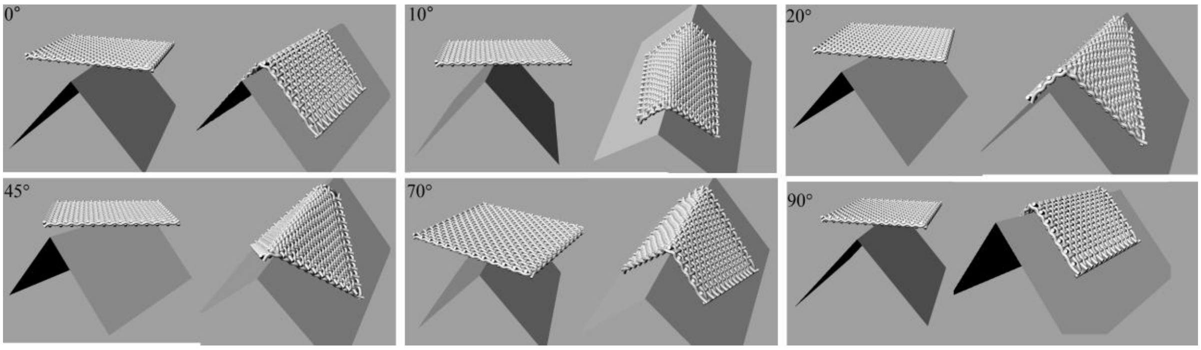

Figure 4. Mechanical modeling of draping process for a number of draping degrees

3 Integration the MCDM-assisted material selection with draping simulation

In order to select the best material of a woven textile, the draping simulation needs to be carried out for a number of draping degrees. The results of all the draping simulations of different drape angles are gathered as a data-set for consideration, in addition to already existed data-sets from the earlier study case[3], including the latter criteria i.e. mechanical, electrical, chemical, cost, life cycle assessment and environmental.

3.1 Visualization; an effective approach to MCDM and material selection

Visualization is an effective approach in the operations research and mathematical programming applications to explore optimal solutions, and to summarize the results into an *insight*, instead of numbers [4,5]. Fortunately during past few years, it has been a huge development in combinatorial optimization, machine learning, intelligent optimization, and reactive search optimization (RSO), which have moved the advanced visualization methods forward [6].

Previous work in the area of visualization for MCDM [6] allowed the user to better formulate the multiple objective functions for large optimization runs. Alternatively in our research utilizing RSO [9], which advocates *learning for optimizing*, the algorithm selection, adaptation and integration, are done in an automated way and the user is kept in the loop for subsequent refinements [3]. Here one of the crucial issue in MCDM is to critically analyzing *a mass of tentative solutions*, which is visually mined to extract useful information. Concerning solving the MCDM problems the final user is not distracted by technical details instead concentrates on using his expertise and informed choice among the large number of possibilities.

3.4 Software architecture of the proposed reactive and interactive MCDM

The proposed software is based on a three-tier model, independent from the optimization package, called *Grapheur* [9] which is an effective and flexible software architecture for integrating problem-solving and optimization schemes into the integrated engineering design processes and optimal design, modeling, and decision-making. The software is implemented an strong interface between a generic optimization algorithm and decision maker. While optimization systems produce different solutions, the decision maker is pursuing conflicting goals and tradeoff policies represented on the multi-dimensional graphs.

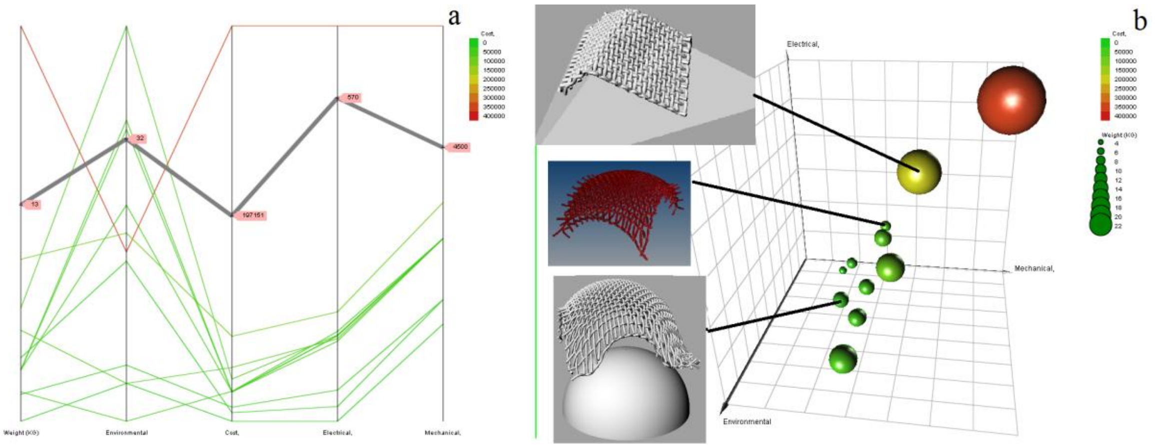

Figure 5. a) Paralel chart considering five optimization objectives b) The 7D visualization graph

4 Conclusions

The utilization of a software architecture for MCDM, including the mechanical modeling the draping, with a particular emphasis on supporting flexible visualization is discussed. The applicability of software can be easily customized for different problems and usage contexts.

The preliminary tests of the software environment in the concrete context of designing a multiple dome shape have shown the effectiveness of the approach in rapidly reaching a design preferred by the decision maker.

References

[1] Ashby M. *Materials selection in mechanical design*. Butterworth-Heinemann, Burlington (1999).
[2] Jahan A., Ismail M. Y., Sapuan S. M., Mustapha F. Material screening and choosing methods – A review. *Materials and Design*, **31**, pp. 696–705 (2010).
[3] Milani, A. S., Eskicioglu C., Robles K., Bujun K., Hosseini-Nasab H. Multiple criteria decision making with life cycle assessment for material selection of composites. *eXPRESS Polymer Letters*, **5**, pp. 1062–1074 (2011).
[4] A.M. Geoffrion. The purpose of mathematical programming is insight, not numbers. *Interfaces*, **7**, pp. 81–92 (1976).
[5] C.V. Jones. Feature Article–Visualization and Optimization. *INFORMS Journal on Computing*, **6**, pp. 221-229 (1994).
[6] Piero P., Subbu R., Lizzi J. MCDM: A framework for research and applications. *IEEE Computational Intelligence Magazine*. **4**, pp. 48–61(2009).
[7] Vassiliadis, S., Kallivretaki, A. and Provatidis, C., Mechanical modelling of multifilament twisted yarns. *Fibers and Polymers*, **11**, pp. 89-96 (2010).
[8] Komeili M., and Milani A. S. *Finite Element Modeling of Woven Fabric Composites at Meso-Level Under Combined Loading Modes* in “Advances in Modern Woven Fabrics Technology”, edited by Vassiliadis S. INTECH, Croatia, pp. 66-77 (2011).
[9] Battiti R., Brunato M. Mascia F., Reactive Search and Intelligent Optimization. *Operations research/Computer Science Interfaces*. Springer Verlag, (2008).
[10] Khabazi Z., *Generative algorithms concepts and experiments weaving*. Morphogenesism, London (2010).