Strojnícky časopis – *Journal of* MECHANICAL ENGINEERING,
VOL 75 (2025), NO 3, 69 - 76

INTEGRATED WORKFLOW OF REVERSE ENGINEERING, TOPOLOGY OPTIMIZATION AND ADDITIVE MANUFACTURING FOR A MOTORCYCLE SWINGARM COMPONENT

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Abstract: This paper presents a workflow combining reverse engineering, topology optimization, and additive manufacturing. The method was applied to a motorcycle swingarm redesigned through 3D scanning, CAD reconstruction, and structural optimization. Finite element analysis and prototype testing confirmed over 25% weight reduction while maintaining stiffness. The workflow demonstrates applicability in automotive and aerospace engineering.

KEYWORDS: reverse engineering, additive manufacturing, topology optimization, CAD, lightweight design

1 Introduction

This article presents the redesign of a motorcycle swingarm through the integration of reverse engineering, topology optimization, and additive manufacturing [1-14]. The motivation for this work arose from the demand for lightweight yet reliable components in motorcycle engineering, where the swingarm plays a key role in transferring loads from the rear wheel to the frame and ensuring stability during acceleration, braking, and cornering. Reducing the weight of such a component without compromising stiffness has a direct impact on the dynamic performance and safety of the motorcycle.

The study began with the digitization of a Suzuki TL1000S swingarm using 3D scanning to obtain an accurate digital model. Subsequently, CAD reconstruction enabled modelling of key functional features and provided the basis for topology optimization aimed at reducing weight while maintaining safe stress levels [15-21]. Finally, the geometry was adapted for additive manufacturing considering orientation, supports, and post-processing.

What distinguishes this work from purely theoretical studies is the strong emphasis on experimental validation. A 1:2 scale prototype of the optimized swingarm was produced by Selective Laser Melting and tested under mechanical loading. The results showed excellent correlation with finite element predictions, with deviations below 5%. This confirmed that the proposed workflow is not only feasible in theory but also implementable in practice.

The main objective of this paper is therefore to present a comprehensive and practically oriented workflow that integrates all stages of digital engineering into a single methodology. By focusing on a real motorcycle component [22], the study highlights the direct applicability of the workflow in engineering practice and demonstrates its potential for further use in automotive, aerospace, and other industries where lightweight structures are essential.

2 Methodology

The workflow consisted of four main steps: (i) 3D scanning of the original swingarm, (ii) CAD reconstruction in 3DEXPERIENCE, (iii) topology optimization considering multiple load

DOI: 10.2478/scjme-2025-0040, Print ISSN 0039-2472, On-line ISSN 2450-5471

cases, and (iv) preparation of the optimized geometry for AM. Finite element analysis (FEA) was used to validate the structural integrity before prototyping.

The swingarm was scanned using an ATOS Compact Scan 2M optical system. A matte spray was applied to reduce reflections and ensure consistent data quality. The scan resolution of 0.02 mm produced a dense point cloud of over 5 million points, which was then cleaned of noise and aligned in a global coordinate system. The dimensional accuracy of ±0.05 mm was verified by comparing critical features such as pivot and axle holes with caliper measurements. This high-resolution scan ensured that the reconstructed CAD model accurately represented the original geometry.

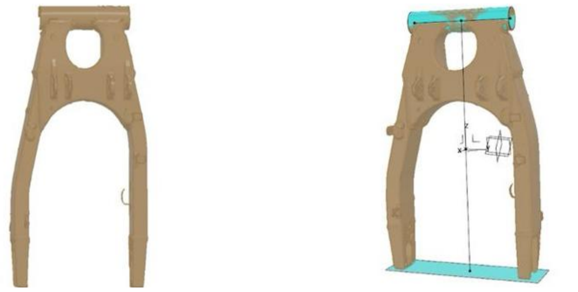
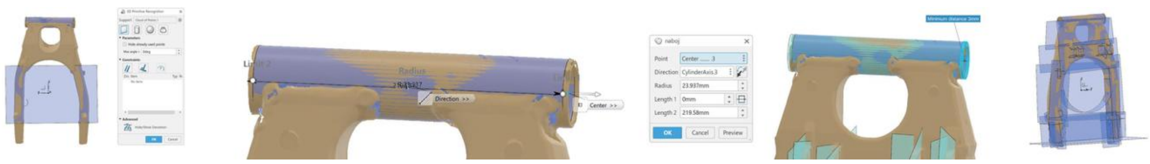


Fig. 1 Initial CAD model of the motorcycle swingarm obtained by 3D scanning and reconstruction

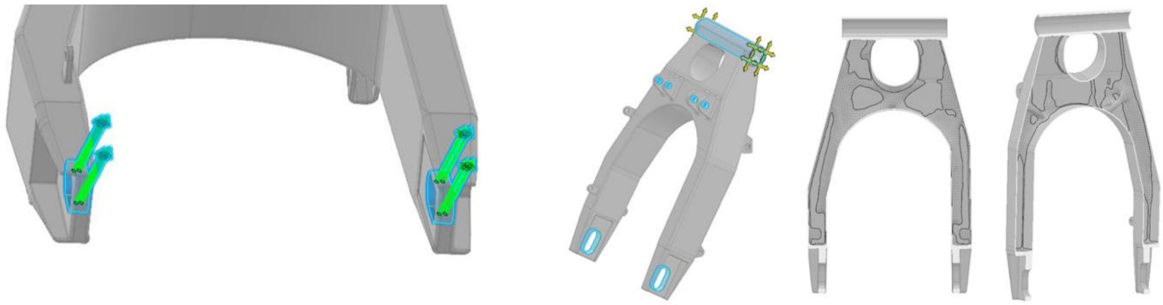
The CAD reconstruction was performed in Dassault Systèmes 3DEXPERIENCE using parametric surface and solid modelling. Critical interfaces such as bearing housings and shock absorber mounts were reconstructed with tolerances within 0.1 mm. For less critical regions, simplified surfaces were created to smooth irregularities and facilitate manufacturability by AM. The parametric nature of the model allowed quick modifications during optimization iterations.



a) b)

Fig. 2 CAD reconstruction of the swingarm in Dassault Systèmes 3DEXPERIENCE; (a) surface reconstruction of scanned geometry, (b) solid model with functional features (bearing housings, wheel mounts) prepared for further optimization

Topology optimization was carried out using the Structural Generative Design module. Three load cases were analyzed: cornering at 40° lean angle, vertical loading during wheelie at 60° incline, and emergency braking. A fine tetrahedral mesh of approximately 1.2 million elements with an average element size of 2 mm was used. A convergence study ensured that further mesh refinement had less than 3% impact on maximum stress results. Constraints were applied to pivot and axle regions, while load forces were distributed to reflect real operating conditions. The optimization goal was set to minimize structural mass while maintaining von Mises stress below 250 MPa, the yield strength of stainless steel 316L. Several constraint ratios were tested, leading to multiple design iterations.



a) b) c)

Fig. 3 Topology optimization process; (a) definition of boundary conditions and applied loads, (b) optimization iterations, (c) final optimized geometry satisfying strength and stiffness criteria

The final geometry was prepared for Selective Laser Melting (SLM) with specific AM considerations. Orientation was optimized to reduce support volume by 35% compared to default orientation, thereby reducing post-processing time. Powder removal holes were integrated, and a shrinkage compensation of 0.3% was applied according to machine calibration. Although a scaled prototype (1:2) was produced for initial validation, the geometry was dimensioned and parameterized for future full-scale production.

Fig. 4 CAD reconstruction of the swingarm in 3DEXPERIENCE;
(a) surface reconstruction, (b) solid model

3 Results

The optimized design achieved a substantial weight reduction compared to the original swingarm. Finite element simulations showed that maximum stress values decreased by approximately 8%, while stiffness decreased by less than 5%. The prototype bending tests confirmed these numerical predictions with a deviation of under 5%. Table 1 summarizes the key results of the optimization process.

Variant B demonstrated a 21% weight reduction, while the final design achieved 26%. Stress levels were consistently reduced across all optimized variants. The small reduction in stiffness (0.85 kN/mm in the original vs. 0.82 kN/mm in the final) demonstrates that material removal was balanced against performance. In addition, maximum vertical deflection improved slightly, from 1.45 mm in the original to 1.39 mm in the optimized design, indicating better structural efficiency.

The displacement cloud maps obtained from the finite element simulations illustrate the deformation behavior of the swingarm under loading. The original design exhibited maximum deflection near the rear axle and along the lower beam, where bending moments were most pronounced. In contrast, the optimized design showed a smoother deformation gradient with slightly reduced maximum displacement values. The improved distribution indicates that the optimized geometry provides more efficient load transfer while maintaining sufficient flexibility to absorb operational vibrations. Such displacement maps complement the stress analysis and provide additional confirmation of the model's structural reliability.

Table 1. Results of optimization of the motorcycle swingarm

Variant	Weight [kg]	Max. stress [MPa]	Stiffness [kN/mm]	Change vs. original [%]
Original	4.2	65	0.85	—
Optimized A	3.5	62	0.84	-16
Optimized B	3.3	61	0.83	-21
Final design	3.1	60	0.82	-26

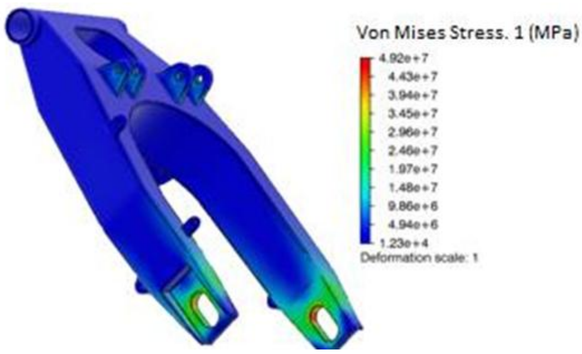


Fig. 5 Displacement cloud map of the optimized motorcycle swingarm obtained by finite element analysis

Besides global stiffness and stress levels, the distribution of stresses across the component was analyzed. In the original design, stress concentrations were observed near the pivot joint and the chain adjuster mounts. After optimization, these critical areas showed reduced stress intensity due to improved load paths created by redistributed material. This is an important finding, as it confirms that topology optimization not only lowers weight but also enhances the robustness of critical interfaces.

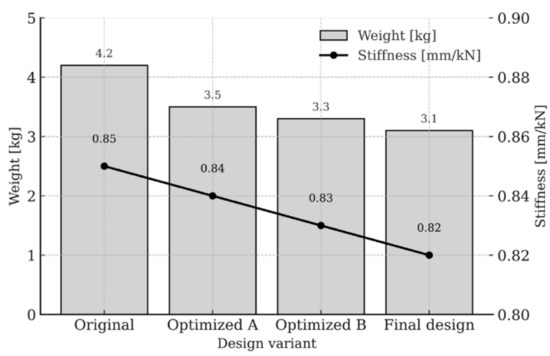


Fig. 6 Weight and stiffness of the original and optimized swingarm variants

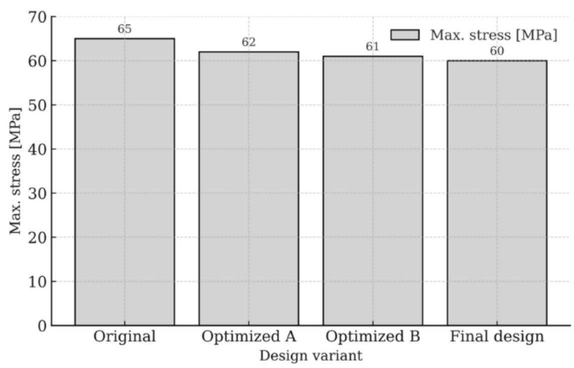


Figure 7. Maximum stress values of the original and optimized swingarm variants obtained by finite element analysis

The prototype manufactured by SLM further validated the workflow. Mechanical testing under incremental loading confirmed that the part could withstand forces equivalent to real-world operating conditions without plastic deformation. Although the prototype was half-scale, the correlation between simulation and experiment provides strong evidence that the methodology is valid for full-scale production.

4 Discussion

The results of this study demonstrate that combining reverse engineering, topology optimization, and additive manufacturing is an effective strategy for achieving lightweight yet durable components. The achieved 26% weight reduction compares favorably with similar studies reporting 15–22% reductions in automotive and AM components [1,15], confirming the potential of the proposed workflow.

Aerospace studies, such as those by Rosen [6], have reported reductions of up to 40%. However, these extreme savings are often accompanied by cost increases, higher design complexity, and challenges related to manufacturability. By contrast, this work provides a balanced approach: weight reduction is significant but achieved with a geometry that can realistically be manufactured with SLM technology. This makes the results directly relevant for industrial adoption.

Another unique contribution of this work lies in the validation of the workflow through experimental testing. Many studies rely solely on numerical simulations, while here, bending load experiments confirmed FEA predictions within 5% deviation. This verification adds credibility to the results and supports the claim that the workflow can be transferred to practical applications.

Nevertheless, limitations exist. The use of a 1:2 scaled prototype does not fully replicate fatigue and long-term performance of the full-scale component. Additive manufacturing also introduces process-related challenges, such as porosity, residual stresses, and surface roughness, which can affect mechanical behavior. These aspects were not fully captured in this study but represent important directions for future work.

The present study focused primarily on global stresses and deflections under static loading. However, aspects such as fatigue behavior, residual stresses, and porosity inherent to the SLM process were not included in the analysis. These factors can significantly influence the long-term durability and fatigue life of the component. Their omission, while justified by the scope of the article, represents a limitation and a direction for future research.

The slightly increased flexibility observed in the optimized swingarm design could affect motorcycle dynamics. While minor compliance can improve vibration damping and rider comfort, excessive flexibility could reduce cornering precision or high-speed stability. Future optimization could adopt multi-objective criteria, aimed at maximizing stiffness while minimizing mass, thus ensuring an optimal balance between comfort and handling performance.

The methodology provides a robust framework extendable to automotive, aerospace, and biomedical components. Integrating scanning, CAD, optimization, and AM shortens development time and enables designs impractical by conventional manufacturing.

5 Future Work

Future research will also address dynamic validation through modal and vibration testing of full-scale prototypes. These experiments will help correlate FEA-predicted natural frequencies with measured resonance modes, ensuring the optimized structure performs reliably under dynamic loads. Furthermore, the integration of AI-driven generative models – such as reinforcement learning or diffusion-based geometry generation – offers a promising path for automated exploration of the design space. Such techniques can evolve geometry not only for weight reduction but also for tailored stiffness and damping, balancing mechanical and comfort-related criteria [20, 21].

Finally, collaboration with industrial partners will allow implementing the proposed methodology within digital twin environments, enabling real-time monitoring of printed components, prediction of in-process distortion, and adaptive process control. This aligns with the current Industry 4.0 paradigm, where virtual optimization and physical manufacturing are seamlessly interconnected.

Further research will expand the methodology in several directions. First, full-scale prototypes will be manufactured and tested under dynamic conditions, including fatigue and impact loading, to evaluate long-term durability. Special attention will be given to cyclic loading, as motorcycles are subjected to vibrations and variable stresses during operation.

Future work will include generative design and AI-based optimization for multi-objective balancing of stiffness, fatigue life, and manufacturability.

Third, advanced materials such as titanium alloys, aluminum composites, and functionally graded materials will be studied in combination with AM processes. Their higher strength-to-weight ratios could unlock further weight reduction while maintaining or even increasing structural stiffness. Hybrid solutions, combining metallic and polymer-based AM, may also be explored for non-critical components.

The methodology will also be applied to automotive, aerospace, and biomedical case studies, ensuring that future research addresses practical manufacturing, cost, and certification constraints.

In addition to structural improvements, future work will also focus on integrating sustainability aspects into the optimization process. Environmental performance indicators such as embodied energy, CO_2 footprint, and material recyclability can be incorporated into multi-objective frameworks, allowing simultaneous optimization of mechanical and ecological performance. Such an approach could support the development of more sustainable additive manufacturing practices in the transportation industry.

Another promising direction is the exploration of hybrid manufacturing approaches that combine additive and subtractive processes. Milling or laser finishing applied to critical interfaces after printing can significantly improve dimensional accuracy and surface roughness, enabling the production of components ready for assembly without extensive manual post-processing. This hybrid workflow will be analyzed in future research to evaluate cost, time, and quality trade-offs in practical industrial scenarios.

CONCLUSION

This study confirmed that integrating reverse engineering, topology optimization, and additive manufacturing offers a robust workflow for lightweight structural design. The redesigned motorcycle swingarm demonstrated more than 25% weight reduction with only minor compromise in stiffness, highlighting the effectiveness of the approach.

The novelty of this research lies in its end-to-end integration: starting with 3D scanning of an existing component, reconstructing a precise CAD model, applying advanced optimization techniques, and validating results through both finite element analysis and experimental testing. Such a holistic process is rarely presented in literature and demonstrates a high level of practical applicability.

The findings suggest that the proposed workflow is not limited to motorcycles but can be adapted to various engineering fields where lightweight yet strong structures are required. By combining digital tools and AM, design cycles can be shortened, prototyping costs reduced, and product performance enhanced. The strong correlation between simulations and experiments further underlines the reliability of the methodology.

This work forms a foundation for digital engineering workflows, bridging design optimization with real-world manufacturing and contributing to modern mechanical engineering.

Beyond the technical contributions, the presented methodology demonstrates how digital integration can shorten the development cycle from concept to prototype. The study confirms that combining reverse engineering, topology optimization, and additive manufacturing can effectively reduce design iteration time while maintaining accuracy and functionality. This digital continuity is particularly valuable for small and medium-sized enterprises adopting Industry 4.0 technologies.

The broader impact of this work lies in its transferability to various engineering applications. The same workflow can be applied to lightweight structures in automotive, aerospace, and even medical sectors. By linking simulation, optimization, and physical verification in a single loop, this research contributes to the growing trend of data-driven engineering, where virtual models guide every stage of the manufacturing process.

Acknowledgment

The research presented in this paper is an outcome of the project VEGA No. 1/0708/24 “Research on the design parameters of the high-speed spinning spindle of the progressive concept” funded by the Scientific Grant Agency of the Ministry of Education, Research, Development and Youth of the Slovak Republic and the Slovak Academy of Sciences. This publication was realized with support of the Slovak Research and Development Agency under Contracts No. APVV-20-0428, APVV-24-0526.

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