

## Reverse Engineering Applied to a Circuit Breaker Lever: Case Study

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The obsolescence of components in industrial systems has become a significant and growing challenge for corrective maintenance and operational continuity of complex and high-cost equipment. To address this issue, this work proposes an integrated multidisciplinary approach combining reverse engineering, design for additive manufacturing, structural simulation, and 3D printing technique for recovering and refurbishing obsolete components. As a detailed case study, the functional restoration of a high-power circuit breaker used in a hospital environment was performed, where conventional replacement would involve high costs and prolonged downtime, with direct impact on system safety and reliability. The process involved precise 3D scanning of the original component, followed by parametric modeling with geometric and structural optimization. Computational simulations were conducted to verify mechanical performance under operating conditions. The component was manufactured using an additive manufacturing technique with high-performance engineering resin. The result was a carefully redesigned part showing significant improvements in geometry, strength, and robustness while maintaining full dimensional compatibility and functional interchangeability with the original system. Comprehensive tests demonstrated adequate dimensional accuracy and satisfactory mechanical performance, along with substantial reductions in costs and repair time compared to conventional replacement methods. The developed methodology proved effective as a strategic alternative to address parts' unavailability in the market, providing greater technical autonomy and flexibility in maintaining complex industrial assets, and highlighting the promising potential of integrating digital technologies with reverse engineering as a sustainable and innovative solution for managing obsolescence challenges in electromechanical systems.

**Keywords:** Reverse Engineering. 3D Scanning. Structural Analysis. Additive Manufacturing.

Maintenance of industrial components is fundamental to ensuring operational continuity and system safety. However, the obsolescence of critical parts, which are often discontinued by manufacturers, poses a significant challenge by hindering direct replacement and increasing maintenance costs and lead times.

In this scenario, reverse engineering emerges as an effective strategy for producing replacement parts. Through advanced three-dimensional scanning technologies such as photogrammetry, stereoscopy, and laser triangulation, and the reconstruction of CAD models, it is possible

to replicate complex components, ensuring functional compatibility with the original equipment and avoiding complete system replacement [1-6].

To guarantee the reliability of these replicated parts, the use of computer-aided engineering (CAE) tools becomes essential. Techniques such as the finite element method and meshless methods allow predicting the mechanical behavior of parts, identifying critical points, and validating potential design modifications prior to manufacturing [1].

In parallel, additive manufacturing (AM) arises as a fast and flexible solution for producing these parts, eliminating the need for traditional tooling and enabling the fabrication of complex geometries with high precision. This results in significant reductions in time and cost involved in component replacement [6].

Within this context, Design for Additive Manufacturing (DfAM) complements the process by guiding the redesign of parts to optimize their

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functionality, performance, and manufacturability via additive manufacturing. This approach allows incorporating improvements and adaptations not possible with conventional methods.

Several studies demonstrate that the integrated combination of reverse engineering, DfAM, CAE, and additive manufacturing constitutes an effective methodology for replacing obsolete parts, especially in industrial and automotive sectors, bringing benefits such as cost reduction, time savings, and improved component performance [2,5-7].

The present work presents a methodology applied as a case study aimed at cost reduction and the rapid availability of a critical piece of equipment. To this end, it proposes the development of a new lever for circuit breakers by unifying two originally separate components into a single part through the integration of reverse engineering and additive manufacturing. The three-dimensional model will be created from precise measurements and validated by structural simulation using the meshless method, aiming to optimize both functionality and the production process, thus offering an efficient solution for replacing obsolete components in industrial electrical systems.

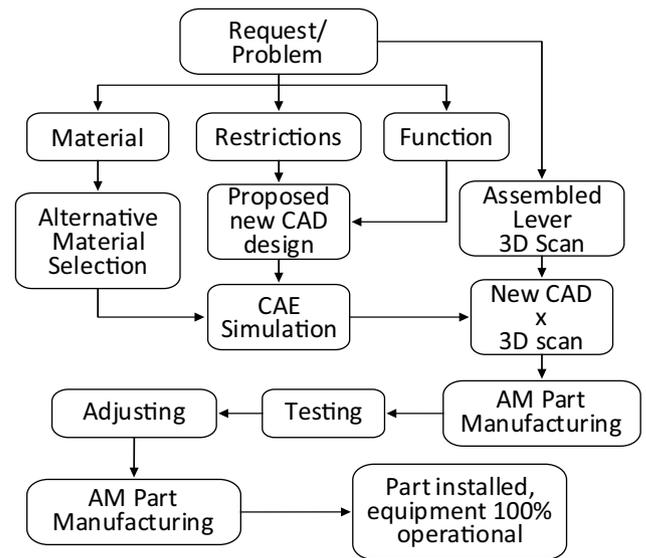
### Circuit Braker

The circuit breaker is a safety device that automatically cuts the electrical power supply to a circuit in case of system overload, protecting the entire system from severe damage [8]. Its operation can also be performed manually through a switch to turn the power supply to the circuit on or off. The damaged part was the lever switch of the equipment made from reinforced polycarbonate with 10% fiberglass. The complete equipment costs R\$ 30,000.00.

### Materials and Methods

Figure 1 presents the system of the case study process.

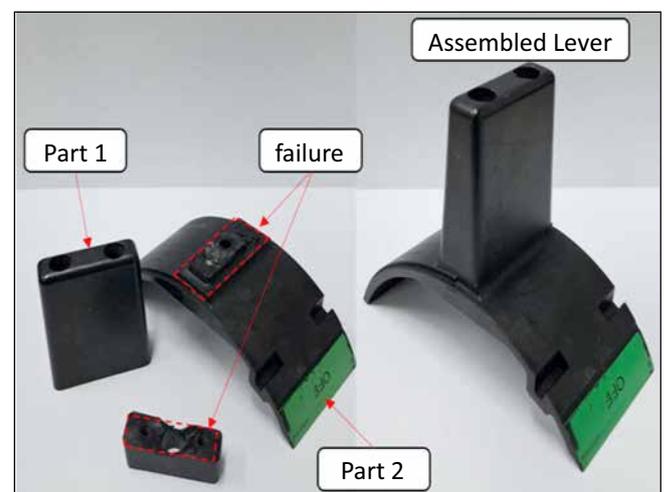
**Figure 1.** Flowchart of the case study process.



### Equipment and Part Evaluation

Figure 2 presents the piece that is the object of study of this work. It can be observed that the switch suffered a fracture in the region of the coupling between the lever (Part 1) and the circuit breaker actuator (Part 2), and the fracture was initiated in the fixing hole location. The component was designed to withstand forces on the order of 30 kgf. The flap is secured in a way that allows it to slide. The movement of the part is restricted by an upper stop and a lower stop that lock the movement of the sliding flap, preventing shocks between the lever and the equipment.

**Figure 2.** Original part.



### 3D Scan Data Acquisition

To obtain the geometry of the damaged part, detailed dimensions were obtained using a Mitutoyo analog caliper model 530-114 with a resolution of 0.05 mm and an accuracy of  $\pm 0.05$  mm, as well as by scanning the component using the Zeiss 3D scanner model T-SCAN Hawk 2 with a resolution of 0.02 mm and an accuracy of 0.02 mm + 0.015 mm/m, carried out with the assistance of a rotary base using the laser scanning method with reference points positioned on the rotary base, considering a mesh refinement of 0.1 mm. The scanner uses stereo technology with laser triangulation and stereo. Three measurements were taken: left side, right side, and bottom, with the point clouds aligned using the alignment method through Root Mean Square Error (RMSE).

Subsequently, the point clouds were converted into an STL file. The acquisition and processing of the data obtained through the scanner was carried out with the aid of Zeiss GOM INSPECT software. This approach, which combines manual measurements with 3D scanning, is widely recognized as an effective methodology for the accurate reconstruction of parts intended for additive manufacturing [9].

### 3D CAD modelling and DfAM

For the modeling of the component, the software SOLIDWORKS 2023 was used. The parametric model of the switch was built considering the geometric constraints that require high precision and detailing, as well as the location of the failure, which occurs near the interface of the components, where there is stress concentration. Thus, the All-in-one design was adopted, combining the 2 components into 1, preserving the geometry of the tab required to perform the primary functions of the component and maintaining the main fastening hole, reducing the existing stress concentration, increasing the mechanical strength of the part, and decreasing the number of components for assembly.

### Structural CAE

The structural model to verify the performance of the structure after reverse engineering and the change in the manufacturing process was developed using the Altair Simsolid program, which allows for linear or nonlinear structural analyses through the Meshless method. In the structural model, a linear static structural simulation was performed using a material based on ultra-high strength resin manufactured by the company Solidator [10]. Based on the information provided on the manufacturer's website, the process, and the type of resin used, the model was developed considering a linear isotropic elastic material, provided that the maximum deformation is less than 2%, meeting the linear requirement of the material and the numerical model that underpins the Meshless method. For the structural model, three boundary conditions were considered: Force (F) with a magnitude of 350 N applied to the top face of the lever, sliding support (SS) on the rear faces of the circuit breaker actuator, and fixed support (FS) on the faces of the switch mounting hole. Since in the version manufactured by additive manufacturing, the two parts of the original switch were integrated into a single component, contacts or the coupling between the actuator and the lever were not considered.

### Additive Manufacturing

The part was designed to be manufactured using the Solidator 8K printer, which allows for production using the SLA technique with the ultra-resistant black resin from the same manufacturer. Table 1 shows the comparison of properties about the original part material and the new part material [10-12].

The equipment operates through a closed solution, so it is not possible to obtain the process parameter information used in the manufacturing of the parts, with only the inclination of the part being modified, positioning it 10 mm above the base of the table and tilted in two planes at  $45^\circ$  to reduce warping effects and distortions of the part (Figure 3).

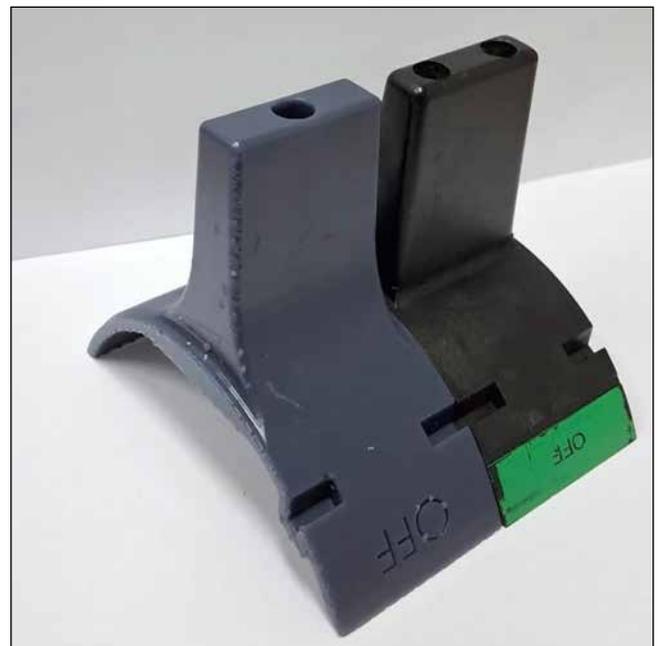
**Table 1.** Comparison of properties.

Property	Solidator Ultra-Tough Black Resin	PC+10 GF	Unit
Density	1.19	1.25 –1.28	g/cm <sup>3</sup>
Modulus of Elasticity	1600	3500	MPa
Tensile Strength	32	60–65	MPa
Elongation at Break	39	5–6	%
Poisson	0.39	0.38	-

**Figure 3.** Parts hanging on the machine build platform after being manufactured.



**Figure 4.** Design comparison.



**Results**

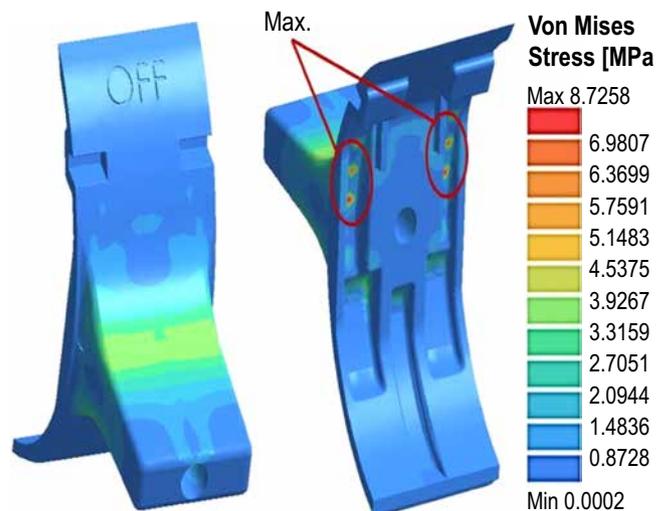
Design Comparison

When comparing the design of the original part with the one made in AM, as shown in Figure 4, the latter stands out for reducing the number of components for assembly and eliminating the weak point that was the interface between the components, removing the need to use screws and presenting a fillet in the fragile area.

Structural Results

Figure 5 shows the equivalent Von Mises stress field in the switch structure. It can be observed that the maximum stress experienced by the switch is 8.72 MPa, at the back part of the piece where it

**Figure 5.** Von Mises equivalent stress field.



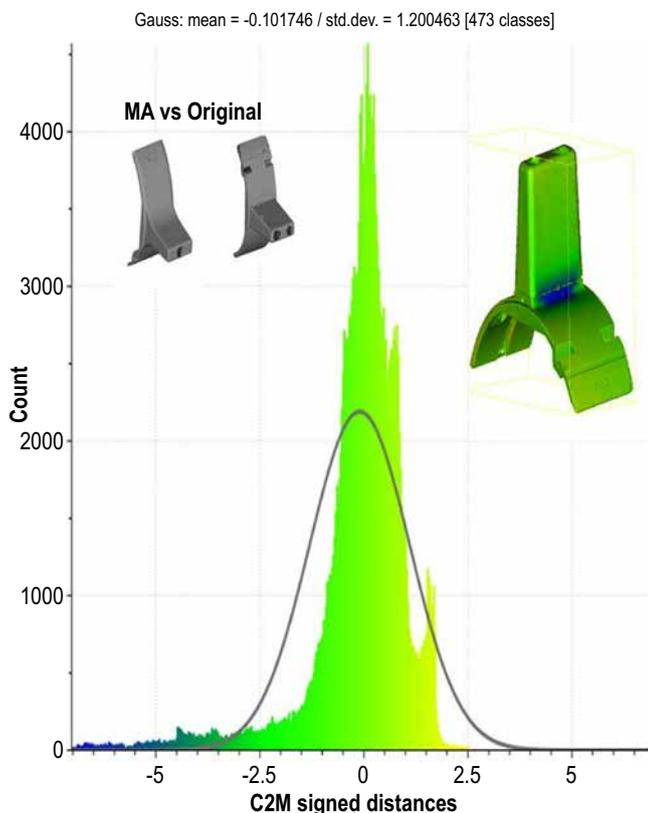
is fixed, the area where the switch contacts the circuit breaker.

In this condition the new part material has a safety factor of 3.67.

### Dimensional Evaluation

In this study, measurements were taken using a 3D scanner on the original switch and after the additive manufacturing process, to verify the difference between the original part and the reverse-engineered part. Both measurements on the scanner were performed under the same conditions mentioned earlier. The difference between the original part and the part manufactured by additive manufacturing was assessed using the Cloud Compare program, also employing the RMSE method to compare the average deviation between the two geometries. Graphic 1 shows the comparison between the geometry manufactured by additive manufacturing and the original

**Graphic 1.** Comparison between the manufactured geometry and the original geometry.



geometry. The bottom and top parts of the original geometry were fixed to facilitate the scanning process. Subsequently, the same scanning positions were used to evaluate the geometry manufactured through additive manufacturing. It can be observed that the greatest divergences between the original and altered piece occur in the lever region, resulting in an average deviation of - 0.1017 mm.

### Functionality Evaluation

When trying to use the designed part for the first time, a slight interference was noticed in the main fixing hole, requiring the tolerance of the hole to be adjusted by about 0.1mm to ensure that there was no interference due to contraction during the manufacturing process. The part subsequently withstood the stresses, and its operation after the adjustment was satisfactory (Figure 6).

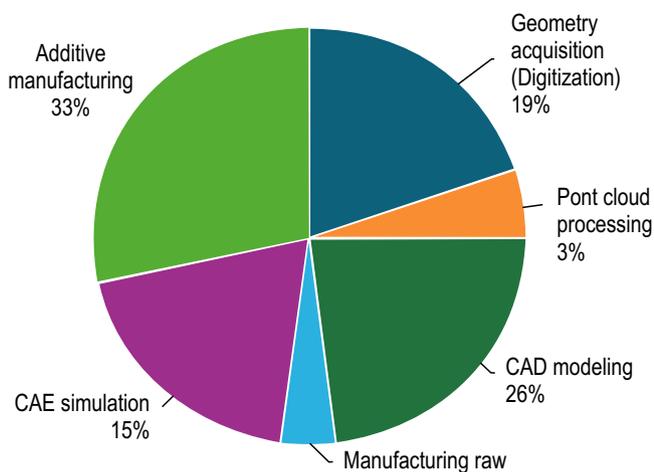
**Figure 6.** Manufactured part being used in the circuit breaker.



## Cost Analysis

Since the part has no replacement and it is necessary to replace the entire equipment, the usual cost to replace the obsolete part amounts to the full value of new equipment, totaling R\$ 30,000.00. However, the budget for the reverse engineering service, geometry validation by scanning, structural simulation, and manufacturing is estimated as shown in Graphic 2. This totals R\$ 1,500.00, resulting in a savings of 19 times the original value of the circuit breaker.

**Graphic 2.** Cost per stage of part development



## Conclusion

This work demonstrated that the replacement of obsolete components through reverse engineering, combined with structural simulation and additive manufacturing, is a technically and economically viable solution. The circuit breaker lever was redesigned as a single piece while fully maintaining its original functionality. Previous studies have already validated the use of 3D-printed components in industrial contexts (Baladés, 2023 [1]), which reinforces the results obtained. Thus, it is concluded that the proposed objectives were achieved, demonstrating that the adopted methodology is effective for replacing critical parts, promoting operational continuity and cost reduction in industrial systems.

As a proposal for future work, it is suggested

to conduct a life cycle analysis of the component produced, comparing its durability to that of the original complete assembly. This investigation would enable a more comprehensive assessment of the technical and economic feasibility of the replacement, considering not only the initial manufacturing costs but also long-term maintenance expenses and replacement frequency over time.

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