Doctoral Dissertation Review

Candidate: Zhenghui Lu

Title: Data-Driven Personalized Lattice Footwear Design and Biomechanical Optimization Doctoral school: University of Pannonia, Doctoral School of Chemical Engineering and Material Sciences

Supervisors: Dr. habil. Gusztáv Fekete and Dr. András Kovács

Reviewer: Yan Zhang (Faculty of Sports Science, Ningbo University, China)

1. Overall Evaluation

This doctoral dissertation, entitled "Data-Driven Personalized Lattice Footwear Design and Biomechanical Optimization," investigates the integration of biomechanics, finite element analysis, additive manufacturing, machine learning, and personalized footwear engineering within a unified research framework. The study establishes a complete closed-loop workflow encompassing individualized foot-data acquisition, parametric lattice modeling, finite element simulation, machine-learning-based optimization, and experimental validation through 3D-printed prototypes.

The dissertation addresses a highly relevant and timely topic. Conventional footwear design is largely dependent on empirical material tuning and standardized structural configurations, which cannot adequately accommodate inter-individual differences in cushioning, stability, and propulsion requirements. By introducing a personalized lattice-based footwear design methodology driven by dynamic gait characteristics, the candidate responds effectively to emerging trends in intelligent sports equipment, personalized manufacturing, and biomechanical optimization.

The overall structure of the dissertation is logical and coherent. The research progresses systematically from biomechanical background and footwear theory to modeling, simulation, optimization, and experimental validation. The English writing is professional and technically accurate, while the figures and tables effectively support the interpretation of the findings.

2. Major Contributions and Innovations

2.1 Establishment of a Parametric Lattice Design Framework

The dissertation develops a multidimensional parametric lattice modeling framework integrating unit-cell topology, strut thickness, porosity, and spatial orientation. This framework enables programmable control of footwear mechanical behavior through structural geometry rather than material composition alone. The work represents an important conceptual shift from traditional material-based footwear design toward geometry-driven functional regulation.

2.2 Development of a Region-Specific Midsole Design Strategy

The candidate proposes a region-specific lattice midsole design approach based on the functional demands of different gait phases, including rearfoot cushioning, midfoot stabilization, and forefoot propulsion. Furthermore, the dissertation introduces the concept of dynamic functional coupling among different plantar regions, demonstrating strong system-level understanding of lower-limb biomechanics.

2.3 Dynamic-Gait-Driven Multiobjective Optimization

A major strength of the dissertation is the integration of individualized gait data, finite element simulation, and machine-learning surrogate models into a unified optimization framework. Compared with conventional static-loading approaches, this methodology better reflects authentic gait conditions and allows simultaneous optimization of cushioning, stability, and propulsion performance.

2.4 Cross-Scale Biomechanical Validation

The study systematically validates the biomechanical effectiveness of the optimized lattice structures through material testing, finite element validation, plantar-pressure experiments, and gait biomechanics analysis. The dissertation successfully establishes a mapping relationship between microstructural lattice parameters and macroscopic human movement performance.

3. Limitations and Suggestions

3.1 Further Clarification of the Theoretical Significance of Dynamic Gait-Driven Design

The theoretical advantages over conventional static-loading optimization approaches could be more explicitly articulated. The candidate is encouraged to further discuss the broader implications of dynamic gait-driven design for future personalized footwear development, particularly how this approach may facilitate the transition from static, experience-based optimization toward function-oriented design under authentic movement conditions, as well as its potential significance for digitalized, personalized, and intelligent footwear manufacturing.

3.2 Greater Consistency in the Use of Core Terminology

Several terms, including "functional chain," "functional coupling," "regional synergy," and "dynamic coordination," are used throughout the dissertation to describe the cooperative interactions among different footwear regions. However, the usage of these concepts partially overlaps across chapters. The candidate is encouraged to establish clearer and more unified definitions of these key terms and to include concise terminology explanations in the Introduction or Discussion sections in order to improve conceptual clarity and theoretical consistency.

3.3 Engineering Translation and Implications for Digital Manufacturing Could Be Further Elaborated

The dissertation has already addressed applications related to personalized footwear, sports-performance enhancement, and rehabilitation. Nevertheless, the engineering and translational significance of the proposed framework could be summarized more explicitly. The candidate is encouraged to further clarify, in the Conclusions or Future Work sections, the advantages of the proposed framework over conventional footwear development workflows, as well as its implications for future digital footwear manufacturing, on-demand production, and intelligent wearable systems, thereby further highlighting its industrial relevance and application potential.

3.4 Generalizability of the Findings Requires Further Validation in Future Studies

Most experimental validations in the dissertation were conducted using a single participant or relatively small sample sizes. This design is appropriate for methodological and proof-of-concept studies because it minimizes the influence of inter-subject variability during framework validation. However, the applicability of the proposed lattice-footwear structures across different foot morphologies, gait patterns, and pathological populations should be further investigated in future studies involving larger cohorts to strengthen the generalizability and potential clinical relevance of the findings.

4. Questions for the Candidate

1. The current study mainly relies on a single-participant design. How would the optimization framework adapt to variability in foot morphology, gait patterns, and pathological conditions in future large-scale studies?

2. Lattice structures may experience fatigue damage and mechanical degradation under long-term cyclic loading. How do you evaluate the reliability of the proposed footwear design during prolonged real-world use?

3. The current machine-learning optimization framework is mainly trained using finite element simulation data. How can its generalizability be improved for broader populations and more complex movement conditions?
4. The manufacturing time of the current 3D-printed footwear remains relatively long. Which advancements in additive manufacturing technologies or materials do you believe are most promising for industrial-scale implementation?

5. Final Recommendation

Overall, this dissertation presents a clear research objective, a well-structured technical workflow, advanced methodologies, and substantial originality. The work makes meaningful contributions to parametric lattice design, gait-driven optimization, and personalized footwear biomechanics, demonstrating the candidate's strong interdisciplinary research capability.

The dissertation meets the requirements for the degree of Doctor of Philosophy and is recommended for acceptance.

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