

Dear Professor Zhang Yan,

I hope this message finds you well.

I would like to sincerely thank you for your careful review of my doctoral dissertation and for your positive evaluation. I am grateful for your recognition of the research framework, methodological integration, parametric lattice design, dynamic-gait-driven optimization, and cross-scale biomechanical validation presented in the dissertation. At the same time, your suggestions regarding the clarification of theoretical significance, consistency of core terminology, engineering translation, and validation of the generalizability of the findings are highly valuable for further refining my research thinking and guiding my future research directions.

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?

The final physical wearable validation in this study was mainly conducted with a healthy male participant. Therefore, from the perspective of experimental validation, the sample size is indeed limited. However, the computational framework of this study is not based on a fixed footwear geometry or fixed structural parameters. Instead, it is based on personalized modeling and optimization using individual foot morphology, plantar pressure, ground reaction forces, and gait kinematic data. In addition to the healthy participant, the dissertation also included a flatfoot participant and a participant with Becker muscular dystrophy accompanied by pathological flatfoot for subject-specific finite element modeling and structural optimization. Therefore, at the methodological level, the framework has a foundation for extension to different foot types, gait patterns, and pathological conditions.

In future large-scale studies, the participant sample size could first be expanded to include populations with different arch heights, foot widths, body masses, soft-tissue thicknesses, ages, movement habits, and pathological conditions, thereby establishing a richer population-level database of foot morphology and gait characteristics. Second, variables such as three-dimensional foot scans, plantar-pressure distributions, ground reaction forces, joint angles, and joint moments could be used as individualized inputs, enabling the generation of lattice midsole parameters matched to the biomechanical characteristics of each participant. In terms of optimization strategy, two levels of models could be established simultaneously: population-level design rules and individual-level parameter optimization. The former would be used to summarize common design principles across different populations, while the latter would be used for precise structural regulation for specific individuals.

In the future, this framework could therefore be further developed from the current proof-of-concept personalized design method into a more generalizable design system applicable to different foot morphologies, gait patterns, and clinical populations.

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?

I fully agree that fatigue performance and structural reliability under long-term cyclic loading

are critical issues that must be addressed before 3D-printed lattice footwear can move toward real-world application. To be frank, the present study is still at an early stage of methodological validation and prototype development. Its main focus is to establish a closed-loop workflow linking parametric lattice design, finite element analysis, machine-learning-based optimization, and short-term gait validation. Therefore, the TPU material used in this study was mainly selected for prototype fabrication and laboratory validation, and the issues of material fatigue, aging, wear, and structural degradation during long-term daily use were not systematically considered.

For long-term real-world use, the material system and manufacturing process would need to be further upgraded. The material used in the present study is not necessarily the final industrial material most suitable for prolonged wear. In future work, it could be replaced by 3D-printable footwear materials with better fatigue resistance, more stable rebound performance, stronger wear resistance, and improved long-term durability, such as higher-performance TPU, E-TPU, elastic photopolymer materials, multi-material elastomers, or industrial-grade footwear printing materials. For the design framework proposed in this dissertation, changing the material would not alter the overall methodological logic. It would only require re-acquiring the mechanical parameters, compression behavior, rebound performance, fatigue life, and printing accuracy data of the new material, and then incorporating these new parameters into the finite element model and the machine-learning training database. The surrogate model could then be retrained, and a new round of structural optimization could be performed.

Therefore, I believe that the main contribution of the present study is not to prove that one specific material is already sufficient for long-term wear, but rather to propose a parametric design and optimization framework that can be extended to different material systems. When higher-performance materials are adopted, the framework can continue to operate by supplementing the material parameters and experimental data, and can generate lattice structural designs suitable for the characteristics of the new materials. Future studies should include high-cycle compression tests, repeated bending tests, long-duration walking or running wear tests, and damage observations of lattice struts, nodal connections, and interlayer printed structures. The evaluation metrics should include stiffness degradation, changes in energy absorption capacity, changes in rebound performance, permanent deformation, crack initiation, and whether the plantar-pressure regulation effect decreases with usage time.

As far as I know, there are already many footwear-related 3D-printing factories and companies in China that are capable of producing 3D-printed shoes or footwear components with relatively good durability. This suggests that, from the perspectives of manufacturing capability and material application, durable 3D-printed footwear already has a practical foundation. In the future, combining these more mature industrial materials and manufacturing processes with the biomechanical optimization algorithm proposed in this dissertation would help promote the transition of this framework from laboratory prototypes to long-term wear and practical application.

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?

Thank you for this question. The current machine-learning optimization framework is mainly trained using finite element simulation data because finite element simulation allows systematic

exploration of a large structural design space under controlled conditions and provides relatively stable and interpretable mechanical outputs for different lattice parameters. I also agree that relying only on finite element data may limit the model's generalizability to real human movement, complex motion scenarios, and broader populations.

In the future, the generalizability of the model could be improved through a hybrid data strategy combining finite element simulation data, experimental mechanical data, and real human gait data. Finite element simulation data could continue to be used to cover a wide range of lattice parameter combinations and boundary conditions, thereby providing fundamental training samples for the machine-learning model. Experimental compression tests, bending tests, and real wearable validation data could be used to correct the discrepancy between finite element predictions and actual structural performance. Human gait data from larger samples could further improve the model's adaptability to different foot types, body masses, gait strategies, and pathological conditions.

In future work, cross-subject validation, uncertainty quantification, active learning, transfer learning, and physics-informed machine learning could be introduced. Cross-subject validation could examine whether the model depends excessively on data from a specific type of participant. Uncertainty quantification could help identify design regions where model predictions are unreliable. Active learning could guide subsequent finite element simulations or experiments to prioritize the most informative data points. Transfer learning could be used to transfer models trained on healthy populations to flatfoot, diabetic foot, or neuromuscular disease populations. Physics-informed machine learning could prevent the model from generating predictions that are inconsistent with mechanical principles or biomechanical logic.

In addition, future datasets should be expanded from steady walking to running, turning, uphill and downhill walking, uneven-terrain locomotion, post-fatigue gait, and high-intensity movement tasks. This would allow the optimization framework to be applicable not only to standard laboratory gait conditions but also to more complex loading patterns in real movement environments.

The key to improving the generalizability of the machine-learning framework lies in expanding data sources, strengthening experimental calibration, introducing physical constraints, and continuously validating the model across more populations and movement tasks.

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?

In the present study, FDM printing was adopted mainly because the equipment is accessible, the material selection is flexible, and it is suitable for fabricating TPU lattice footwear research prototypes. However, FDM printing is relatively slow, especially when manufacturing a complete lattice midsole or full-shoe structure, and it is indeed difficult for it to directly meet the requirements of industrial-scale production. Therefore, manufacturing efficiency is an important issue that must be addressed for future engineering translation. In my opinion, the most promising directions for promoting industrial-scale implementation mainly include 3 aspects:

First, the development of high-throughput additive manufacturing technologies is essential. Technologies such as Digital Light Synthesis, selective laser sintering, Multi Jet Fusion, high-speed vat photopolymerization, multi-nozzle parallel printing, and continuous printing systems may substantially shorten manufacturing time while improving printing accuracy and batch-to-batch consistency. Compared with traditional FDM, these technologies are more suitable for the efficient

production of complex lattice structures.

Second, the development of high-performance elastomeric materials is also crucial. Lattice footwear requires materials not only to be printable, but also to possess good rebound performance, fatigue resistance, wear resistance, and long-term stability. In the future, the development of high-rebound TPU, E-TPU, flexible photopolymer resins, multiphase elastomers, and multi-material composite systems will help improve the performance and service life of 3D-printed footwear in real-world use.

Third, the design and manufacturing workflow should be further optimized. Future industrial products may not need to print the entire shoe as a fully complex lattice structure. Instead, a hybrid manufacturing strategy could be adopted. For example, 3D-printed lattice structures could be used only in key functional regions, such as the rearfoot, arch, or forefoot, while the upper, outsole, or non-critical support regions could still be manufactured using conventional high-efficiency processes. Manufacturing time and cost could also be reduced through local lattice design, modular midsole components, structural simplification, automated slicing, automated support removal, and digital production lines.

I believe that the most realistic pathway toward industrialization is not to rely solely on a single printing technology, but to combine high-speed additive manufacturing, high-performance elastomeric materials, localized functional lattice design, and hybrid manufacturing workflows. In this way, the biomechanical advantages of personalized lattice structures can be preserved, while production efficiency can be improved and manufacturing costs can be reduced.

Conclusion

Once again, I sincerely thank Professor Zhang Yan for the careful review of my doctoral dissertation and for the constructive suggestions. Your comments have made me more clearly aware that future research should be further deepened in the following aspects: expanding the sample size to verify the generalizability of the findings, conducting long-term fatigue and real-world wear reliability studies, improving the generalizability of machine-learning models under complex populations and movement conditions, and further exploring the engineering translation and industrial implementation of 3D-printed lattice footwear.

These suggestions are highly valuable for my future research on personalized footwear, biomechanical optimization, intelligent wearable systems, and digital manufacturing.

Yours sincerely,

Lu Zhenghui

Lu Zhenghui