Development of a Procedural CAD Pipeline for Biometric-Based Impact Mitigation and Rotational Force Support

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Introduction: Standard athletic head protection utilizes Expanded Polystyrene (EPS) foam, which lacks the non-linear compression properties necessary for biometric tuning. Prompted by the researcher’s experience with a traumatic brain injury (TBI), this project sought to engineer a "Smart Liner" system. The goal was to develop a procedural CAD pipeline to bridge the gap between individual biometric data and mechanical impact protection. Methodology: A custom software-to-hardware pipeline was developed using Python to calculate optimal lattice parameters based on mass inputs, integrated into a parametric OpenSCAD library. Prototypes were fabricated via Fused Filament Fabrication using Thermoplastic Polyurethane (TPU 95A). Evaluation involved standardized coupon testing using a compression rig. Static load analysis and digital calipers were used to measure displacement, specifically evaluating energy dissipation through coordinated geometric buckling. Results: Data analysis identified 1.8mm as the optimal wall thickness to trigger a constant-force buckling plateau. Unlike EPS foam, which sustains permanent deformation, the TPU lattice utilizes non-linear buckling and lateral shearing. This mechanism extends impact duration, reducing peak acceleration and mitigating the rotational forces frequently associated with concussions. Conclusion: This research demonstrates that protective equipment can be mathematically tailored to individual mass requirements. The pipeline provides a scalable, data-driven alternative to mass-produced foam, offering a personalized approach to reducing injury risks in contact sports.

Awards Won:

Adam R. Scripps Foundation: Cash Award