TRIPLE-BENEFIT ENGINEERING EDUCATION: SOLVING REAL-WORLD DURABILITY ISSUES IN LIFTING MECHANISMS THROUGH MULTIDISCIPLINARY UNIVERSITY-INDUSTRY COLLABORATION

Wiliam Manjud MALUF FILHO[1], Vinicius Kaster MARINI[2], Mohammad Hossein SHATERZADEH YAZDI[3], Victor de Faria REGENTE[3] and Marcelo Augusto Leal ALVES[1]
[1]Polytechnical School of the University of São Paulo (EPUSP), Brazil
[2]Federal University of Santa Maria (UFSM), Brazil
[3]Centro Universitário FEI, Brazil

ABSTRACT
This technical paper discusses the involvement of engineering student in industrial problem-solving within a collaborative project involving Brazilian universities and a manufacturer of lifting and transport equipment. The company was facing durability issues in one of its key products, which motivated its management to search for academic support to address the fatigue durability problem. The project involved the guidance of four professors from 3 different academic institutions to a Mechanical Engineering student selected to participate in the research project in an extra-class regime applying concepts from Design Methodology, Machine Elements, Solid Mechanics, and, more specifically, the Finite Element Method. These knowledge areas provided the foundation so that the student would be enabled to diagnose and mitigate the root causes of the durability problem. CAD and CAE software were employed as tools for modelling the components, performing structural analysis, and following it up with structural optimisation, leading to an effective solution that met the company's needs. Once the proposed solution was implemented by the equipment manufacturer, the problem expertise was integrated by the research team into the Machine Elements coursework as a way to reinforce the learning experience for Mechanical Engineering students. Students participating in this coursework were then challenged to solve the problem and encouraged to fabricate scaled prototypes using additive manufacturing techniques, such as 3D printing. This approach enabled a deeper understanding of design concepts, enhancing spatial awareness and comprehension of three-dimensional vector phenomena, while promoting problem-based learning and the practical application of theoretical knowledge.

Keywords: Collaborative design education, additive manufacturing, finite element method, industry-academia partnership, human-centred engineering solution

1 INTRODUCTION
The machinery and equipment industry are a strategic sector in Brazil, encompassing a wide range of products, from heavy machinery to cutting-edge technology, all of which are essential for manufacturing and industrial production. The sector directly employed approximately 385,000 individuals in 2023, offering high-value job opportunities with salaries on average 30% higher than the national wage average [1].

In recent years, increasing consumer demand for sustainable practices have driven significant transformations across the industry and its supply chains. Companies in the sector have prioritised the adoption of lighter and stronger materials to reduce environmental impact while enhancing product efficiency. Within this context, material substitution and advancements in component engineering have become essential strategies for improving competitiveness [2].

This paper presents the role of an academy-industry collaborative research project in the area of lifting and transport equipment in supporting knowledge transfer to enhance real-life problem-solving abilities in Mechanical Engineering coursework. This report will first present the collaborative academy-industry

problem-solving effort with the involvement of a single bachelor student under supervision of faculty and then describe the knowledge transfer from the project to bachelor-level coursework.
The company initially faced durability issues with a critical component in its flagship product, illustrated in Figure 1, which required the student involved in the project to engage onto a structured approach to solve the problem. Although the consultancy project led to a recommended technical solution, when incorporated into the classroom context, the challenge was intentionally kept open-ended, allowing students to explore multiple design alternatives and propose their own solutions.

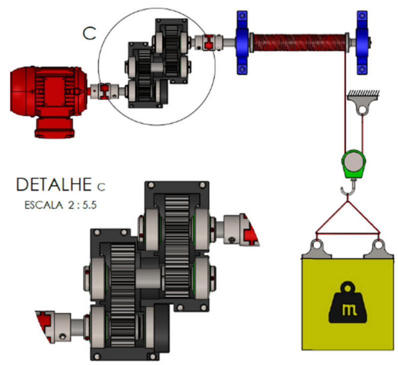

Figure 1. Lifting and transport equipment studied

Seeking an effective solution, the company reached out for technical assistance, thereby enabling a research group to work on the issue. The solution would be delivered at no financial cost to the company, under condition that the findings could be shared with students as part of a Project-Based Learning (PBL) initiative [3]. The project not only provided direct benefits to the company but also contributed significantly to student education, reinforcing an academic approach that integrates theoretical knowledge with hands-on experience.

2 METHODOLOGIES

The methodological approach employed in this study has been performed within following a structured framework, which integrated theoretical analysis, computational modeling, and practical experimentation. The project was conducted in two stages, both involving four key phases. The first stage is the collaborative academia-industry project involving the company (subitems 1 to 3), and the second stage is the knowledge transfer from the project to engineering coursework (subitems 4 to 6).

2.1 Diagnosis and Root Cause Identification

In the beginning of the collaboration project, the client company granted the research team access to its production facility and provided historical data from warranty claims and customer feedback. Additionally, defective components were made available for inspection by the student and the faculty involved in the collaboration project. The research team including the bachelor student conducted a detailed evaluation of the defective component instances using principles from Solid Mechanics [4], Mechanics of Materials [5] and Machine Elements [6]. In parallel, a preliminary failure analysis [7] was performed based on fatigue cycles [8] and the acting stress distributions to identify the root causes of the durability issue [9].

2.2 Computational Modelling and Simulation

The collaboration project proceeded with modelling the designs using Computer-Aided Design (CAD) software (Autodesk Inventor) [10] and performing engineering analysis on them through Finite Element Method (FEM) simulations [11] using Computer-Aided Engineering (CAE) [12] software (ANSYS) [13]. In this task, the student was charged with building the models and performing the work, whereas faculty would support his activity with design checks and model reviews so that to arrive at the intended solution. This stage enabled a precise visualisation of stress distribution and the identification of critical points prone to failure.

2.3 Optimisation and Implementation

Based on the simulation results, the student in charge and the supporting faculty proposed geometric modifications to component designs, alongside the replacement of the original material with high-strength aluminium. Following computational validation of the optimised component geometries through CAE tools, the solution was implemented and tested within the company's operational environment. The results obtained were aligned with the engineering predictions performed by the team and thus confirmed the effectiveness of the proposed action plan, regarding the demonstration of improvement in the durability and performance of the machine.

2.4 Integration into Engineering Education and Practical Application

The project is then incorporated as a Project-Based Learning (PBL) case study into the Machine Elements and Design Methodology courses as an applied learning exercise. Utilising the PBL approach, students were challenged to replicate the study, which included diagnosing the root causes of failure, and proposing alternative solutions regarding their modelling, analysis and prototyping. This hands-on methodology was designed with the intent of fostering the development of analytical skills and reinforcing the application of theoretical concepts in a real-world engineering context.

2.5 Prototyping approach and modelling support

Furthermore, the case study was leveraged to encourage students to engage with maker spaces, by prototyping their solutions through additive manufacturing techniques such as 3D printing. The fabrication of scaled models of the lifting equipment is intended for students to enhance their understanding of the structural behaviour of the mechanism and gain a three-dimensional perspective of stress distribution and load application. To encourage the use of CAD software and enhance students' understanding of the equipment's functionality, the 3D model used in the study is made freely available online for educational purposes [14].

2.6 Provision of supplementary learning resources

As part of the authors' commitment to promoting access to information and inclusion, video lectures related to the respective courses were recorded and made available. These lectures are free and accessible to students as a supplementary learning resource, facilitating content review and fostering autonomy in the learning process. The initiative aims to disseminate scientific knowledge broadly, ensuring that a diverse audience can access fundamental concepts of Mechanical Engineering. Additionally, this effort contributes to academic inclusion, accommodating students with different learning paces and enabling study opportunities beyond regular class hours [15].

3 RESULTS

While technical specifications such as precise geometries, material properties, and load conditions were kept confidential in accordance with the company’s requirements, the general problem statement, functional requirements, and conceptual representation of the lifting mechanism were made freely available to students for educational purposes.

3.1 Winding drum FEA

Structural analyses were performed on the winding drum considering two distinct boundary conditions, each representing different operational loading scenarios. The first configuration (Figure 2) simulated a concentrated load applied at the geometric centre of the drum, representing a scenario in which the lifting force is evenly distributed across the structure. The second configuration (Figure 3) considered a load applied at one of the extremities of the drum, replicating an asymmetric loading condition that may occur due to variations in operational constraints or uneven weight distribution during real-world usage.

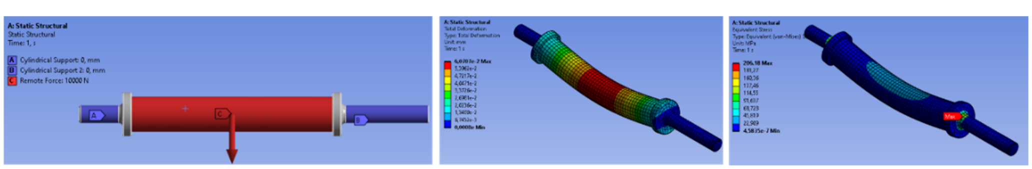

Figure 2. Concentrated load applied at the centre of the winding drum

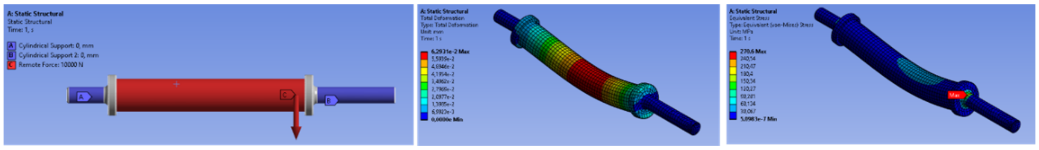

Figure 3. Concentrated load applied at one extremity of the winding drum

For both conditions, finite element analysis (FEA) simulations focused on quantifying total deformation and von Mises equivalent stress, which are critical parameters for assessing the mechanical integrity and failure resistance of the component. By comparing these results across different loading conditions, it was possible to identify potential regions of stress concentration, structural weaknesses, and opportunities for design optimisation to enhance durability and performance.

3.2 Winding drum fatigue life assessment

In addition to the static structural analysis, a fatigue life assessment of the winding drum was conducted to estimate its durability under cyclic loading conditions (Figure 4).

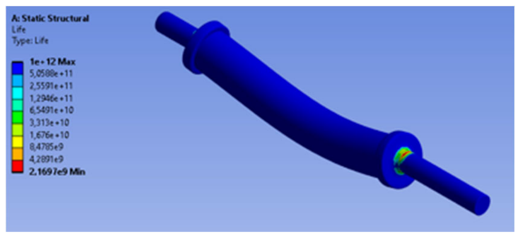

Figure 4. Fatigue analysis of the winding drum

Given that the drum is subjected to repeated load cycles during operation, the analysis considered stress fluctuations, material fatigue properties, and the expected number of load cycles to predict the component's lifespan. By applying fatigue analysis methodologies, it was possible to identify potential failure zones and assess whether the current design meets long-term operational requirements or necessitates further optimisation.

3.3 Gears transmission system FEA

Subsequently, structural analyses were performed on the power transmission system, which is composed of spur gears responsible for transferring mechanical power within the lifting mechanism. At this stage, finite element simulations were conducted to evaluate the total deformation and von Mises equivalent stress within the gear set (Figure 5).

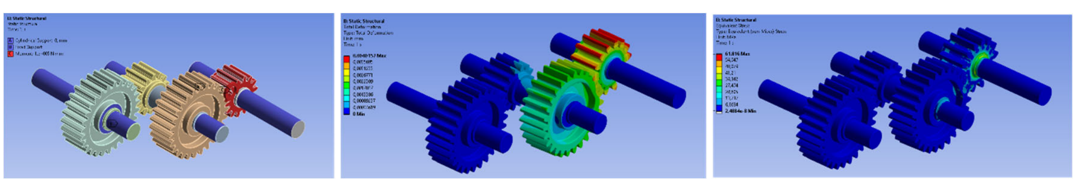

Figure 5. Fatigue analysis of the gearing components

These parameters enabled verifying the structural integrity and load-bearing capacity of the transmission system, guiding potential design improvements to enhance performance and extend service life.
The results demonstrated that material substitution and structural redesign significantly reduced the component's weight without compromising its mechanical strength. The new design met the company's technical specifications and led to an increase in the equipment's service life.

3.4 Knowledge transfer to academic coursework

Furthermore, the collaboration between academia and industry enabled the real-world problem to be integrated into academic activities, fostering a more applied and engaging learning experience. Students were exposed to a real-world engineering challenge, applying theoretical concepts to practical problem-solving. In addition to structural analysis, they were encouraged to fabricate scaled prototypes of the component using additive manufacturing techniques, such as 3D printing (Figure 6).

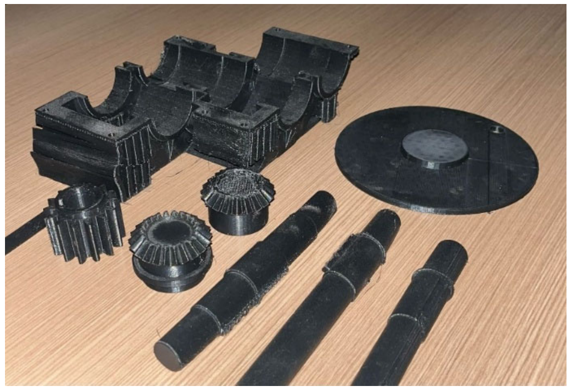

Figure 6. Students' 3D printing trying to assembly the lifting mechanism

This hands-on approach enhanced their physical understanding of the problem, promoting active learning and improving spatial visualisation skills [16].

3.5 Educational Implementation and Student Engagement

The real-world problem was incorporated into both 'Machine Elements' and 'Design Methodology' courses. Although the consultancy project led to a recommended technical solution, when incorporated into the classroom context, the challenge was intentionally kept open-ended – with allowance for students to work with different specifications –, thereby enabling them to explore multiple design alternatives and propose their own solutions.

Students were challenged to analyse the problem, diagnose possible root causes of the failure, and propose their own solutions, independently of the one adopted by the company. The activity fostered creativity, critical thinking, and collaborative work. Furthermore, students were encouraged to use 3D printing to produce scaled prototypes, promoting hands-on learning. The coursework tasks were followed by members of the faculty involved in the project.

Informal feedback collected through classroom discussions revealed that students perceived the activity as highly engaging and valuable for understanding engineering design in real contexts.

4 DISCUSSIONS

The implementation of this project demonstrated the effectiveness of industry-academia collaboration in developing innovative and sustainable solutions. Interdisciplinarity played a key role in the project's success, as the integration of knowledge from multiple engineering disciplines was essential for resolving the durability issues in the lifting mechanism.

Beyond the direct benefits to the company, this initiative also reinforced the importance of problem-based methodologies in engineering education. The inclusion of the case study in the academic curriculum increased student engagement, fostering problem-solving skills and critical thinking [17]. This practical experience not only strengthened the theoretical knowledge acquired in the classroom but also cultivated critical thinking and innovation in solving real-world engineering challenges.

Additionally, the practical experience gained through tackling an industry-relevant challenge provided students with a stronger foundation for the job market, ensuring a more industry-aligned education that better prepares them for real-world engineering demands. The integration of this real-world problem into the curriculum not only provided technical learning outcomes but also fostered soft skills development, such as teamwork, problem-solving, and communication.

Informal classroom observations and student feedback indicated increased motivation and enthusiasm when dealing with authentic industrial challenges. This experience bridges the gap between academic learning and professional engineering practice.

5 CONCLUSIONS

This project illustrates the benefits of university-industry collaboration in solving real-world industrial challenges. The application of advanced structural analysis tools and material substitution strategies resulted in an efficient and sustainable solution, delivering positive impacts for both the company and engineering education.

The methodology employed in this study reinforced the importance of interdisciplinarity in engineering education, demonstrating that incorporating real-world challenges into the academic environment can enhance learning outcomes and better equip students to handle the complex problems they will face in professional practice. The success of this initiative suggests that similar approaches can be replicated in other areas of engineering, further strengthening the connection between academic training and practical application. Therefore, the project successfully demonstrated how university-industry collaboration, when combined with project-based learning strategies, can enrich engineering education by providing students with authentic, complex, and meaningful learning experience.

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