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Structural Optimization of Crane Booms in Compact Lifting Equipment: Foundations, CAE Framework, and Industry Context

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ABSTRACT

Compact lifting machines, commonly known as Mini Lifts or Monkey Lifts, are electrically powered hoisting devices widely used on low-to-mid-rise construction sites to move materials vertically in locations where large tower cranes cannot operate economically or practically. Despite their importance in daily construction operations, the structural design of their components particularly the crane boom has received limited attention in the published engineering literature. Designers have historically relied on conservative empirical rules, leading to boom assemblies that are heavier than structurally necessary. This paper presents the foundational context, conceptual background, and introductory methodological framework for a research effort aimed at filling this gap. It explains what the Mini Lift machine is, how it operates, why its crane boom is a structurally critical component, and how Computer-Aided Engineering (CAE) tools specifically CATIA V5 for 3D modelling and ANSYS Workbench for Finite Element Analysis and Topology Optimization can be used to design a lighter, evidence-based structure without compromising safety. The paper also introduces the preliminary steps of the CAE methodology, including the reverse engineering process used to reconstruct the boom geometry and the finite element modelling strategy. The contribution of this paper lies in establishing a clear, accessible, and well-referenced foundation for research into an underserved class of construction lifting equipment.

Keywords: Mini Lift; Monkey Lift; Crane Boom; Computer-Aided Engineering; Finite Element Analysis; Topology Optimization; SIMP Method; CATIA; ANSYS; Material Handling; Construction Equipment; Structural Design; Reverse Engineering

1. Introduction

Construction projects at every scale depend on the systematic movement of raw materials cement, bricks, steel reinforcement bars, aggregates, and concrete blocks from ground level to upper-floor work areas. This activity, broadly termed material handling, consumes a substantial share of site labour and has direct consequences for project cost, schedule, and worker safety. The construction industry is widely recognized as one of the most hazardous occupational sectors globally, and material handling has been consistently identified as a leading cause

of both acute injuries and chronic musculoskeletal disorders among construction workers [Almaskati et al., 2024; Betit et al., 2017].

The mechanization of vertical material transport has therefore been a persistent engineering and operational priority for the industry. While tower cranes serve high-rise projects effectively, they are impractical and commercially unviable on low-to-mid-rise urban sites where space is constrained, mobilization costs are high, and the volume of work does not justify the capital expenditure. This gap has driven demand for a class of compact, portable, electrically powered hoisting machines that can be set up quickly, operated by two workers, and repositioned as the building rises floor by floor.

The Mini Lift also known commercially as the Monkey Lift or Monkey Hoist represents a prominent example of this class of equipment. It is a compact, wall-anchored electric hoist fitted with a cantilevered crane boom that projects outward over the building edge, guiding the wire rope to the loading area below. Despite its widespread use on construction sites across South Asia, Southeast Asia, the Middle East, and parts of Africa, the structural design of this machine and of its crane boom in particular has received very little rigorous engineering investigation in the published literature.

Most Mini Lift crane booms are designed using inherited empirical rules from large industrial crane practice, resulting in components that are substantially heavier than the structural loading actually requires. This excess weight reduces the portability of the machine, increases raw material and manufacturing costs, and adds to the physical effort required of workers who reposition the equipment floor by floor. At the same time, a boom designed without detailed stress analysis may contain hidden weak points stress concentrations at welds, bends, and mounting interfaces that could lead to fatigue-related failures under prolonged cyclic loading [Chen et al., 2024; Ding et al., 2021].

The application of Computer-Aided Engineering (CAE) tools specifically parametric CAD modelling in CATIA V5 combined with Finite Element Analysis (FEA) and topology optimization in ANSYS Workbench provides a systematic, evidence-based pathway to address both problems simultaneously. This research applies these tools to the crane boom of an actual Mini Lift machine, with the primary aim of achieving a meaningful reduction in boom mass without compromising structural safety under the rated operational loading.

This paper presents the foundational context and preliminary methodological framework for that research. It explains what the Mini Lift machine is and how it operates, why the crane boom is the most structurally critical component, what CAE tools are used and why they are appropriate, and how the geometry and loading were established for analysis. The paper is deliberately written in plain, accessible language so that it can serve both as a technical reference and as an introduction for readers from adjacent fields.

2. Material Handling in Construction: Context and Challenges

2.1 The Operational Significance of Material Transport

Material handling on construction sites encompasses all activities related to the movement, temporary storage, and controlled placement of construction materials. It includes horizontal transport across the site, as well as vertical transport from ground level to upper-floor work areas. The efficiency of these activities has a direct and measurable impact on project productivity, cost performance, and schedule adherence.

Studies in construction ergonomics and occupational health have documented that manual material handling particularly lifting, carrying, and repetitive handling of heavy loads is a leading cause of musculoskeletal disorders (MSDs) among site workers [Akhtar et al., 2025]. Research confirms that falls from height, material handling, and heavy machinery collectively represent the most frequently cited hazard categories across all construction sectors [Almaskati et al., 2024]. The introduction of mechanized lifting significantly reduces this exposure by transferring the physical burden from workers to machines.

2.2 The Gap Served by Compact Portable Lifting Machines

In dense urban environments and on low-to-mid-rise construction projects, large tower cranes are frequently impractical. Their installation requires substantial ground space for the base, significant lead time for erection, and a volume of construction activity sufficient to justify the rental and operational cost. For projects of three to ten storeys on constrained urban plots a category that represents a very large share of global construction activity the economics and logistics of tower cranes are prohibitive.

This creates a practical gap that is filled by compact, portable lifting machines. These devices must satisfy a demanding set of concurrent requirements: they must be light enough to be moved by two workers; small enough to be transported in a standard goods lift or through a standard doorway; structurally robust enough to raise construction materials repeatedly throughout a working shift; and safe enough to operate in proximity to construction workers on upper-floor slabs. The Mini Lift machine is specifically designed to meet these requirements.

3. The Mini Lift Machine: Design, Components, and Operation

3.1 Definition and Commercial Nomenclature

The Mini Lift marketed under various trade names including Monkey Lift, Monkey Hoist, and Mini Crane Hoist is a compact, electrically powered hoisting machine designed for vertical material transport on construction sites. Published technical literature confirms that devices in this class are capable of lifting loads of 200 kg to 700 kg to heights of 10 m to 150 m [Ramteke et al., 2021], making them well suited to the operational demands of low-to-mid-rise building construction.

3.2 Principal Components

A standard Mini Lift machine consists of the following key structural and mechanical elements:

- Rigid welded steel frame the primary structural body, anchored to the building slab or window opening at each floor level using bolted connections and steel clamps
- Electric motor provides motive power for hoisting, typically operating from a single-phase or three-phase power supply at 220V or 380V
- Reduction gearbox steps down motor speed and multiplies torque to drive the wire rope drum, enabling controlled lifting of heavy loads
- Wire rope winch drum winds and unwinds the wire rope to raise and lower the load; the rope is guided by a sheave at the tip of the crane boom
- Crane boom a cantilevered structural arm projecting outward from the main frame over the building edge; this is the component of primary interest in the present research
- Load platform or hook assembly the working end from which materials are suspended during lifting

Among these components, the crane boom is the most structurally demanding. It is the sole load path by which the lifting force is transferred from the wire rope system to the main machine frame. It is subjected to bending, shear, and combined loading during operation, and its design governs both the safety and the portability of the entire machine.

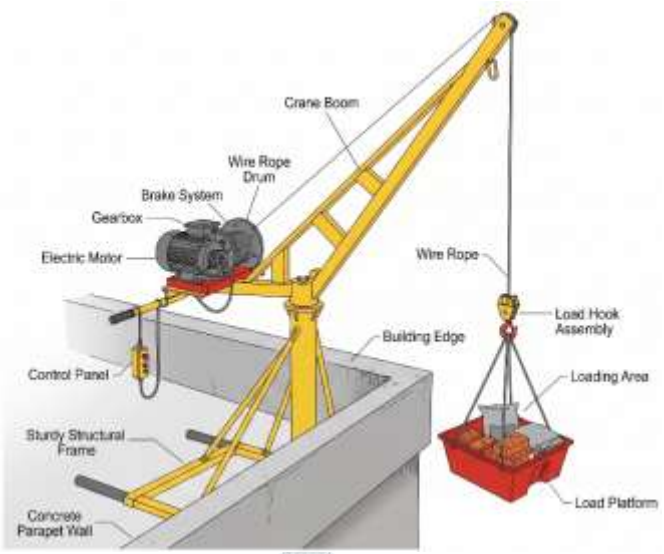


Figure 1. Typical Mini Lift (Monkey Lift) machine installed at a construction site, showing the principal components including the crane boom in its operational position projecting over the building edge.

3.3 The Crane Boom: Structural Role and Loading

The crane boom is a cantilevered steel arm that projects horizontally outward from the top of the machine frame. Its tip supports a sheave (pulley) through which the wire rope passes vertically downward to the load below. The geometry of the boom determines the horizontal reach of the machine and the angle at which the rope load is applied to the main frame.

During normal operation, the boom experiences a complex combination of forces. The dominant loading is the tensile force in the wire rope, transmitted through the sheave at the boom tip. This produces bending moments along the length of the boom, with the maximum bending moment typically occurring at or near the root the connection between the boom and the main frame. Secondary loads include the self-weight of the boom, vibration induced by motor and gearbox operation, and occasional impact loads when the machine is started abruptly or when a load is lowered too rapidly.

Because the machine is repositioned multiple times during a construction project, the boom is also subject to handling loads during transport and installation. These loads are typically informal and variable, but they represent an additional source of stress that a robustly designed boom must be able to withstand without permanent deformation.

4. The Engineering Design Challenge

4.1 Limitations of Empirical Design Methods

The crane booms of Mini Lift machines have historically been designed using empirical methods rules of thumb and safety factors inherited from large industrial crane practice. This approach is practical for manufacturers who lack access to specialized engineering software, but it produces components that are systematically over-engineered. The designer, lacking the ability to calculate the actual stress distribution within the complex three-dimensional boom geometry, compensates by using more material than is strictly necessary.

For a large tower crane, this excess material represents a tolerable cost. For a Mini Lift that must be repositioned by workers, every kilogram of unnecessary mass translates directly into greater handling effort, higher risk of handling injury, increased raw material consumption, and higher unit manufacturing cost. The business case for lightweight design is therefore particularly strong for this class of equipment.

A second limitation of empirical design is that it cannot detect hidden structural inefficiencies. Stress concentrations at welds, bends, and mounting holes may go undetected without detailed analysis, creating weak points that are prone to fatigue crack initiation under the cyclic loading experienced during normal operation.

Research on fatigue life prediction in lifting machinery confirms that cumulative fatigue damage at high-stress regions is the most common mode of structural failure in repeatedly loaded steel structures [Chen et al., 2024; Liu et al., 2024; Ding et al., 2021].

4.2 The Need for a Computational Approach

Computer-Aided Engineering (CAE) addresses both limitations simultaneously. By creating a virtual model of the boom geometry and applying realistic loads and boundary conditions, engineers can calculate the actual stress state throughout the component with high accuracy. Regions of high stress which must be retained or reinforced are clearly identified, as are regions of low stress where material can be safely removed. This dual insight is the foundation of topology optimization. Research in lifting equipment structural analysis confirms that FEA-based approaches enable accurate prediction of stress, deformation, and safety factor before a physical prototype is built, dramatically reducing both development risk and testing cost [Habib et al., 2025; Huang et al., 2023].

For welded steel structures, CAE also provides important advantages in detecting stress concentrations at welds and geometric discontinuities. A study on bridge crane main girders using FEM demonstrated that the highest stress regions occurred at connection points between structural members locations that empirical methods typically treat as averaged and uniform [Ling et al., 2018]. This kind of spatial resolution is only achievable through computational simulation.

5. Computer-Aided Engineering Tools

5.1 CATIA V5 Parametric 3D Modelling

CATIA V5, developed by Dassault Systèmes, is a parametric Computer-Aided Design (CAD) platform widely used in aerospace, automotive, and heavy engineering. It allows engineers to create precise three-dimensional solid models using feature-based modelling, where the geometry is defined by a sequence of operations extrusions, revolves, fillets, and cuts each governed by explicit dimensional parameters. Because the model is parametric, any parameter can be modified and the entire geometry updates automatically, making CATIA well suited to iterative design workflows.

The use of CATIA for three-dimensional modelling followed by import into ANSYS Workbench for analysis is a well-established workflow in mechanical engineering research. Studies on dental implants modelled in CATIA and analysed in ANSYS reported excellent geometric fidelity and accurate stress distribution results [Kaur et al., 2025]. Similarly, research on automotive structural components using CATIA V5 for geometry preparation followed by FEA in ANSYS confirmed the reliability of the interoperability pathway between the two platforms [Mehra et al., 2025].

5.2 Reverse Engineering Reconstructing the Boom Geometry

Because no formal engineering drawing exists for the Mini Lift crane boom studied in this research, the geometry was obtained through reverse engineering of a physical unit available at the research site. Reverse engineering is the process of measuring an existing physical object and using those measurements to reconstruct its geometry in digital form. It is widely used in mechanical engineering to recover design information for components that were manufactured without formal CAD documentation.

In the present research, the reverse engineering was performed using manual measuring instruments vernier calipers, a measuring tape, a depth gauge, a square, and a surface plate to capture all critical dimensions of the crane boom. This approach is consistent with established practice in the field; research on reverse engineering of mechanical components confirms that manual measurement tools are effective for reconstructing geometries of moderate complexity, provided measurements are taken systematically and verified for internal consistency [Dhipakumar et al., 2019; Kiran, 2025].

A more sophisticated alternative laser scanning or computed tomography was not required for this geometry, given

the relatively simple prismatic and curved surfaces of the crane boom. Research comparing different reverse engineering approaches confirms that for components of this type, manual measurement followed by CAD reconstruction is both sufficiently accurate and far more accessible than scanning-based methods [Buonamici et al., 2018].

Once all dimensions were recorded, the geometry was reconstructed in CATIA V5 as a parametric solid model. The model includes all functionally significant features: the pivot bolt hole at the root of the boom, the wire rope attachment point and sheave housing at the tip, the transition geometry between the boom arm and mounting bracket, and the structural web sections along the length of the arm. The completed model was verified against the physical component and then exported in STEP format for import into ANSYS Workbench.

5.3 Finite Element Analysis in ANSYS Workbench

ANSYS Workbench is a commercial FEA platform that provides an integrated environment for geometry import, mesh generation, boundary condition application, static structural analysis, and post-processing of results. It is one of the most widely used and well-validated tools in structural engineering research, and its capabilities are directly applicable to the structural analysis of welded steel crane components.

5.3.1 Meshing Strategy

The crane boom geometry was meshed using SOLID187 ten-node tetrahedral elements. This element type is well suited to complex, curved three-dimensional geometries such as the crane boom because it can represent irregular surfaces accurately without the structured mesh generation required by hexahedral elements. Research comparing tetrahedral and hexahedral elements for static structural analysis confirms that quadratic tetrahedral elements (such as SOLID187) perform equally well or better than hexahedral elements for complex geometries while being significantly easier to generate automatically [Schneider et al., 2019]. A mesh convergence study was conducted to ensure that the solution was not sensitive to the mesh density, in accordance with established best practice in finite element simulation [Kikale et al., 2024].

Mesh refinement was applied selectively at regions of geometric discontinuity specifically the pivot hole area, the wire rope attachment point, and the fillet transitions between the boom arm and mounting bracket. These regions are the most likely locations of stress concentration and therefore require a finer mesh to capture the stress gradient accurately. In lower-stress regions away from geometric features, a coarser mesh was used to maintain computational efficiency.

5.3.2 Boundary Conditions and Load Application

The boundary conditions applied in ANSYS Workbench were selected to accurately represent the physical constraints and loading experienced by the crane boom during operation. A cylindrical support boundary condition was applied at the pivot bolt hole, constraining translational motion while permitting rotation about the pivot axis. This accurately replicates the physical kinematic constraint at the pin joint between the boom and the main machine frame.

The applied load represents the static equivalent of the rated payload of the Mini Lift, transmitted through the wire rope at the boom tip. For a machine rated at a payload of approximately 50 kg, the corresponding force including an appropriate dynamic factor for lifting operations was applied at the wire rope attachment point on the boom. This loading configuration is consistent with established practice in lifting equipment structural assessment and with the load application methods used in comparable published studies [Habib et al., 2025; Wibawa, 2020].

5.4 Material Properties of Structural Steel

The crane boom material is structural steel conforming to applicable standard grades. The material is selected for its combination of weldability, yield strength, toughness, and cost-effectiveness all essential properties for fabricated lifting equipment components. The mechanical properties used in the finite element model are listed in Table 1 below.

Property	Value	Unit
Density	7850	kg/m³
Young's Modulus	200×10^9 (2×10^{11})	Pa
Poisson's Ratio	0.3	
Yield Strength	250 – 280	MPa
Ultimate Tensile Strength	400 – 550	MPa

Table 1. Mechanical properties of structural steel assigned to the crane boom baseline model in ANSYS Workbench.

6. Structural Optimization: Concepts and Relevance

6.1 What Is Structural Optimization?

Structural optimization is the computational process of finding the best possible design for a structural component subject to a defined set of objectives and constraints. In practical terms, it answers the question: given that this component must carry a specific load safely, how can the designer use as little material as possible while ensuring that the component does not exceed allowable stress or deformation limits?

There are three main levels of structural optimization, and they are commonly applied in sequence. Topology optimization determines where material should and should not exist within the available design space. Shape optimization then refines the boundaries of the retained material to improve the stress distribution. Size optimization selects the optimal thickness or cross-sectional dimensions of individual structural members. The present research employs topology optimization as the primary computational tool, with shape optimization applied to refine the resulting design into a manufacturable geometry.

6.2 Topology Optimization and the SIMP Method

Topology optimization determines the most efficient distribution of material within a given design domain by iteratively removing elements that contribute least to structural performance. The algorithm retains material along the principal load paths and eliminates it from regions that carry negligible stress. The most widely used method for this purpose in industrial FEA platforms is the Solid Isotropic Material with Penalization (SIMP) algorithm. In SIMP, each finite element is assigned a density variable between zero (no material) and one (full material). The stiffness of each element is penalized as a function of its density, creating a mathematical incentive for the algorithm to push element densities toward zero or one, producing a clear binary layout of material and void [Yago et al., 2021].

The SIMP method is available natively in ANSYS Workbench and has been applied successfully to a wide variety of structural steel components in the lifting equipment and construction machinery sector. Key findings from the literature are summarized below to establish the achievable performance envelope for the Mini Lift crane boom optimization.

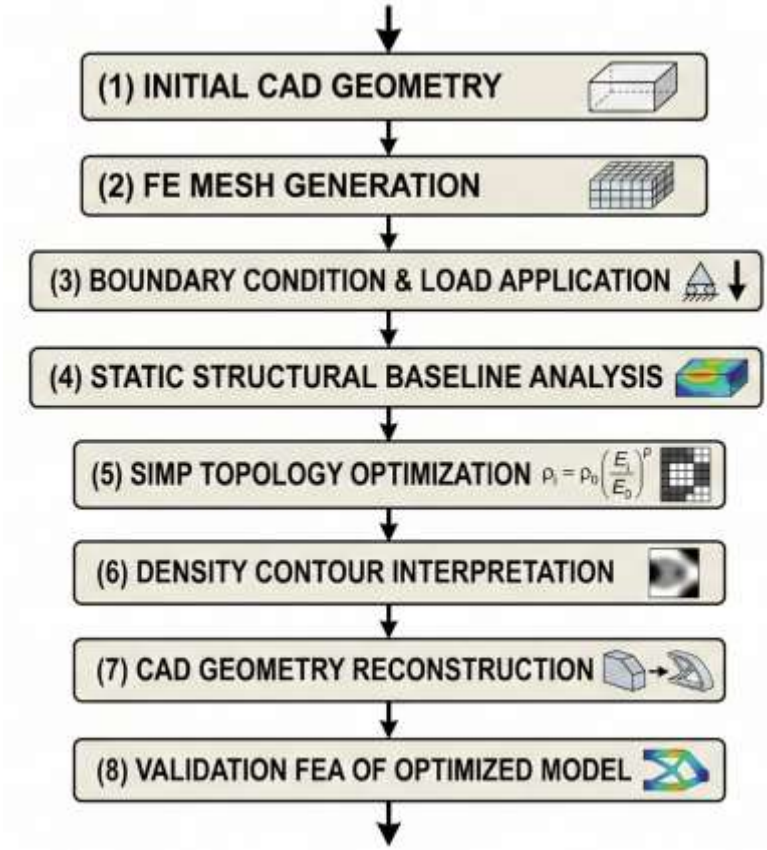


Figure 2. Flowchart of the SIMP topology optimization workflow applied to the Mini Lift crane boom. The process begins with the baseline CAD model and proceeds through FEA, topology optimization, geometry reconstruction, and re-analysis for validation.

6.3 Evidence from the Literature

The potential for significant mass reduction through topology optimization in crane and lifting structures is well documented. One study on overhead crane girder design applied topology optimization in Inspire software to achieve an 18.97% reduction in girder mass without any compromise in structural integrity [Navale et al., 2023]. A study on a ship crane manipulator boom applied numerical optimization methods across 465 design parameters, achieving an 18% reduction in structural mass [Suvorov et al., 2023]. Research on crane hook geometry demonstrated a 23.45% weight reduction while maintaining full structural integrity, validated against photoelastic experimental results [Avilasha et al., 2023].

In the excavator boom domain structurally similar to the Mini Lift crane boom in terms of cantilever loading and welded steel construction an EDEM-ADAMS coupled simulation-based optimization study achieved a 13.8% mass reduction alongside a 26.12% reduction in maximum stress, demonstrating that topology optimization can simultaneously improve both weight efficiency and stress performance [Wu et al., 2025]. A study on a bell-crank component using reverse engineering combined with topology optimization confirmed a 16.5% reduction in von Mises stress alongside mass reduction, validating the approach for irregular welded steel geometries [Pang et al., 2020].

Research on mobile crane telescopic boom design applied finite element analysis in ANSYS Workbench to identify optimal boom dimensions and verify stress and stiffness criteria, providing both modal and flexural analysis of the optimized design [Wang et al., 2023]. A design study on jib boom mechanisms in mobile cranes confirmed that FEA-based numerical analysis and dimension optimization can achieve meaningful weight savings while maintaining full safety compliance [Yunus et al., 2024].

The collective evidence from these studies establishes that mass savings of 12% to 47% are achievable in structural steel crane components without violating yield or serviceability criteria. These findings define a realistic and well-supported performance envelope for the Mini Lift crane boom optimization study.

7. Research Gap and Positioning

7.1 What the Literature Has Addressed

The published literature on structural optimization of lifting equipment is extensive in certain directions. Large overhead cranes and their girders, hook assemblies, and support structures have been studied systematically using FEA and topology optimization. Telescopic mobile crane booms have received detailed attention with respect to cross-section optimization and response surface methods. Ship crane boom structures have been studied using multi-parameter optimization algorithms. Lifting spreaders and below-the-hook devices have been analysed and certified using integrated FEA and physical proof testing workflows.

7.2 What the Literature Has Not Addressed

Despite this body of work, a significant and clearly defined gap remains: the systematic application of computational structural analysis and optimization to small-scale, site-portable lifting equipment of the Mini Lift class. This gap arises from several overlapping factors. First, Mini Lifts are manufactured by small and medium-sized enterprises who typically lack the resources and specialist knowledge for formal CAE-based product development. Second, the academic and research communities have historically focused on capital-intensive equipment where the engineering challenges and commercial incentives are more visible. Third, the unique combination of constraints compact geometry, conventional welded construction, low-cost manufacturing environment, and portability imperative makes the Mini Lift crane boom a distinct design problem that does not map cleanly onto existing optimization frameworks developed for larger equipment.

The gap is particularly acute at the component level. While some published work discusses Mini Lift or Monkey Hoist machines in qualitative terms, none of the peer-reviewed literature identified in this review presents a systematic FEA-based stress analysis or topology optimization of the crane boom. This means that the actual safety margins, stress distribution, and mass efficiency of this widely used component have never been rigorously documented in the open literature.

7.3 Positioning of the Present Research

The present research directly addresses this gap. By applying CATIA V5 for parametric CAD reconstruction through reverse engineering, and ANSYS Workbench for finite element static structural analysis and SIMP-based topology optimization, it provides both a practically usable optimized design for the Mini Lift crane boom and a repeatable, low-cost digital design methodology that can be extended to other components of the same machine family. The research uses physical measurements of an actual Mini Lift machine available at the research site, applies realistic boundary conditions and loading consistent with the machine's operational rating, and validates the analysis against established convergence and safety criteria. This combination of practical grounding and computational rigour addresses the research gap identified above.

8. Introductory Overview of the Research Methodology

The research follows a structured and systematic workflow integrating reverse engineering, parametric CAD modelling, and computational simulation. The purpose of this section is to outline the principal steps of that workflow at a conceptual level, providing enough context for the reader to understand the technical approach without presenting the detailed implementation or numerical results, which are addressed in the subsequent paper.

8.1 Problem Identification and Geometry Acquisition

The study begins with the identification of structural inefficiency in the conventional Mini Lift crane boom. The baseline boom geometry was obtained through reverse engineering of a physical unit, using manual measuring instruments to record all critical dimensions. These dimensions were then used to create a precise parametric CAD model in CATIA V5, incorporating all load-bearing and functionally significant geometric features.

8.2 Finite Element Modelling and Baseline Analysis

The CATIA model was exported in STEP format and imported into ANSYS Workbench. Material properties for structural steel were assigned, a SOLID187 tetrahedral mesh was generated with selective refinement at stress concentration regions, and boundary conditions representing the physical constraints and operational loading of the machine were applied. A static structural analysis was then performed to establish the baseline performance of the unoptimized design: stress distribution, total deformation, equivalent elastic strain, and maximum shear stress. These results identify the principal load paths and reveal regions of the boom that are either over-stressed or underutilized.

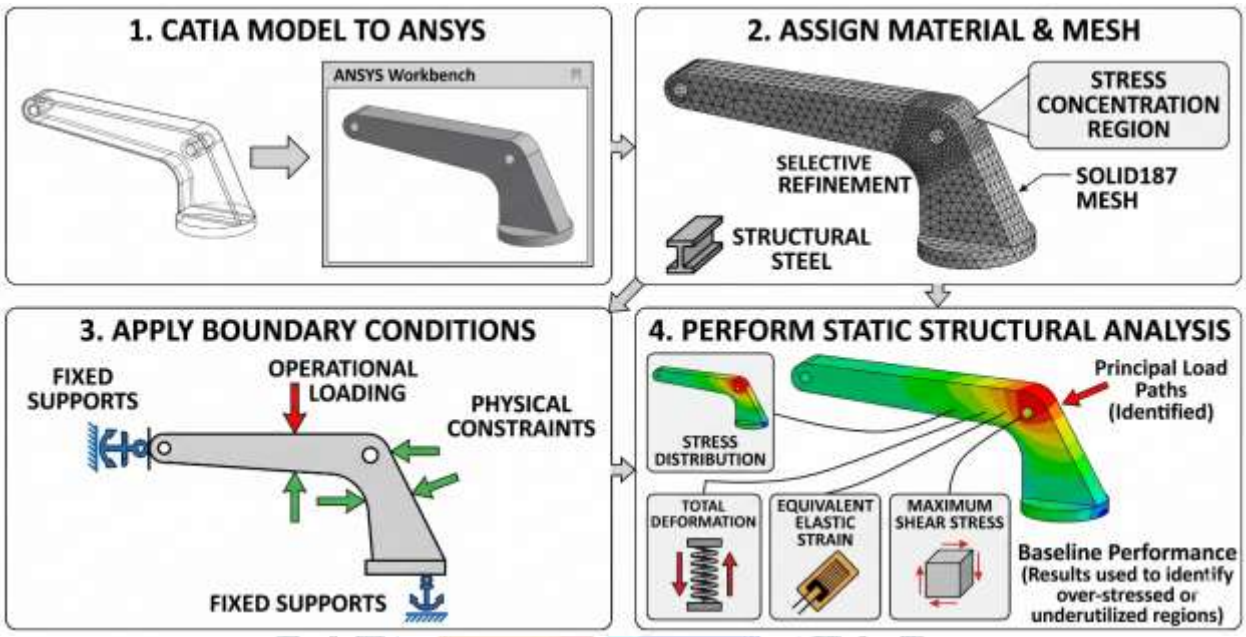


Figure 3: Finite Element Modelling and Baseline Analysis

8.3 Topology Optimization

Using the baseline FEA results as the starting point, SIMP-based topology optimization was performed in ANSYS Workbench. The design domain was defined as the full volume of the crane boom, with certain geometric features specifically the pivot hole, wire rope attachment point, and mounting surfaces designated as non-design regions where material removal was not permitted. The optimization objective was mass minimization subject to a stress constraint ensuring that the maximum stress in the optimized design remained below the material's yield strength. The optimization was run until convergence, producing a density contour map showing which regions of the boom are essential to structural performance and which can be removed.

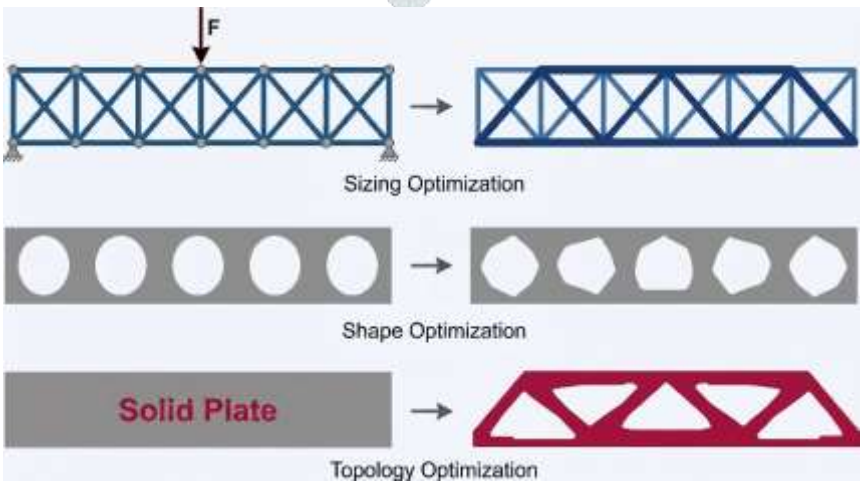


Figure 4: Topology Optimization Process

8.4 Design Reconstruction and Validation

The topology optimization output a density contour rather than a clean geometric model was interpreted and converted back into a manufacturable CAD geometry. The optimized geometry was then re-imported into ANSYS Workbench for a full static structural re-analysis under the same boundary conditions and loading as the baseline. This validation step confirms that the optimized design maintains the required structural safety while achieving the targeted mass reduction. Comparison of the baseline and optimized results provides the primary quantitative evidence for the value of the CAE-driven design approach applied in this research.

9. Conclusions

This paper has presented a comprehensive foundational treatment of the engineering context, conceptual tools, and preliminary methodological framework for a research study focused on the structural optimization of the crane boom of a Mini Lift (Monkey Lift) construction machine. The following principal conclusions are drawn from this foundational review:

- Material handling is a critical, high-risk activity on construction sites, and the mechanization of vertical material transport through compact portable lifting equipment such as the Mini Lift makes a significant contribution to worker safety, productivity, and project performance.
- The crane boom is the most structurally important component of the Mini Lift machine. It carries the full lifting load in bending, is subjected to repeated cyclic loading throughout its service life, and its mass directly determines the portability of the machine.
- Traditional empirical design methods produce crane booms that are heavier than structurally necessary, increasing cost and reducing portability, while also potentially concealing stress concentrations at welds and geometric discontinuities.
- Computer-Aided Engineering tools specifically CATIA V5 for parametric modelling and ANSYS Workbench for FEA and topology optimization provide a systematic, evidence-based alternative that can simultaneously reduce mass and improve structural understanding.
- The SIMP topology optimization algorithm, native to ANSYS Workbench, is a proven and effective method for structural mass reduction in welded steel crane and lifting equipment components, with documented mass savings of 12% to 47% across comparable applications in the literature.
- A significant and well-defined gap exists in the published literature regarding the systematic CAE-based structural analysis and optimization of Mini Lift class equipment. The present research directly addresses this gap using reverse-engineered geometry, realistic operational loading, and standard structural steel material properties.

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