REVIEW OF THE DOCTORAL DISSERTATION

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: Gusztáv Fekete and András Kovács

Reviewer: Sándor Manó (Department of Mechanical Engineering, Faculty of Engineering, University of Debrecen)

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1. Summary of the dissertation

This dissertation presents a comprehensive, closed-loop framework for the design, optimization, and validation of personalized footwear. The core of the research is the use of parametrically defined lattice structures, which allow for the fine-tuning of mechanical properties through geometry rather than material composition alone.

The candidate addresses the principal limitations of conventional footwear design—namely, its reliance on static, "average-foot" models and localized optimization—by developing an integrated, data-driven pipeline. This workflow begins with individual-specific data acquisition (3D foot scanning, dynamic gait analysis), proceeds to Finite Element Analysis, employs machine learning for multiobjective optimization, and culminates in the fabrication (3D printing) and experimental validation of a physical prototype.

The research successfully demonstrates that this framework can generate footwear that systematically improves key biomechanical functions—rearfoot impact absorption, midfoot stability, and forefoot propulsion—concurrently. The findings are validated through both objective biomechanical measurements and subjective user feedback, confirming the real-world efficacy of the computationally derived design.

2. Strengths of the dissertation

The dissertation is of exceptional quality and demonstrates a mastery of a complex, interdisciplinary field. Its primary strengths are:

Content:

The topic is highly innovative and addresses a critical need in biomechanics, sports science, and clinical orthotics. The development of an end-to-end, dynamic-gait-driven optimization framework represents a substantial and original contribution to the field, moving it from empirical design towards a paradigm of personalized, computer-based engineering.

The "closed-loop" methodology is a standout feature. The integration of experimental data, advanced simulation (FEA), and intelligent optimization (ML) into a unified workflow is executed with remarkable thoroughness. This approach provides a robust and replicable blueprint for future research in personalized wearable technology.

The work is impressively multiscale. It successfully connects the micro-level mechanics of lattice unit cells to the macro-level performance of the entire lower-limb kinetic chain and the subjective experience of the user. This holistic perspective is rare and adds significant depth to the analysis.

The candidate's extensive list of publications in high-impact, peer-reviewed journals provides powerful external validation of the quality, novelty, and significance of this research.

The discussion chapter is not merely a restatement of the results. It provides a sophisticated synthesis of the findings, thoughtfully exploring concepts like "functional coupling," "regional synergy," and the system-level implications of the design. The inclusion of a self-aware and well-argued limitations further strengthens the work.

Form:

The dissertation is perfectly organized. The chapters flow logically from background and theory to methods, results, and interpretation. The complex methodology is explained with clarity and precision, making the work accessible despite its technical depth. The figures, tables, and diagrams are of professional quality, well-labeled, and effectively used to illustrate complex data and concepts.

3. Weaknesses and areas for improvement

The dissertation has very few weaknesses, and those that exist are largely inherent to the practical constraints of doctoral research. The candidate acknowledges most of these in the limitations section.

- The primary limitation is the use of a single participant for the in-depth validation study. While this case-study approach is well-justified for demonstrating the proof-of-concept and validating the methodology by minimizing inter-subject variability, it naturally limits the statistical generalizability of the specific footwear prototype's effectiveness across a broader population.
- The study focuses on the immediate biomechanical performance of the prototype. The long-term durability of the TPU-based lattice structures under high-cycle fatigue (i.e., months of daily use) is not assessed. This is a crucial consideration for real-world application but falls outside the scope of this foundational work.
- The document contains several formatting and typo errors (i.e. many orphan and widow lines, large white-space imbalance).

4. Evaluation of the thesis points

The dissertation presents five central thesis points, which serve as the core claims of the work. My evaluation is as follows:

- **Thesis Point 1 (Programmable Parametric Lattice Modeling Framework):** This point is convincingly established. The dissertation clearly details the development of a multiparameter framework and uses simulation data to demonstrate its ability to modulate mechanical properties across a wide spectrum. **This thesis is acceptable.**

- **Thesis Point 2 (Region-Specific Midsole Design and Coupling Mechanism):** This point is wellsupported by both the design methodology and the results. The concept of a "continuous functional chain" is a key theoretical contribution, and the discussion effectively elucidates the dynamic coupling between different footwear regions. **This thesis is acceptable.**

- **Thesis Point 3 (Dynamic-Gait-Driven Multi-Objective Optimization):** The successful implementation and validation of the FEA-ML optimization loop provides strong evidence for this claim. The ability to use dynamic gait data to drive the design process is a major innovation. **This thesis is acceptable.**

- **Thesis Point 4 (Systematic Validation and Cross-Scale Mapping):** The experimental results, which show strong concordance with simulation predictions and demonstrate clear biomechanical and subjective benefits, fully support this point. The link between microstructural geometry and human-scale movement is successfully demonstrated. **This thesis is acceptable.**

- **Thesis Point 5 (Engineering Potential and Generalizable Workflow):** The dissertation makes a powerful case for the broad applicability of the framework to athletics, clinical orthotics, and other wearable systems. The work serves as a robust proof-of-concept for a new generation of personalized, on-demand manufacturing. **This thesis is acceptable.**

All five thesis points are well-defended, supported by rigorous research, and represent significant contributions.

5. Questions for the Doctoral Candidate

1. Your validation was based on a single-subject design, which was effective for validating the framework itself. If you were to design a follow-up study with a cohort of 50 individuals, how would your data-driven workflow adapt?

2. The printing time of approximately 50 hours per shoe is a practical barrier to on-demand commercialization. Based on your knowledge of additive manufacturing, what are the most promising advancements in materials or printing technologies that could drastically reduce this time while maintaining the required geometric precision and mechanical properties?

6. Summary and recommendation

This dissertation is a work of outstanding scholarship. It is ambitious in scope, methodologically rigorous, and highly original. The candidate has not only demonstrated a deep understanding of a complex, multidisciplinary field but has also made a significant and validated contribution to it. The research is of a quality that far exceeds the standard requirements for a doctoral degree.

I unequivocally recommend that this dissertation be accepted as the basis for the award of a Doctor of Philosophy degree following the defence.

Debrecen, 29-05-2026

Sándor Manó