# AI-Assisted Concept Evaluation and Structural Validation of a Household Debris Collection Tool.

**#1 Rohith B R**
M.Tech Student
R.V College of Engineering
Bengaluru, India

**#2 Mennangkhraw Diengdoh**
M.Tech Student
R.V College of Engineering
Bengaluru, India

**#3 Dr.Sujan Chakraborty**
Assistant Professor
R.V College of Engineering
Bengaluru, India

**#4 Vinayak R Hebbar**
M.Tech Student
R.V college of Engineering
Bengaluru, India

**#5 Dr. Ramesh S Sharma**
Professor and Associate Dean
R.V College of Engineering
Bengaluru, India

**ABSTRACT**

Household dustpans are commonly used cleaning implements; however, many commercially available designs continue to present practical challenges during routine domestic use. Frequent issues include excessive bending during operation, inadequate containment of collected debris, instability during sweeping or storage, and overall user discomfort. Although significant progress has been made in ergonomics and systematic product design, comparatively little attention has been given to the structured evaluation and validation of dustpan concepts through the combined use of engineering analysis and intelligent decision-support methods.

To address this limitation, the present study proposes an AI-assisted framework for the comparative evaluation and structural validation of a household debris collection tool. Three alternative dustpan concepts were generated using a structured conceptual design methodology and assessed under representative operating scenarios.

Static structural analyses were carried out using polypropylene material properties to examine mechanical behaviour during sweeping, lifting, and upright load-bearing conditions. Key simulation outputs, including stress distribution and displacement characteristics, were extracted and utilized as quantitative inputs for AI-driven concept comparison and ranking.

In parallel, an AI-supported ergonomic assessment was conducted using geometric parameters derived from two-dimensional design representations to evaluate factors such as handle length, posture influence, and effective dust collection width. Based on the combined outcomes of the structural and ergonomic analyses, one concept consistently demonstrated superior performance relative to the other alternatives. Subsequent AI-assisted dimensional refinement was applied exclusively to this highest-ranked concept to support informed decisions regarding handle length and dustpan width.

The results indicate that integrating AI-based decision-support techniques with simulation-driven validation enhances objectivity and consistency in early-stage concept selection, even for low-complexity household

products. Rather than replacing conventional design reasoning, the proposed approach strengthens engineering judgment by providing structured, data-informed support during the conceptual design phase.

**Index terms-** Household product design, dustpan concept evaluation, artificial intelligence, decision support systems, ergonomic assessment, static structural analysis, simulation-based validation, conceptual design, usability-focused design.

## I. INTRODUCTION

Household cleaning implements contribute significantly to maintaining sanitary and comfortable living spaces. Among these implements, dustpans are routinely used to collect dry debris generated during sweeping. Although they are simple and widely adopted tools, many commercially available dustpans continue to present usability challenges, including excessive forward bending during operation, incomplete debris containment, spillage during lifting or transport, and insufficient stability in both use and storage. Such limitations often result in physical discomfort, repeated cleaning actions, and reduced overall efficiency in everyday domestic environments.

Advances in ergonomics and product development methodologies have increasingly highlighted the importance of posture, comfort, and usability in product design. Nevertheless, the systematic application of these principles to low-complexity household products, such as dustpans, has received relatively little attention. Existing design solutions frequently target individual shortcomings—for instance, extending handle length to reduce bending or incorporating covers to limit spillage—yet these modifications may introduce secondary drawbacks, including compromised stability, awkward handling, or increased maintenance requirements. This trade-off-driven design landscape underscores the need for a comprehensive evaluation approach that simultaneously considers mechanical behaviour and ergonomic performance under realistic usage conditions.

During the early stages of product development, concept selection is often guided by subjective judgment, visual inspection, or limited user input. While numerical simulations can offer insight into structural performance, comparing multiple design alternatives becomes increasingly complex when diverse criteria—such as stress response, deformation, posture influence, and operational usability—must be assessed concurrently. In this regard, intelligent decision-support systems provide an opportunity to structure and interpret multi-criteria evaluation data, thereby reducing subjectivity and enhancing transparency in the selection process.

Artificial intelligence has been progressively integrated into engineering design workflows to support evaluation, comparison, and validation tasks. Rather than supplanting conventional design reasoning, AI-based tools can complement engineering judgment by organizing performance indicators, ranking competing concepts, and assisting in dimensional refinement based on quantitative inputs. When coupled with simulation outputs and geometric descriptors, intelligent decision-support methods are particularly effective during early-stage evaluation, where relatively small design modifications can substantially affect user interaction and product performance.

In this study, an AI-assisted framework is proposed for the comparative evaluation and structural validation of a household debris collection tool. Three dustpan concepts were developed and assessed under representative sweeping, lifting, and upright load-bearing scenarios using static structural analysis. Key simulation results were subsequently employed as inputs for AI-driven concept comparison and ranking. In parallel, ergonomic performance was evaluated using AI-assisted analysis of geometric parameters derived from two-dimensional design representations. Following the combined assessment, the highest-ranked concept underwent further AI-supported dimensional validation and was fabricated using additive manufacturing to confirm feasibility. The results illustrate that integrating simulation-based analysis with intelligent decision-support techniques can enhance objectivity and consistency in early-stage concept selection for simple household products, while preserving engineering rigor and design transparency.

## II. PROBLEM STATEMENT

Household dustpans are routinely employed during cleaning tasks, and their functional performance has a direct influence on both user comfort and operational efficiency. Although these tools are widely adopted, many current designs continue to exhibit recurring shortcomings during everyday use. Typical problems include excessive forward bending during sweeping, inadequate retention of fine debris, loss of collected waste during lifting or transport, and insufficient stability when positioned on the floor or stored in an upright orientation. Collectively, these deficiencies contribute to repeated cleaning actions, increased physical strain, and diminished usability in domestic settings.

Despite substantial progress in ergonomics and systematic product design, the translation of these principles to basic household cleaning implements has remained relatively limited. Many existing dustpan solutions attempt to resolve specific deficiencies in isolation—for example, minimizing bending through elongated handles or limiting spillage through enclosure features—yet such modifications often introduce secondary issues related to balance, handling complexity, maintenance demands, or user effort. Consequently, an integrated dustpan configuration that simultaneously satisfies structural integrity, ergonomic comfort, and everyday practicality has yet to be clearly established.

In early phases of product development, concept selection is frequently guided by subjective assessment, visual comparison, or restricted qualitative feedback. When multiple design alternatives are under consideration, the absence of a structured evaluation framework makes it difficult to compare concepts in a consistent and objective manner, particularly when both mechanical performance and ergonomic factors must be considered. This reliance on informal decision-making increases the likelihood of suboptimal concept selection and reduces confidence in early-stage design choices.

Accordingly, a structured evaluation strategy is required to enable systematic comparison of dustpan concepts under representative usage conditions. Such a strategy should combine engineering-based validation with intelligent decision-support techniques to facilitate objective concept ranking and informed dimensional refinement during the conceptual design stage.

Implementing this approach has the potential to strengthen early design decisions and contribute to the development of household debris collection tools that are more comfortable, stable, and reliable in practical use.

## III. LITERATURE REVIEW

Ergonomics and user-centred design principles have long been recognized as essential contributors to product usability, particularly for items subjected to frequent and repetitive use. Sharma *et al.* developed an ergonomics-integrated design framework incorporating parameter optimization, computer-aided design, and digital human modelling to evaluate posture and physical effort in cleaning equipment [1].

Their findings demonstrate that handle placement, interaction geometry, and user posture significantly influence comfort during repeated tasks. Although their methodology targets structured design workflows, the underlying insight reinforces the importance of designing even simple tools around realistic human interaction rather than conventional form assumptions.

Recent literature has also emphasized the role of design thinking supported by computational tools in early-stage product development. Leão *et al.* investigated the combined use of ergonomics, design thinking, and artificial intelligence in design innovation [2]. The authors argue that intelligent systems are most effective when employed as decision-support tools that assist designers in interpreting user needs, rather than as replacements for human-centred reasoning. Their work highlights the potential of AI-based methods for comparing and validating design concepts before physical realization, particularly when usability-related parameters are involved.

The application of ergonomic principles through digital design environments has been further explored by Wu, who examined the use of computer-aided design tools for ergonomic product development [3]. The study emphasizes that products intended for regular daily use must prioritize ease of handling, comfort, and operational reliability. Importantly, the research supports the integration of ergonomic evaluation at the conceptual design stage, where fundamental design decisions can be made more effectively than through post-design modifications.

Extending ergonomics into data-driven domains, Dong and Wang introduced the concept of intelligent safety ergonomics within the context of big data and intelligent systems [4]. While their work focuses on advanced applications, it underscores a broader design objective: minimizing physical strain and unpredictable interaction across routine activities. This perspective reinforces the relevance of stability and controlled behaviour in products designed for everyday tasks.

Cleaning tools have also received targeted attention in product-oriented studies. Arciniega-Rocha *et al.* explored emerging trends in broomstick and dustpan design, identifying reduced physical effort and improved comfort as primary design goals [5].

At the same time, the authors caution that excessive mechanical complexity can compromise usability, suggesting that effective cleaning tools should balance ergonomic enhancement with structural simplicity.

Sustainability-oriented approaches to cleaning system design have been proposed by Antonio *et al.*, who examined modular and compact solutions for solid waste management [6]. Although their work primarily addresses attachment-based and larger-scale systems, it highlights the continued importance of compact, standalone tools for routine household cleaning. This observation supports the need for improving basic cleaning implements alongside more advanced waste management technologies.

Broader reviews of ergonomic research further reveal gaps in application. You surveyed novel developments in ergonomic design and noted that many studies concentrate on industrial or complex systems, with comparatively limited focus on everyday household products [7]. Similarly, Mugisha emphasized that ergonomic strategies aimed at reducing repetitive physical strain are equally applicable to domestic activities, despite being predominantly discussed in workplace contexts [8].

Collectively, the reviewed studies provide a strong theoretical foundation in ergonomics, user-centred design, and intelligent decision-support methods. However, they largely remain at the level of general principles and methodological frameworks, with limited translation into systematic design validation for simple household cleaning tools. This gap highlights the opportunity to apply established ergonomic and AI-assisted evaluation concepts within a practical, application-driven design context.

## IV. DESIGN MOTIVATION AND PROBLEM IDENTIFICATION

**Fig 1: Hand-held Dustpan**

**Fig 2: Long Handle Dustpan**

**Fig 3: Cover Lid Dustpan**

In **Fig 1**, Traditional hand-held dustpans require users to adopt a low, forward-bent posture while maintaining continuous manual support of the pan during sweeping. Prolonged repetition of this posture often results in discomfort and fatigue, particularly among elderly users and individuals experiencing back or knee-related limitations. Moreover, the shallow profiles typical of standard dustpans provide inadequate containment for lightweight debris such as fine dust, hair, and small paper fragments, which frequently escape during transport to disposal locations. Users are commonly required to interrupt cleaning to shake or reposition the pan to settle collected waste, reducing overall efficiency. The inability of such dustpans to stand independently further restricts usability, as even minor secondary actions—such as opening doors or moving objects—become inconvenient during cleaning.

In **Fig 2**, Long-handled dustpans partially address postural discomfort by enabling sweeping in a more upright stance; however, they introduce additional challenges in everyday use. Many such designs exhibit insufficient stability and are prone to tipping when subjected to minor disturbances, resulting in the loss of collected debris. Open-front configurations further exacerbate spillage during movement, particularly on uneven indoor surfaces. Storage also presents difficulties, as long-handled dustpans often fail to remain upright without external support and occupy valuable space in compact household settings.

In **Fig 3,** Dustpans incorporating covers or lids seek to improve waste containment, yet their reliance on moving components leads to new usability concerns. Frequent opening and closing of the lid interrupt the natural flow of cleaning tasks, while hinges and enclosed cavities tend to accumulate dust, moisture, and Odor over time. These components can be difficult to clean and may degrade with prolonged use. In addition, the reduced entry opening created by the lid requires precise alignment between the broom and dustpan, increasing the likelihood of debris scattering during quick or casual sweeping actions.

Taken together, these observations indicate that existing dustpan designs tend to resolve isolated problems while introducing new limitations under realistic usage conditions. This highlights the need for a dustpan concept that minimizes extreme bending without sacrificing stability, ensures secure waste retention without dependence on complex or movable parts, facilitates quick and effortless sweeping, and remains stable during both operation and storage. Addressing these practical shortcomings provided the central motivation for the present study and informed the systematic development and evaluation of multiple dustpan concepts under representative household conditions.

## V. METHODOLOGY

The methodology adopted in this study follows a structured workflow designed to support objective concept evaluation and validation during the early stages of product development. The approach integrates conceptual design generation, simulation-based structural assessment, and artificial intelligence–assisted decision support to reduce subjectivity and strengthen confidence in concept selection. The key stages of the methodology are outlined below.

### ➔ Concept Generation and Representation

Drawing from the practical shortcomings identified in existing household dustpans, three alternative design concepts were developed during the conceptual design phase. Each concept was formulated to satisfy the same functional objectives while differing in overall form, handle configuration, and geometric layout.

A structured concept generation process was employed to ensure consistency across alternatives and comparability in terms of intended usage. Two-dimensional design representations were prepared for each concept to clearly define essential dimensions and geometric parameters required for subsequent evaluation stages.

### ➔ Structural Analysis Configuration

To examine the mechanical performance of the proposed concepts under realistic household conditions, static structural analyses were performed for all three designs. Polypropylene (PP), a material widely used in domestic cleaning products, was selected to represent realistic manufacturing conditions. Three representative loading scenarios were defined to reflect common user interactions: sweeping, lifting, and upright load-bearing.

For each scenario, appropriate boundary conditions and load applications were assigned to replicate typical handling and usage conditions. The analyses focused on identifying stress distribution patterns and total displacement responses to verify structural safety and acceptable deformation during operation. Simulation results were recorded in a consistent manner across all concepts to enable direct and unbiased comparison.

### ➔ AI-Based Structural Performance Comparison

Quantitative results obtained from the structural simulations were utilized as inputs for AI-assisted concept comparison. Performance indicators such as maximum stress and displacement values under each loading condition were processed through an AI-based decision-support framework. The role of the AI system at this stage was to systematically organize and compare multi-criteria performance data, enabling objective ranking of the concepts based on overall structural behaviour. This process helped minimize reliance on subjective assessment during early concept selection.

### ➔ AI-Supported Ergonomic Assessment

In parallel with structural evaluation, an AI-assisted ergonomic assessment was conducted using geometric parameters extracted from the two-dimensional drawings of each concept. Parameters related to handle length, posture influence, and effective dust collection width were analysed to assess ergonomic suitability and anticipated usability. The AI framework facilitated comparison across concepts based on these geometric indicators, allowing ergonomic considerations to be incorporated objectively without requiring physical user trials at the conceptual stage.

### ➔ AI-Assisted Dimensional Refinement

Following the combined structural and ergonomic evaluations, the highest-ranked concept was identified for further refinement. AI-assisted dimensional validation was then applied exclusively to this selected design to support informed decision-making related to key parameters such as handle length and dustpan width. At this stage, the AI system functioned as a validation aid, reinforcing design choices through data-driven insights while complementing, rather than replacing, conventional engineering judgment.

## VI. CONCEPT GENERATION AND REPRESENTATION

The concept development phase focused on generating and representing multiple design alternatives for a household debris collection tool derived from the identified problem context and design motivation. Three dustpan concepts were developed with identical functional objectives but differing geometric layouts and handling strategies to enable structured comparison. Early-stage conceptual sketches were employed to explore overall form, handle orientation, pan geometry, and anticipated user posture, allowing rapid evaluation prior to imposing dimensional constraints. These sketches were subsequently translated into two-dimensional drawings to define key proportions, geometric relationships, and dimensional parameters required for ergonomic and AI-assisted evaluation. Three-dimensional models were then created from the 2D representations to support spatial visualization, interaction assessment, and structural simulation. This progressive transition from sketches to 2D drawings and 3D models ensured design consistency across concepts and established a robust basis for objective evaluation in subsequent stages.

### A) CONCEPT 1

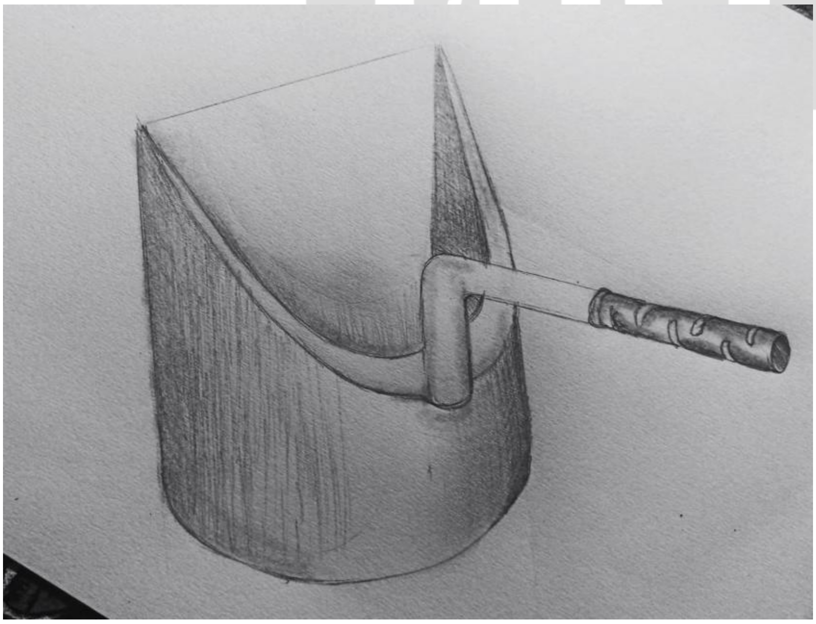


**Fig 4: Sketch of Concept 1**

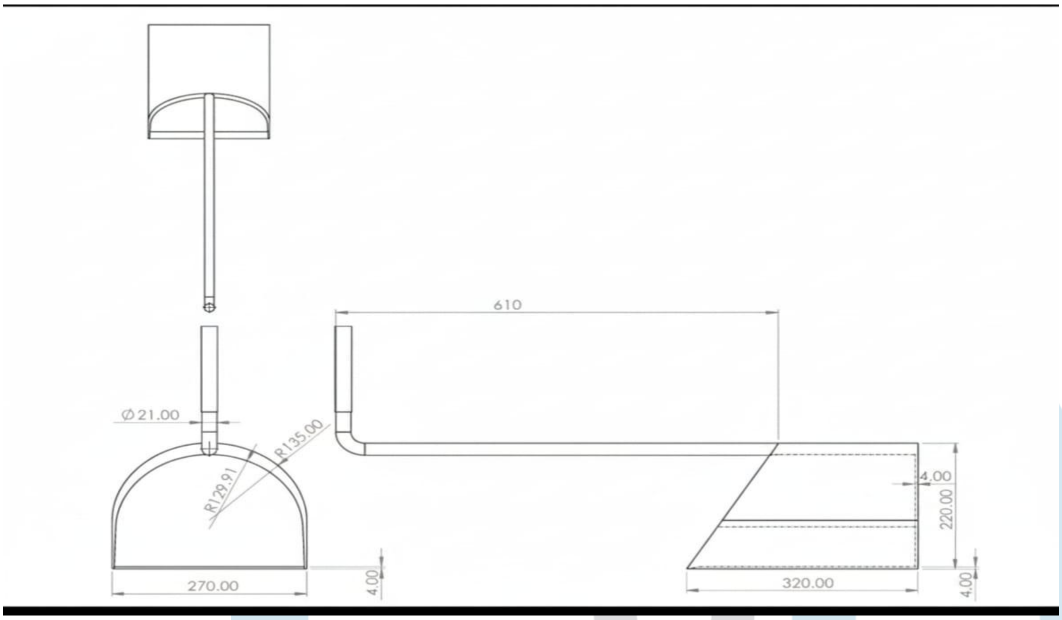



**Fig 5: 2D draft of concept 1**

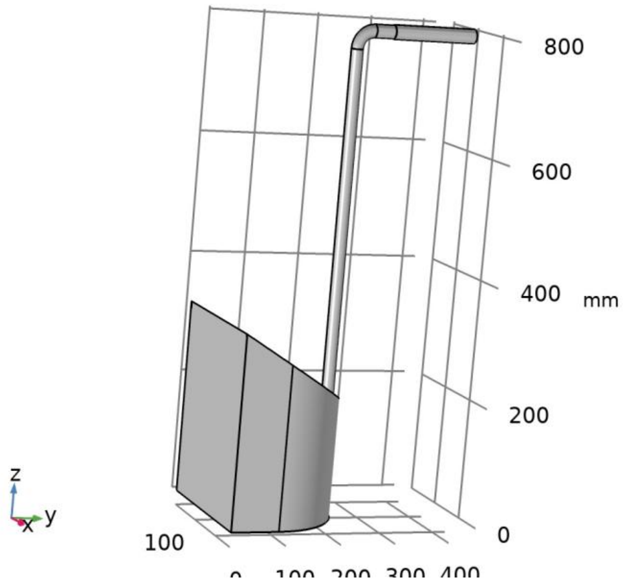



**Fig 6: 3D model of Concept 1**

**Concept 1** was developed to minimize extreme bending during sweeping while maintaining a simple, stable form suitable for routine household use. The design originated from a hand-drawn conceptual sketch in **Fig 4** that examined user posture, introducing a long handle to enable sweeping in a more upright position and thereby reduce physical strain. This concept was subsequently translated into a two-dimensional technical draft in **Fig 5** to establish clear proportions and dimensional relationships. A dustpan width of 270 mm was selected to align with typical household broom widths, while a pan depth of 320 mm was incorporated to provide adequate waste capacity without frequent emptying. The overall dustpan height of 220 mm supports effective debris containment while preserving close contact with the floor surface. A handle length of 610 mm, aligned at approximately 180 degrees, was adopted to promote natural arm movement during sweeping. The curved pan geometry assists in directing debris inward, reducing spillage and repeated cleaning actions, while a smooth front edge enables fine dust and hair to enter the pan with minimal resistance. The corresponding three-dimensional model in **Fig 6** was used to verify spatial balance, stability, and usability, confirming the concept's suitability for further evaluation and comparative analysis.

### B) CONCEPT 2

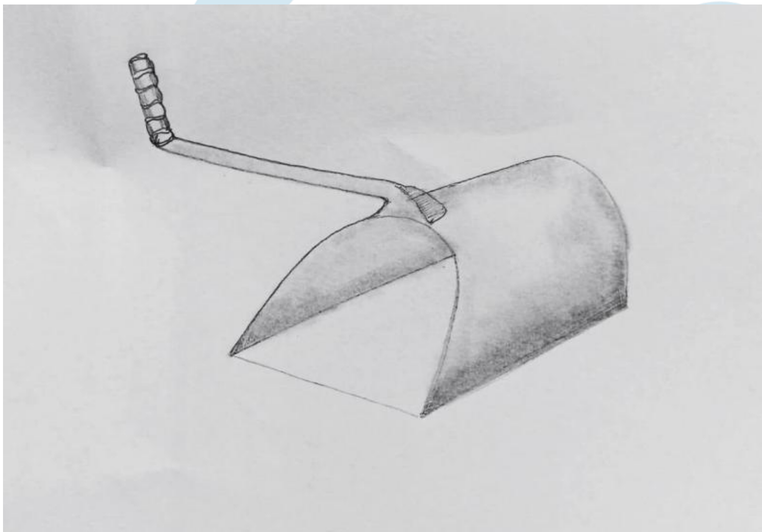


**Fig 7: Sketch of Concept 2**

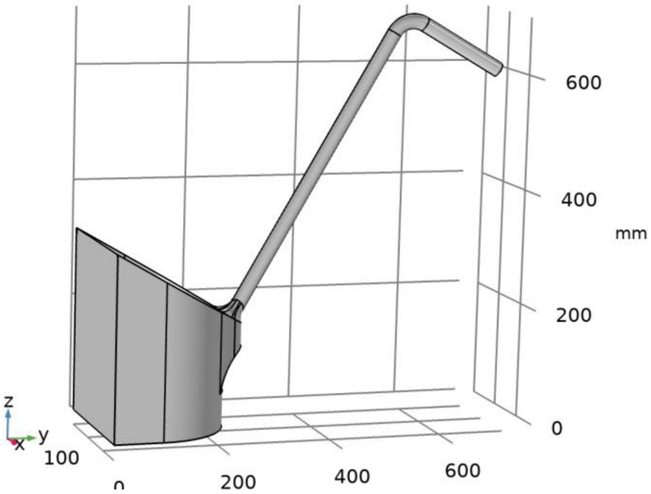



**Fig 8: 3D model of Concept 2**

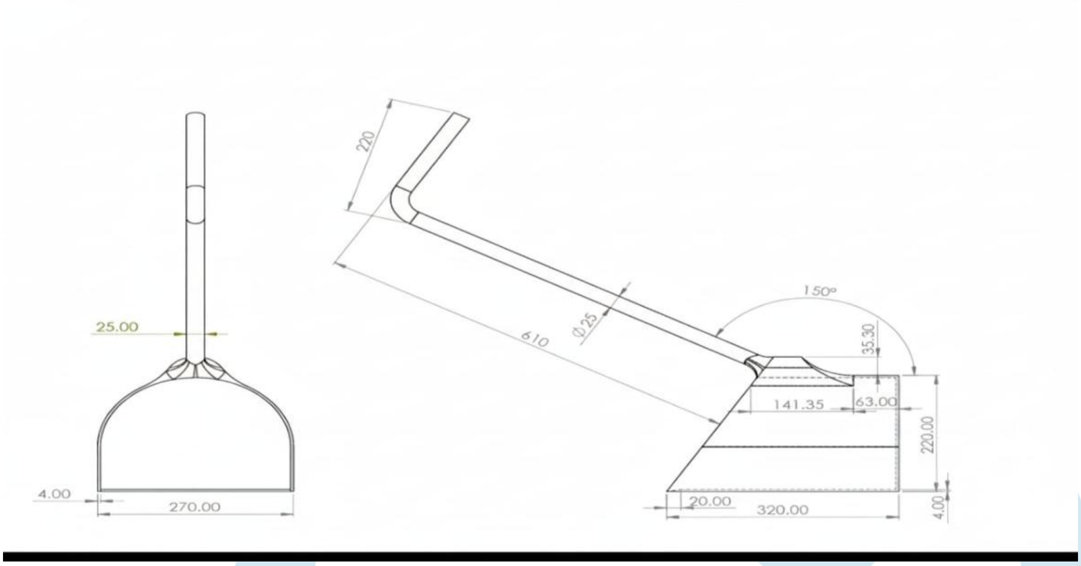



**Fig 9: 2D Draft of Concept 2**

**Concept 2** was developed as an iterative refinement of the initial design, with emphasis on enhancing ergonomic comfort, user control, and operational stability during sweeping. The conceptual sketch in **Fig 7** investigates an adjusted handle orientation intended to support a more natural arm and wrist alignment while pushing debris, thereby reducing fatigue during extended use. This concept maintains a wide and deep dustpan profile to ensure effective debris retention while improving balance during lifting and movement. The design was translated into a two-dimensional technical representation as in **Fig 9** defining key dimensions, including a handle length of 610 mm, a dustpan width of 270 mm, a base depth of 320 mm, and a pan height of 220 mm, providing adequate collection capacity and consistent floor contact. Unlike the straight handle configuration used in Concept 1, a handle inclination of approximately 150° was introduced to improve pushing comfort and force application. A handle diameter of 25 mm was retained to support a secure and comfortable grip during repeated use. The front edge geometry was preserved to facilitate smooth entry of fine dust across common household floor surfaces. The corresponding three-dimensional model as in **Fig 8** was used to verify spatial proportions, interaction geometry, and overall usability under representative operating conditions.

### C) CONCEPT 3

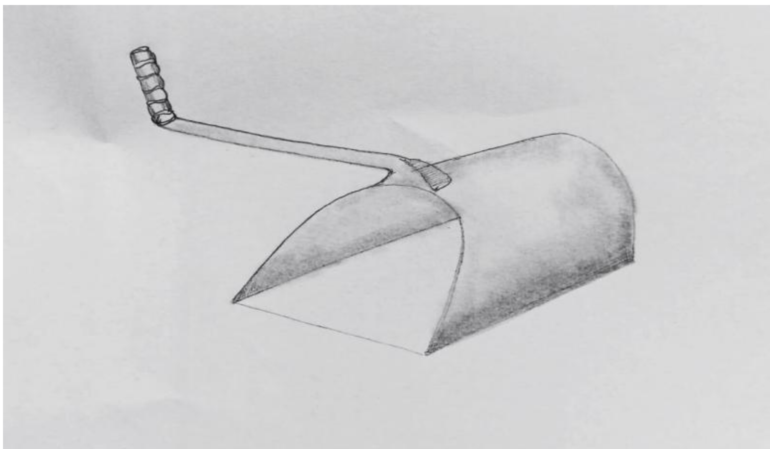


**Fig 10: Sketch of Concept 3**

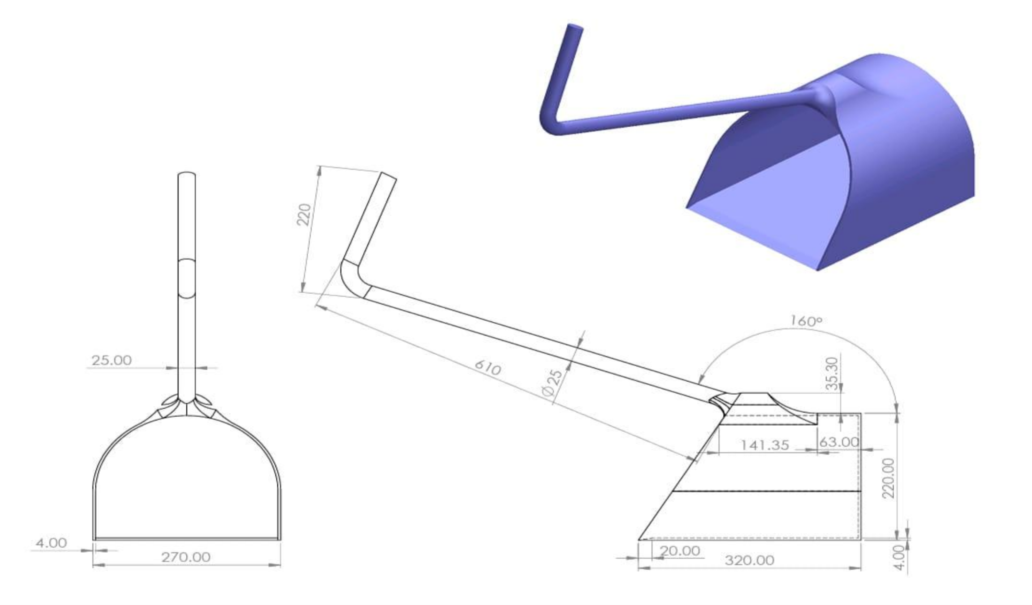



**Fig 11: 2D Draft of Concept 3**

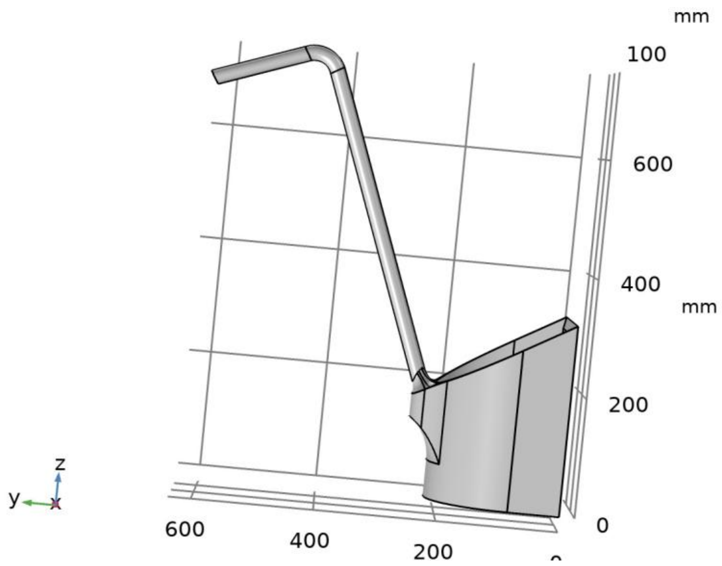



**Fig 12: 3D model of Concept 3**

**Concept 3** was formulated as a comparative design alternative to Concepts 1 and 2, intended to investigate the influence of handle orientation and pan geometry rather than serving as an iterative refinement. The initial conceptual sketch in **Fig 10** focused on examining a modified handle inclination to evaluate its effect on user posture, sweeping control, and interaction during routine household cleaning. The dustpan body maintains a deep and wide configuration to provide sufficient debris containment while enabling direct comparison of balance and stability with the other proposed concepts. These design features were translated into a two-dimensional technical representation in **Fig 11** defining consistent dimensions, including a pan width of 270 mm, a base length of 320 mm, a pan height of 220 mm, and a handle length of 610 mm, to support objective comparative evaluation. A handle inclination of 160° was introduced to assess ergonomic differences relative to the straight handle of Concept 1 and the inclined configuration of Concept 2. The front edge geometry was preserved to facilitate smooth entry of fine dust from common household floor surfaces. A corresponding three-dimensional model as in **Fig 12** was developed to visualize spatial relationships, handling posture, and interaction geometry under realistic operating conditions. Overall, Concept 3 functions as a benchmark design to assess how variations in handle angle and geometry affect usability, ergonomic comfort, and operational stability in comparison with the other concepts.

## VII. STRUCTURAL ANALYSIS CONFIGURATION

To enable objective and repeatable comparison, all three dustpan concepts were analysed using an identical structural simulation framework. The analyses were configured to represent realistic household usage scenarios while ensuring direct comparability across concepts. Polypropylene material properties were consistently assigned to all models, and uniform meshing strategies and solver parameters were maintained throughout the study. Three representative operating scenarios were defined to capture typical user interactions: lifting, sweeping, and upright load-bearing.

For the lifting scenario, a uniform pressure of **8000 N/m²** was applied to the inner base surface of the dustpan to represent the load associated with collected debris during lifting. The handle grip region was constrained to simulate user support, allowing evaluation of stress distribution and deformation in the pan–handle assembly when the dustpan is raised after sweeping.

In the sweeping scenario, a pressure of **5000 N/m²** was applied at the handle grip to represent the force exerted by the user during sweeping motions. The sweeping base of the dustpan was constrained to replicate contact with the floor surface. This loading condition was used to assess structural stiffness and deformation behaviour of the assembly under repeated pushing actions.

For the upright load-bearing scenario, a pressure of **1000 N/m²** was applied to the inner base of the dustpan while the rear standing surface was fixed, representing the dustpan positioned vertically with debris retained inside. This case was intended to evaluate stability and deformation characteristics during stationary storage.

In addition to the nominal load cases, parametric analyses were performed for each operating scenario to examine structural response trends under varying force levels. For each condition, multiple pressure values were applied to reflect realistic variations in user-applied loads, while maintaining identical loading patterns across all concepts. The resulting maximum von Mises stress and total displacement values were extracted and plotted as functions of the applied load, enabling consistent comparison of stiffness, deformation behaviour, and response linearity among the three concepts.

- **CONCEPT 1 ANALYSIS**

**A) UNDER LIFTING CONDITION**

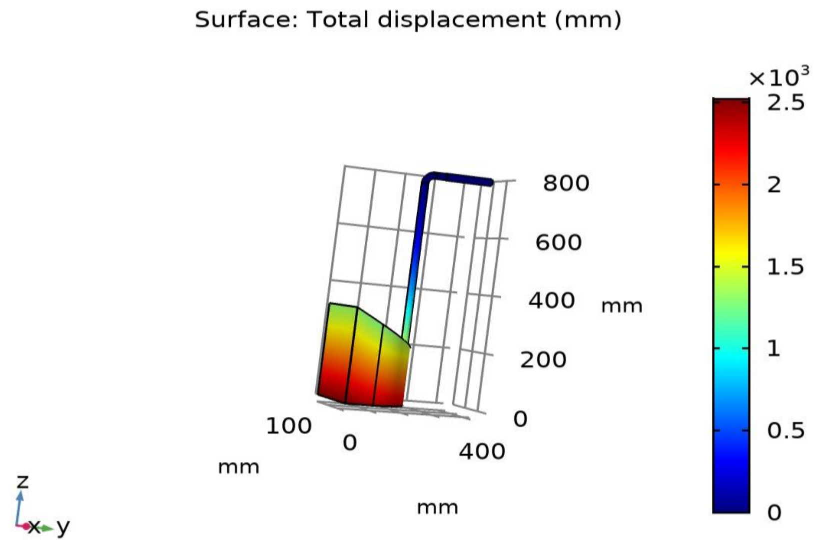



**Fig 13: Total Displacement under load(8000N/m^2)**

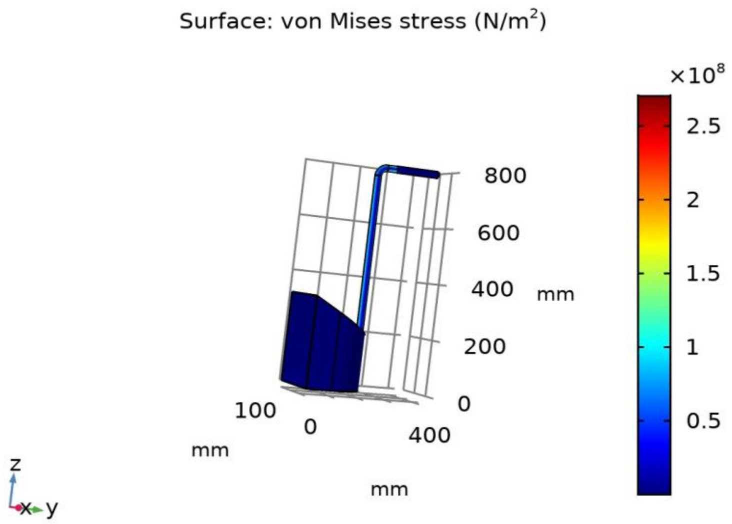
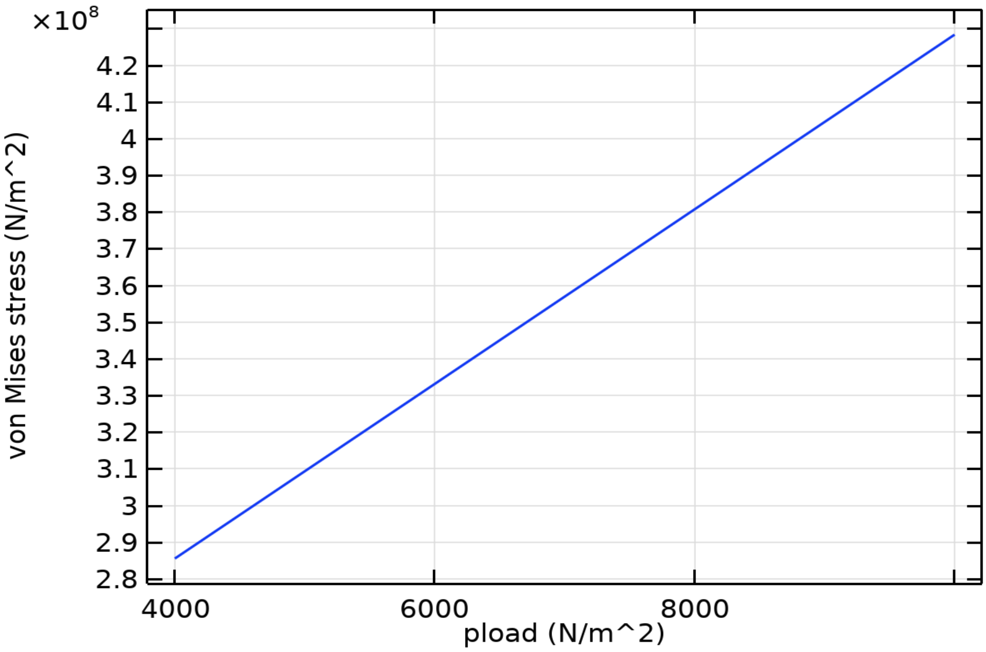



**Fig 14: Von Mises Stress under load (8000N/m^2)**

**Volume Maximum 1 (solid.mises)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 4000.0 | 2.8556E8 |
| 6000.0 | 3.3315E8 |
| 8000.0 | 3.8075E8 |
| 10000 | 4.2834E8 |

**Table 1: Von mises stress under different loads (lifting)**




**Volume Maximum 2 (solid.disp)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 4000.0 | 1679.9 |
| 6000.0 | 1959.9 |
| 8000.0 | 2239.9 |
| 10000 | 2519.8 |

**Table 2: Total Displacement under different loads (Lifting)**

**Fig 16: Total Displacement Vs Load Graph (Lifting)**

## B) UNDER SWEEPING CONDITION

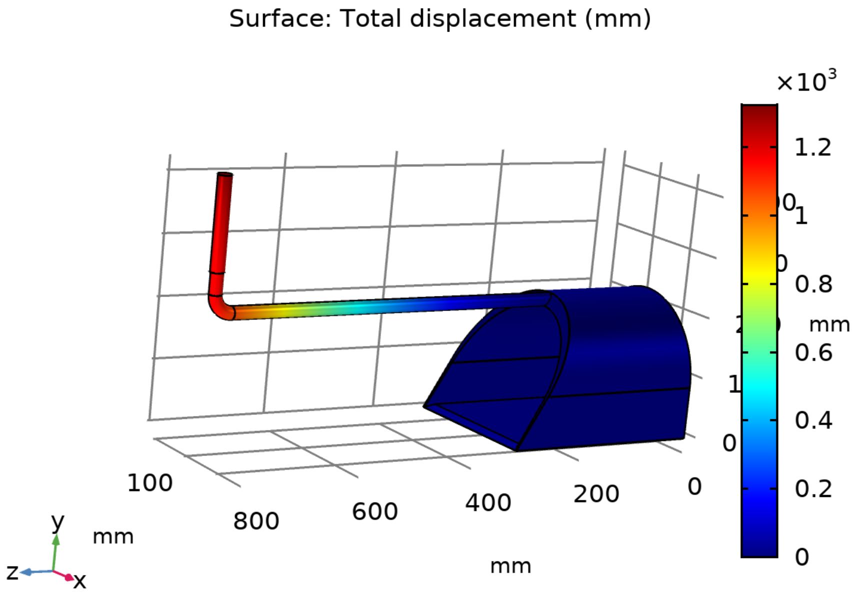



**Fig 17: Total Displacement under load (5000N/m^2)**



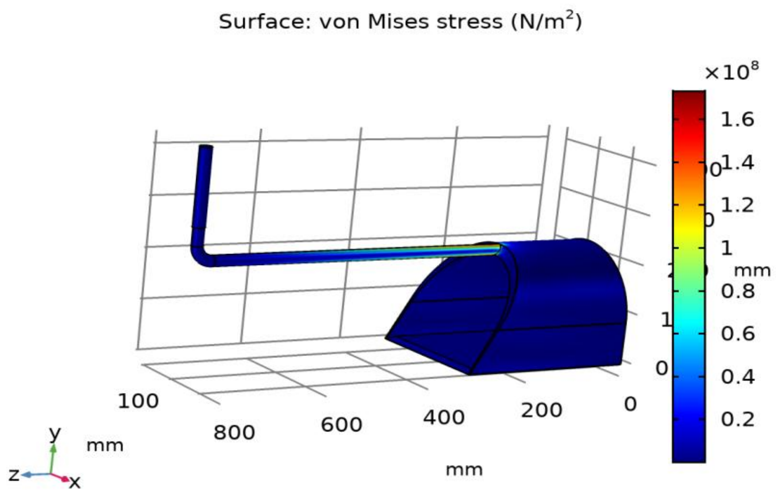



**Fig 18: Von Mises Stress under load (5000 N/m^2)**

**Volume Maximum 2 (solid.disp)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 1000.0 | 397.04 |
| 5000.0 | 661.73 |
| 10000 | 992.60 |
| 15000 | 1323.5 |

**Table 3: Total Displacement Under different loads (sweeping)**

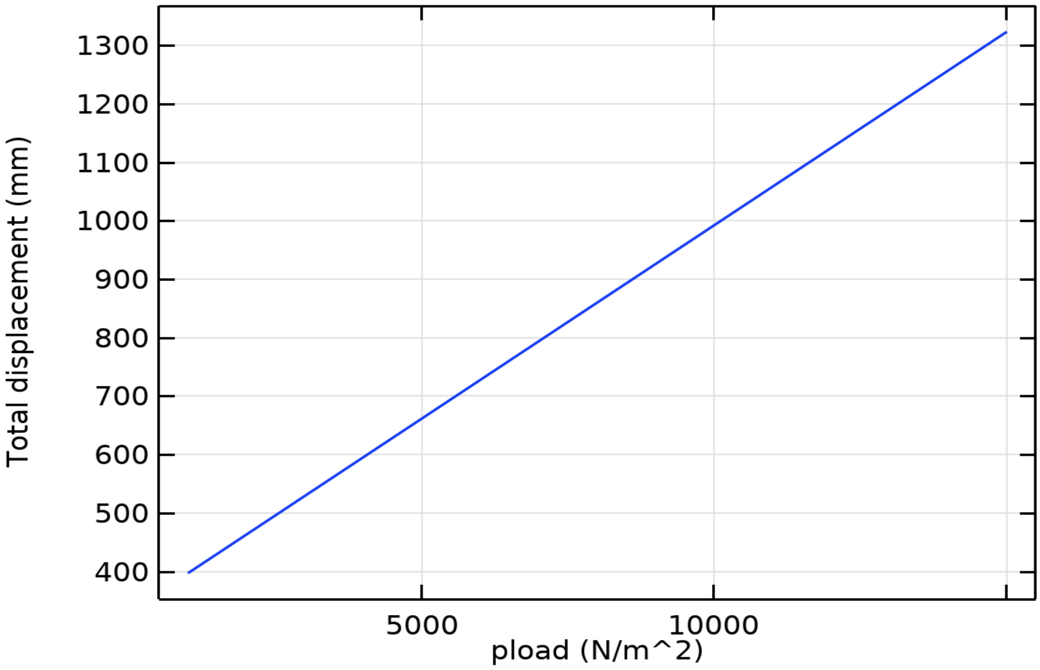



**Fig 19: Total Displacement Vs Load Graph (sweeping)**

**Volume Maximum 1 (solid.mises)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 1000.0 | 6.3896E7 |
| 5000.0 | 1.0649E8 |
| 10000 | 1.5974E8 |
| 15000 | 2.1299E8 |

**Table 4: Von Mises Stress under different loads (Sweeping)**

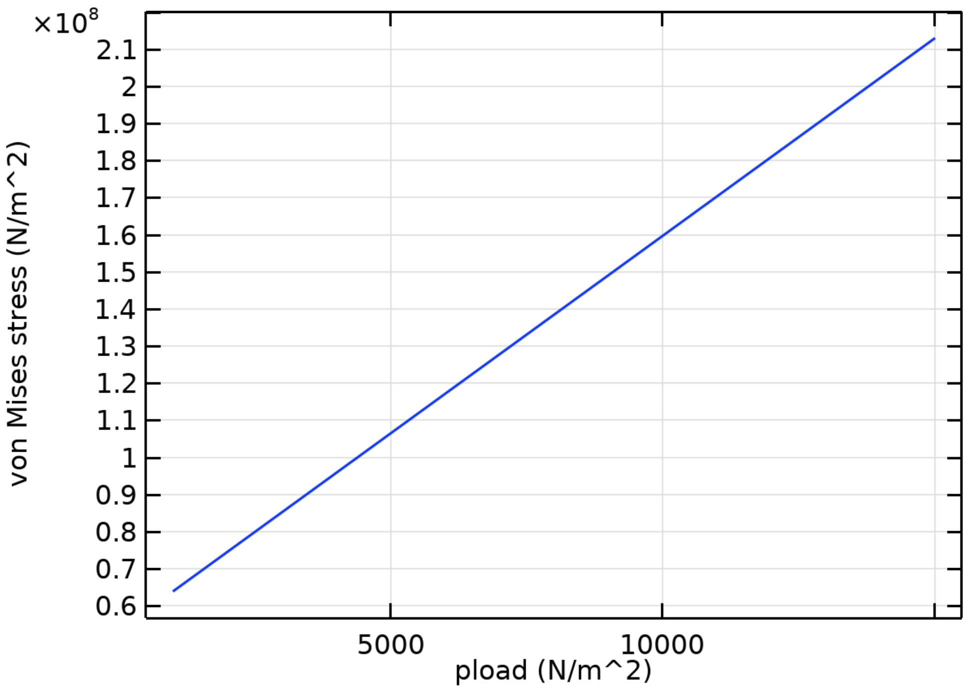



**Fig 20: Von mises Stress Vs Load Graph (sweeping)**

## C) UNDER LOAD BEARING CAPACITY CONDITION

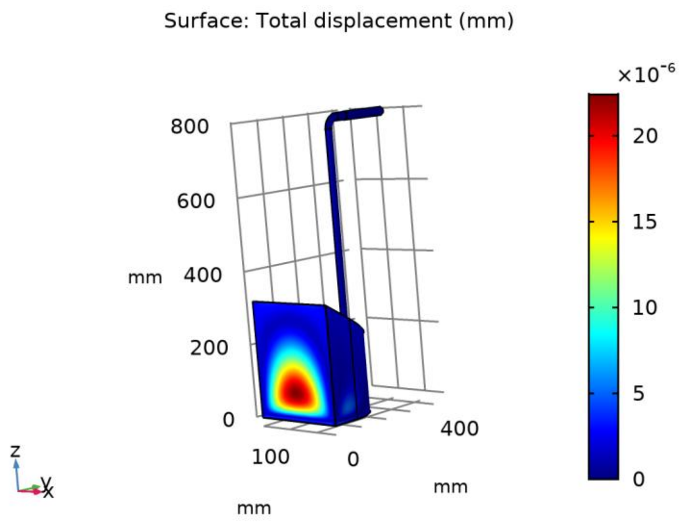



**Fig 21: Total Displacement under load (1000N/m^2)**

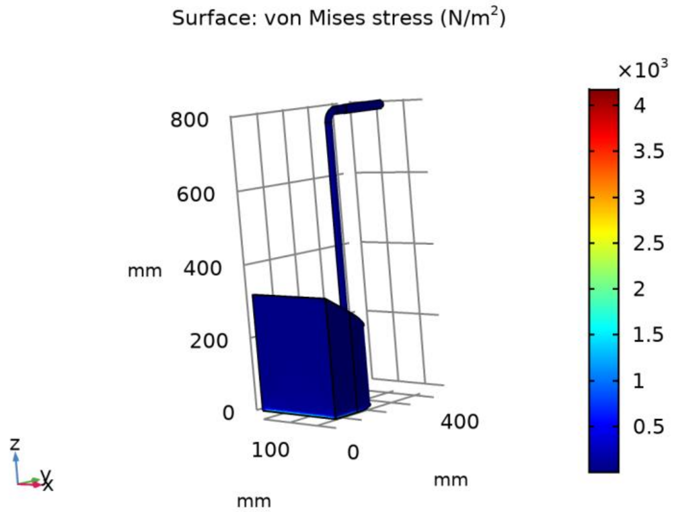



**Fig 22: Von mises stress under load (1000N/m^2)**

**Volume Maximum 1 (solid.mises)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 500.00 | 1372.3 |
| 1000.0 | 1829.8 |
| 2000.0 | 2744.7 |
| 4000.0 | 4574.5 |
| 5000.0 | 5489.3 |

**Table 5: Von Mises Stress under different loads (Load bearing)**

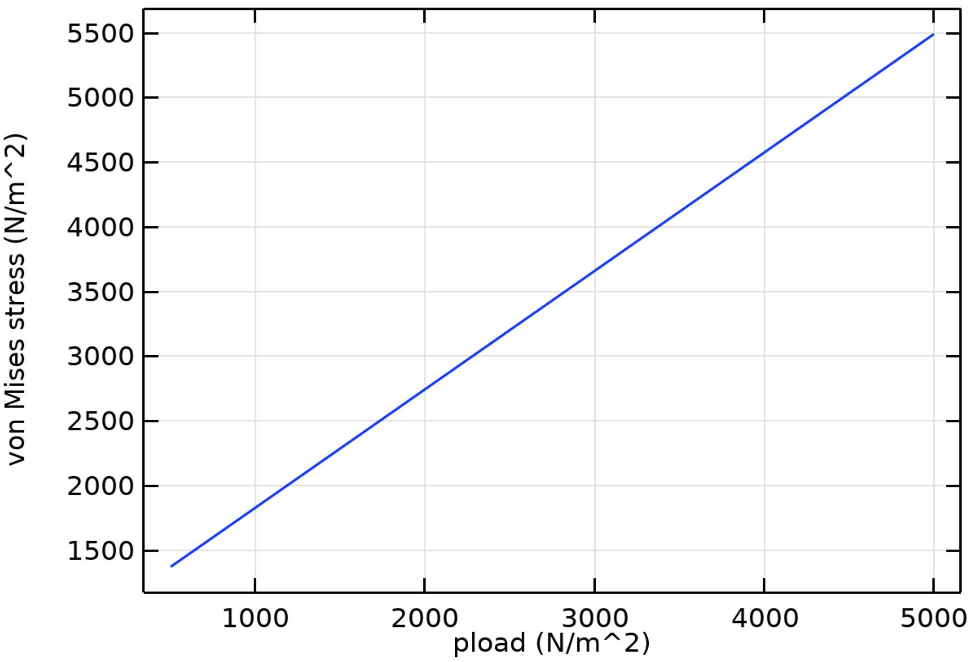



**Fig 23: Von mises Stress Vs Load Graph (Load bearing)**

**Volume Maximum 2 (solid.disp)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 500.00 | 5.6068E-6 |
| 1000.0 | 7.4757E-6 |
| 2000.0 | 1.1214E-5 |
| 4000.0 | 1.8689E-5 |
| 5000.0 | 2.2427E-5 |

**Table 6: Total Displacement under different loads (Load Bearing)**

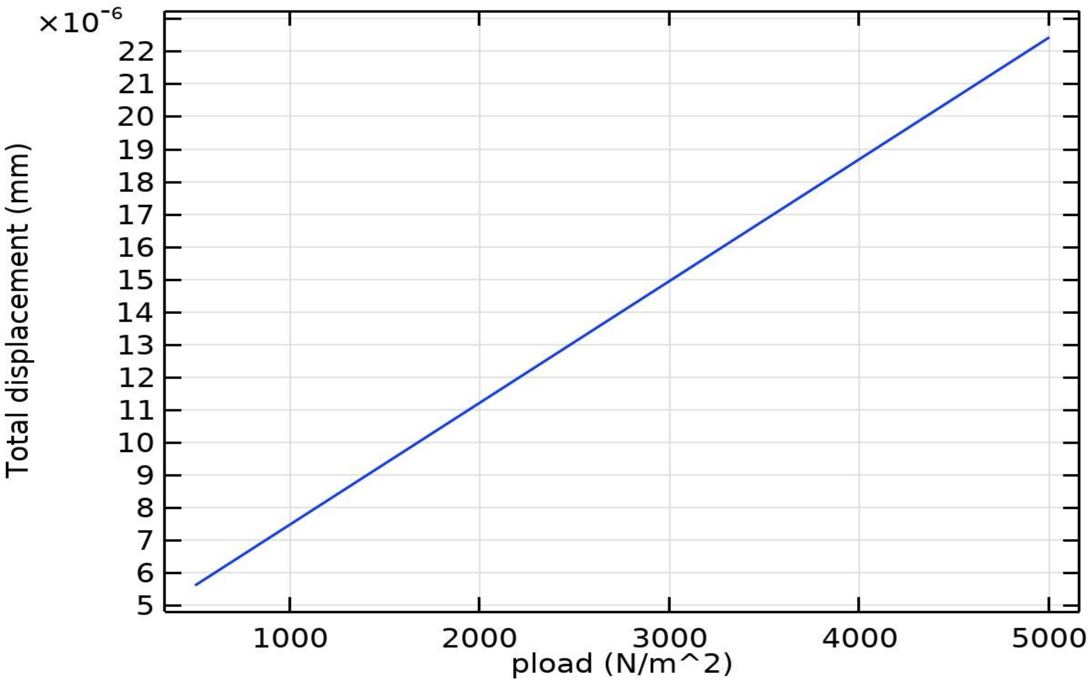



**Fig 24: Total Displacement Vs Load Graph (Load bearing)**

Under the **lifting condition**, the structural response of **Concept 1** at an applied pressure of **8000 N/m²** is illustrated by the total displacement distribution in Fig. 13, where deformation is predominantly concentrated along the handle, with the highest values appearing near its upper region, while the dustpan body exhibits comparatively lower but noticeable movement. This deformation pattern corresponds to the practical scenario in which the dustpan is lifted after debris collection, causing the handle to flex under load and transmit motion to the pan. The gradual variation in displacement contours indicates elastic deformation without abrupt distortion, suggesting mechanically stable behaviour. The associated von Mises stress distribution presented in **Fig. 14** shows localized stress intensification at the handle–pan junction and along the curved handle section, whereas the remaining regions of the pan experience relatively low stress levels, confirming adequate structural integrity during lifting. As summarized in Table 1 and depicted in **Fig. 15,** increasing the lifting pressure from **4000 N/m² to 10000 N/m²** results in an almost linear rise in von Mises stress from approximately **2.8556 × 10⁸ N/m² to 4.2834 × 10⁸ N/m²**, indicating proportional load transfer through the structure. Within the range of typical household lifting loads **(6000–8000 N/m²)**, the stress remains within acceptable limits, while higher loads suggest increased demand on the handle joint over repeated use. A similar linear trend is observed for total displacement, as reported in **Table 2** and illustrated in **Fig. 16**, where values increase from **1679.9 mm to 2519.8 mm** with increasing load, reflecting progressive handle flexibility that remains controlled at moderate loads but becomes more pronounced at higher pressures, potentially influencing perceived stiffness.

During **sweeping**, the displacement contours shown in **Fig. 17** for an applied pressure of **5000 N/m²** indicate that deformation is mainly confined to the free end and curved region of the handle, while the dustpan body remains largely undeformed, ensuring consistent floor contact during cleaning. This localized flexibility contributes to smoother sweeping action by accommodating user-applied forces. The corresponding stress distribution in **Fig. 18** highlights stress concentration near the handle–pan interface and along the handle curvature, with minimal stress across the pan body, demonstrating effective load transfer under normal sweeping conditions. As detailed in **Table 3** and plotted in **Fig. 19**, increasing the sweeping pressure from **1000 N/m² to 15000 N/m²** leads to a near-linear increase in total displacement from **397.04 mm to 1323.5 mm**, indicating predictable deformation behaviour.

Likewise, the von Mises stress values reported in **Table 4** and shown in **Fig. 20** rise steadily from **6.3896 × 10⁷ N/m² to 2.1299 × 10⁸ N/m²**, confirming that stresses remain moderate at typical sweeping loads of around **5000 N/m²**, while higher pressures may influence long-term durability if applied repeatedly.

For the **load-bearing condition**, where the dustpan is maintained in an upright position and subjected to a pressure of **1000 N/m²,** the total displacement distribution in **Fig. 21** reveals minimal deformation concentrated near the base, with the handle and upper regions remaining effectively rigid. This indicates that the structure provides stable support for collected debris without compromising handling. The corresponding von Mises stress contours in **Fig. 22** show uniformly low stress levels throughout the dustpan, with slightly higher values at the lower edges where the load is transferred to the ground. As summarized in **Table 5** and illustrated in **Fig. 23**, a gradual increase in load-bearing pressure from **500 N/m² to 5000 N/m²** results in a smooth rise in von Mises stress from **1372.3 N/m² to 5489.3 N/m²**, remaining well below critical limits. Meanwhile, the displacement values listed in **Table 6** and plotted in **Fig. 24** remain extremely small, on the order of **10⁻⁶ mm,** even at the highest applied load, confirming high stiffness and negligible visible deformation. Collectively, these results demonstrate that Concept 1 exhibits consistent, linear, and structurally reliable behaviour under lifting, sweeping, and load-bearing conditions, while identifying the handle–pan junction as the primary region influencing long-term durability.

★ **CONCEPT 2 ANALYSIS**

**A) UNDER LIFTING CONDITION**

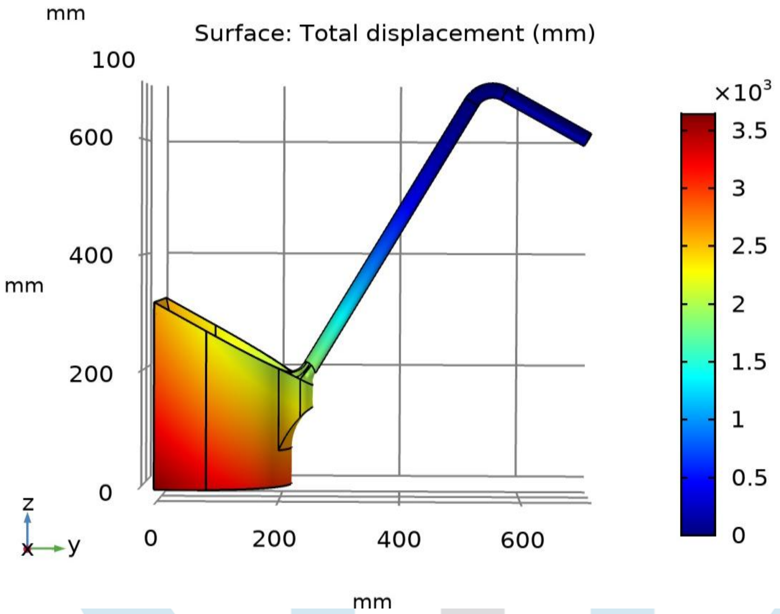



**Fig 25: Total Displacement under load (8000N/m^2)**

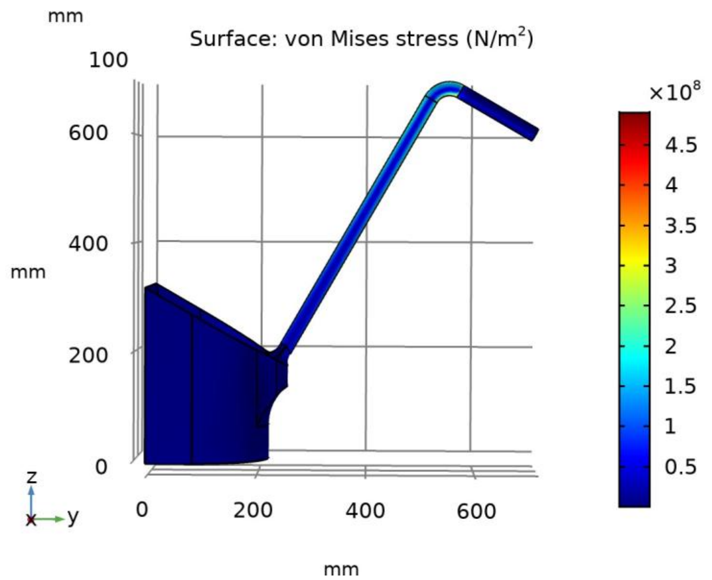



**Fig 26: Von Mises Stress under load (8000N/m^2)**

**Volume Maximum 1 (solid.mises)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 4000.0 | 3.3994E8 |
| 6000.0 | 3.9659E8 |
| 8000.0 | 4.5325E8 |
| 10000 | 5.0991E8 |

**Table 7: Von Mises Stress under different loads (Lifting)**

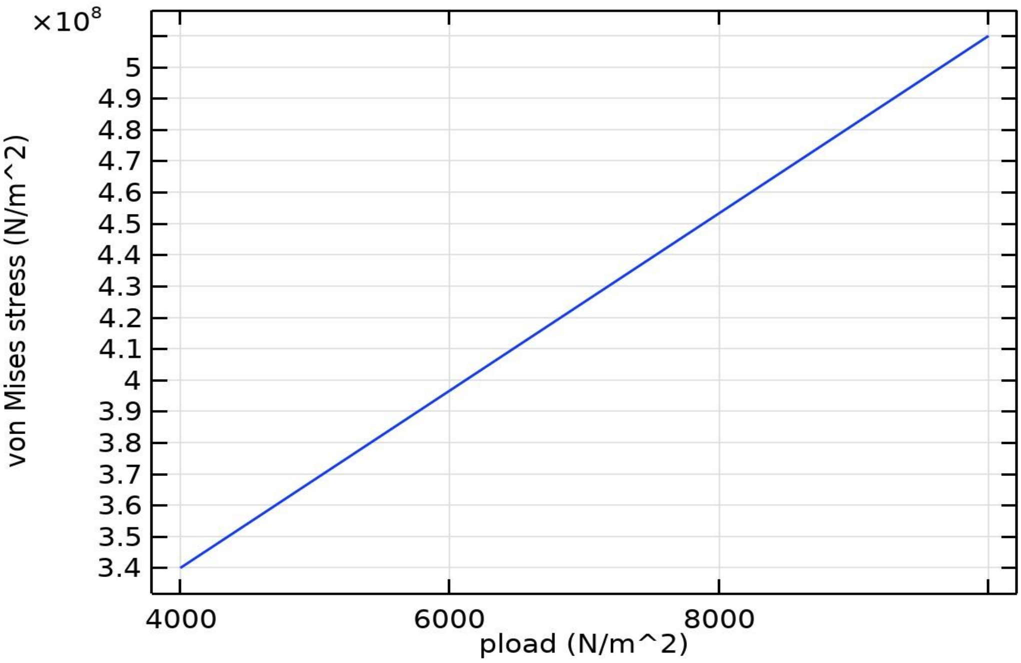



**Fig 27: Von Mises Stress Vs Load graph (Lifting)**

**Volume Maximum 2 (solid.disp)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 4000.0 | 2427.8 |
| 6000.0 | 2832.5 |
| 8000.0 | 3237.1 |
| 10000 | 3641.7 |

**Table 8: Total Displacement under different loads (Lifting)**

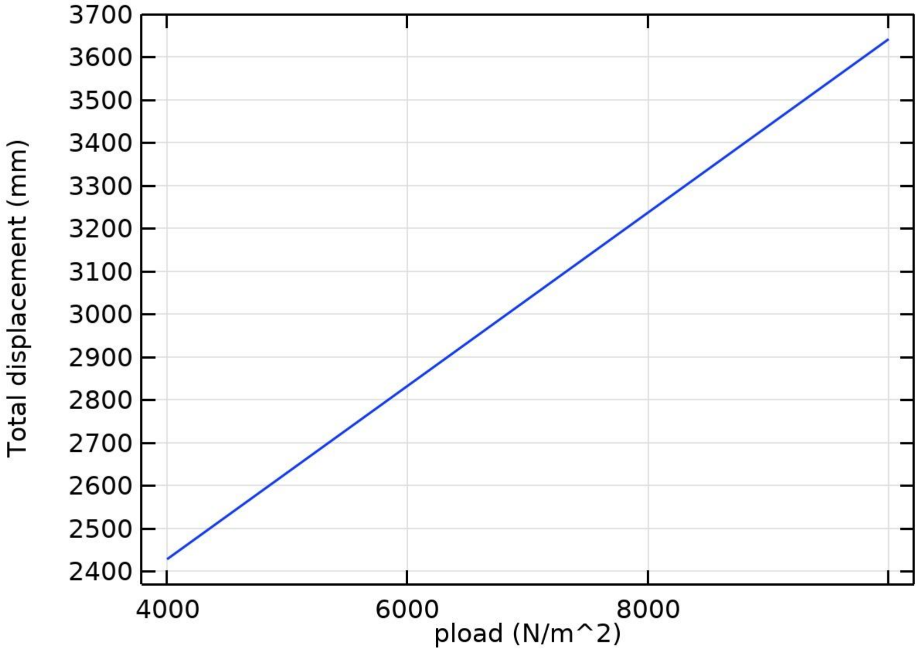



**Fig 28: Total Displacement Vs Load Graph (Lifting)**

## B) UNDER SWEEPING CONDITION

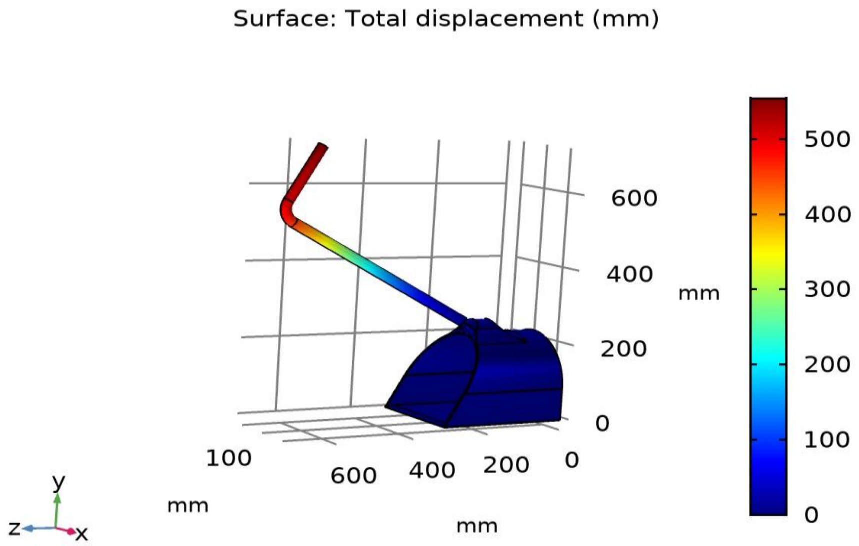



**Fig 29: Total Displacement under load (5000N/m^2)**

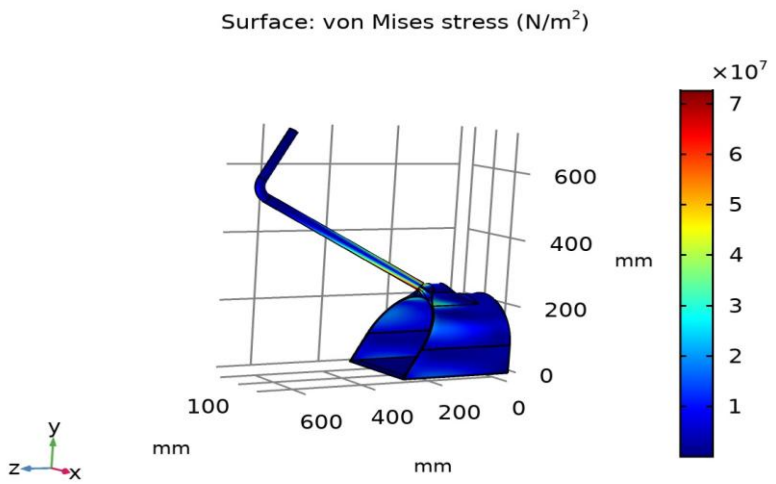



**Fig 30: Von Mises Stress under load (5000N/m^2)**

**Volume Maximum 1 (solid.mises)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 1000.0 | 2.1849E7 |
| 5000.0 | 3.6415E7 |
| 10000 | 5.4622E7 |
| 15000 | 7.2829E7 |

**Table 9: Von Mises Stress under different loads (Sweeping)**

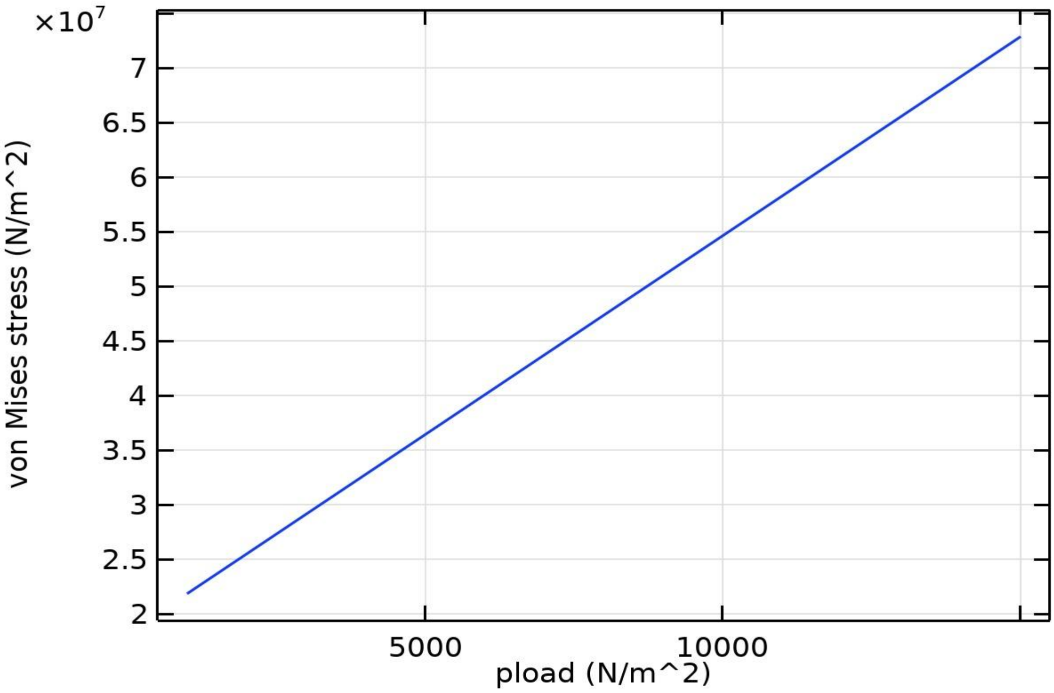



**Fig 31: Von Mises stress vs load Graph (Sweeping)**

**Volume Maximum 2 (solid.disp)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 1000.0 | 166.14 |
| 5000.0 | 276.91 |
| 10000 | 415.36 |
| 15000 | 553.81 |

**Table 10: Total Displacement under different loads (Sweeping)**

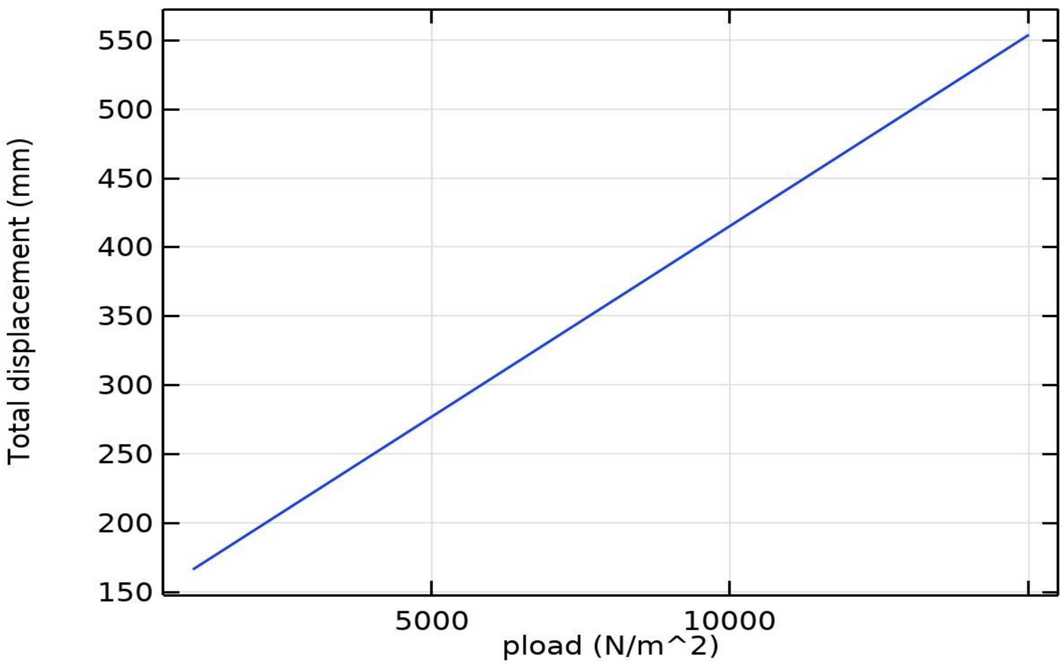



**Fig 32: Total Displacement vs load Graph (Sweeping)**

### C) UNDER LOAD BEARING CAPACITY CONDITION

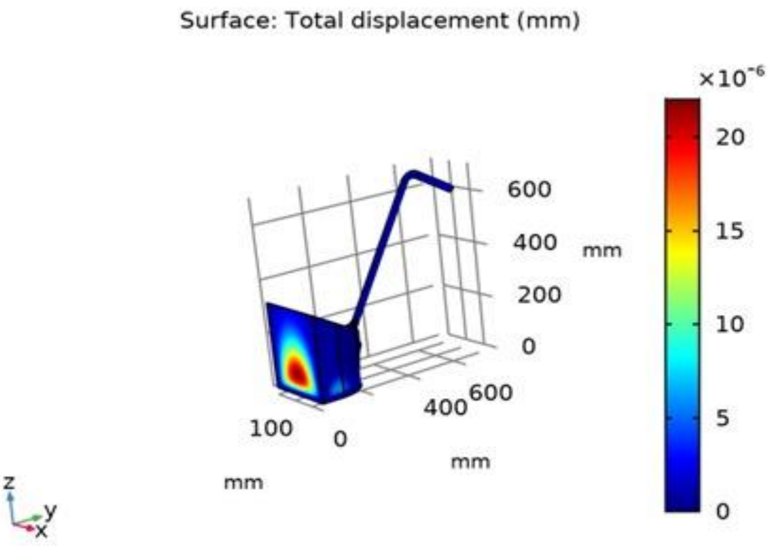



**Fig 33: Total Displacement under load (1000N/m^2)**

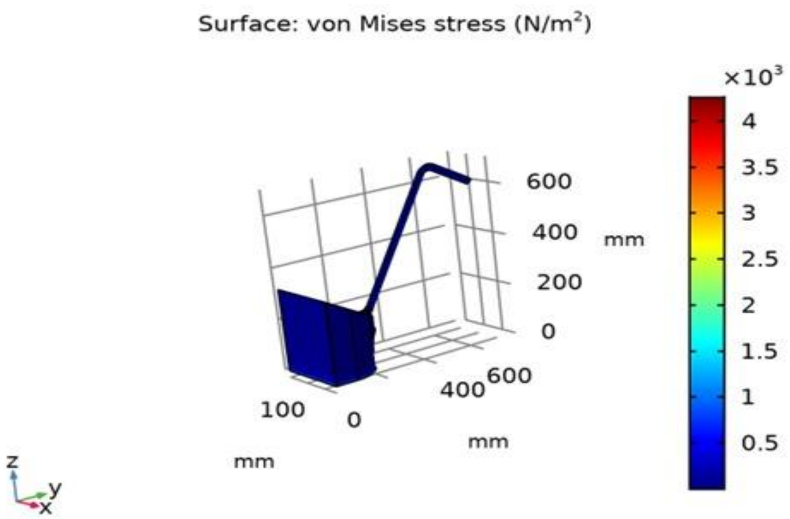



**Fig 34: Von Mises Stress under load (1000 N/m^2)**

**Volume Maximum 2 (solid.disp)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 500.00 | 5.5126E-6 |
| 1000.0 | 7.3502E-6 |
| 2000.0 | 1.1025E-5 |
| 3000.0 | 1.4700E-5 |
| 4000.0 | 1.8375E-5 |
| 5000.0 | 2.2051E-5 |

**Table 11 : Total Displacement under different loads (Load Bearing)**

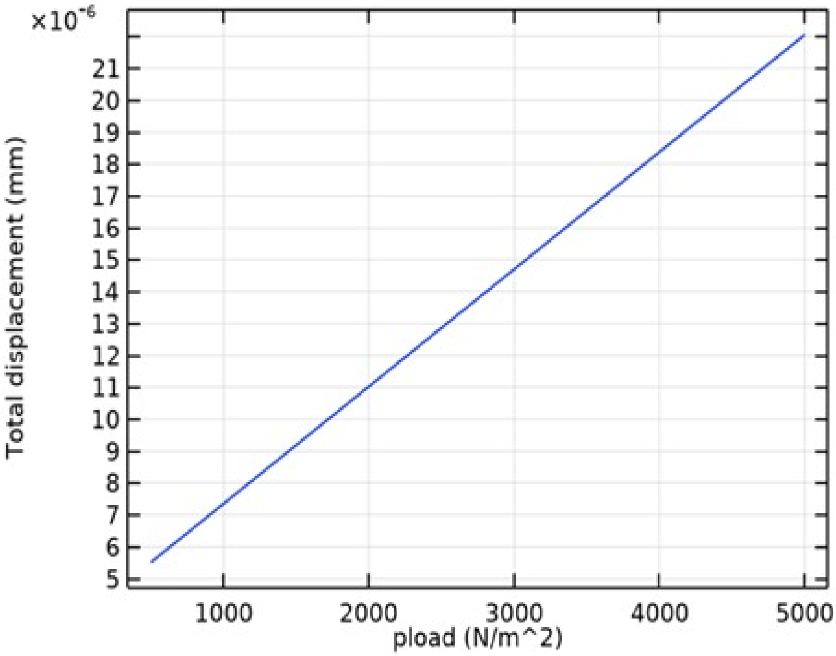



**Fig 35: Total Displacement vs load Graph (Load Bearing)**

**Volume Maximum 1 (solid.mises)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 500.00 | 1253.6 |
| 1000.0 | 1671.4 |
| 2000.0 | 2507.1 |
| 3000.0 | 3342.8 |
| 4000.0 | 4178.6 |
| 5000.0 | 5014.3 |

**Table 12: Von Mises Stress under different loads (Load Bearing)**

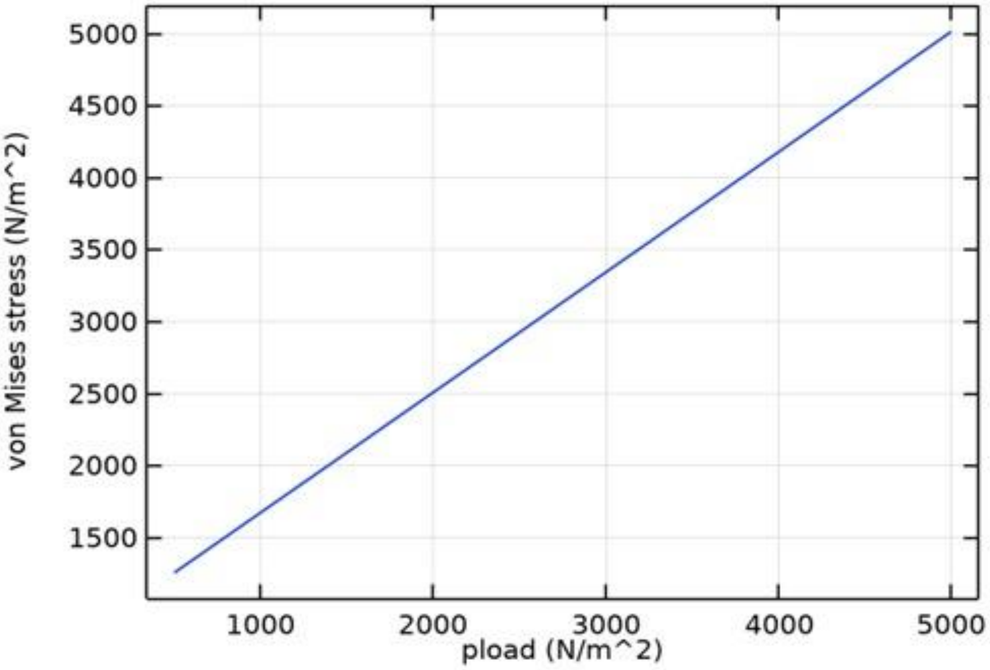



**Fig 36: Von Mises stress vs load graph (Load bearing)**

For **Concept 2** under lifting conditions, the total displacement distribution obtained at an applied pressure of **8000 N/m² (Fig. 25)** indicates that deformation is primarily concentrated within the dustpan body and near the handle–pan junction, while the upper portion of the handle remains comparatively rigid. This behaviour reflects a realistic lifting scenario in which controlled flexibility allows the structure to accommodate load without exhibiting unstable motion, thereby maintaining usability during debris transfer. The corresponding von Mises stress contours shown in **Fig. 26** reveal peak stress localization at the handle–

pan connection and along the curved segment of the handle, which serves as the main load transfer path during lifting, while the remainder of the dustpan body experiences relatively low stress levels. As summarized in **Table 7** and illustrated in **Fig. 27**, von Mises stress increases in an almost linear manner from approximately **3.3994 × $10^8$ N/m² at 4000 N/m² to 5.0991 × $10^8$ N/m² at 10000 N/m²**, indicating stable load transfer without sudden stress escalation. At a representative household lifting pressure of **8000 N/m²**, stress values remain within a consistent range, suggesting suitability for repeated lifting operations. A similar trend is observed in total displacement during lifting, where values reported in Table 8 and plotted in **Fig. 28** increase smoothly from approximately **2427.8 mm to 3641.7 mm** with increasing load, reflecting progressive and controlled flexibility characteristic of plastic household products, with higher loads approaching the practical comfort limit.

Under sweeping conditions, with an applied pressure of **5000 N/m²**, the total displacement contours shown in **Fig. 29** demonstrate that deformation is largely confined to the bent and extended portions of the handle, while the dustpan body remains comparatively rigid. This response ensures stable floor contact during sweeping while allowing limited handle flexibility to absorb user-applied forces and reduce shock transmission to the wrist. The von Mises stress distribution presented in **Fig. 30** confirms that stress concentrations are primarily located along the handle and at the handle–pan junction, with minimal stress observed across the pan body. As the sweeping pressure increases from **1000 N/m² to 15000 N/m²**, the stress values listed in **Table 9** and plotted in **Fig. 31** rise in a near-linear fashion from approximately **2.1849 × $10^7$ N/m² to 7.2829 × $10^7$ N/m²**, indicating structurally stable behaviour without abrupt stress concentration.

Correspondingly, the total displacement values summarized in **Table 10** and shown in **Fig. 32** increase smoothly from about **166.14 mm** to **553.81 mm**, demonstrating predictable deformation that remains controlled even under higher sweeping forces.

For the upright load-bearing condition, where the dustpan is positioned vertically and subjected to a pressure of **1000 N/m²,** the displacement contours in **Fig. 33** show negligible deformation localized near the base, while the handle remains effectively rigid. The associated von Mises stress distribution in **Fig. 34** indicates uniformly low stress levels throughout the structure. As the applied load increases from **500 N/m² to 5000 N/m²**, the total displacement values reported in **Table 11** and plotted in **Fig. 35** remain within the micrometre range, indicating no visible structural deformation. Similarly, the von Mises stress values summarized in **Table 12** and illustrated in **Fig. 36** increase smoothly from approximately **1253.6 N/m² to 5014.3 N/m²**, confirming elastic and predictable structural behaviour. Overall, the results indicate that Concept 2 exhibits consistent, linear, and structurally reliable performance across lifting, sweeping, and load-bearing conditions, supporting durability, functional safety, and user confidence during normal household use.

★ **CONCEPT 3 ANALYSIS**

**A) UNDER LIFTING CONDITION**

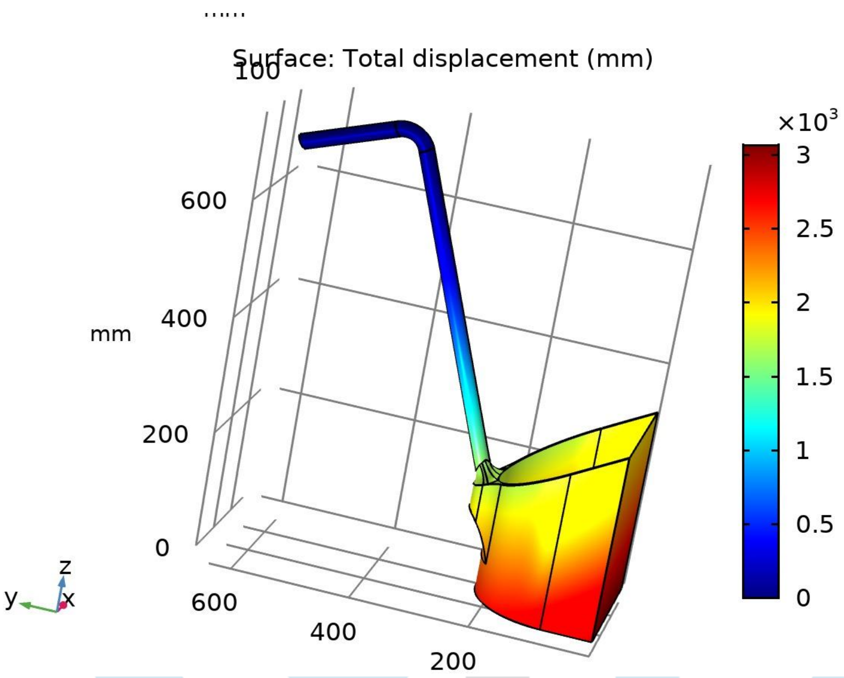



**Fig 37: Total Displacement under load (8000N/m^2)**

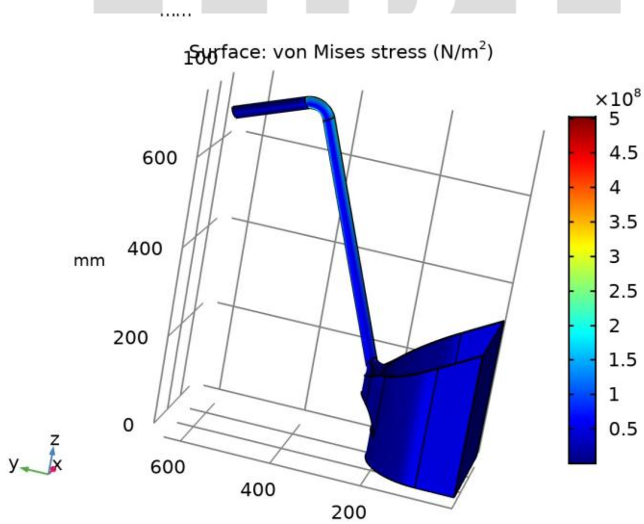



**Fig 38: Von Mises Stress under load (8000N/m^2)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 4000.0 | 3.5313E8 |
| 6000.0 | 4.1198E8 |
| 8000.0 | 4.7084E8 |
| 10000 | 5.2969E8 |

**Table 13: Von Mises stress under different loads (Lifting)**

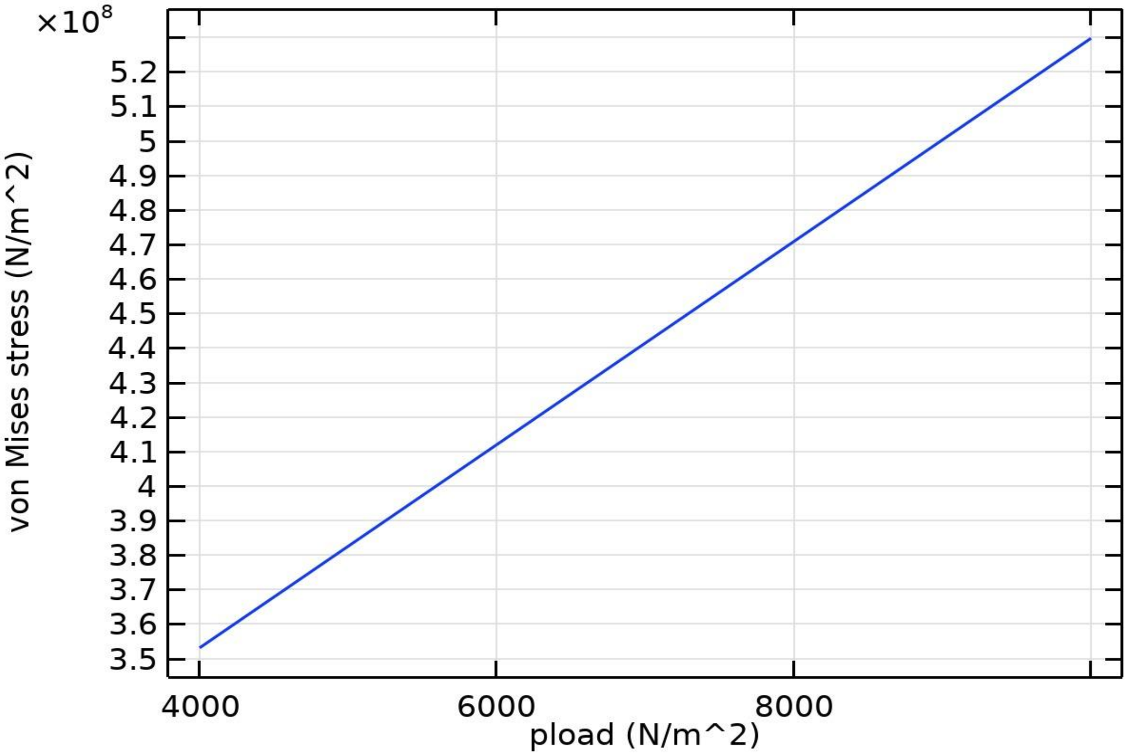



**Fig 39: Von Mises stress vs load Graph (Lifting)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 4000.0 | 2043.7 |
| 6000.0 | 2384.3 |
| 8000.0 | 2724.9 |
| 10000 | 3065.6 |

**Table 14: Total Displacement under different loads (Lifting)**

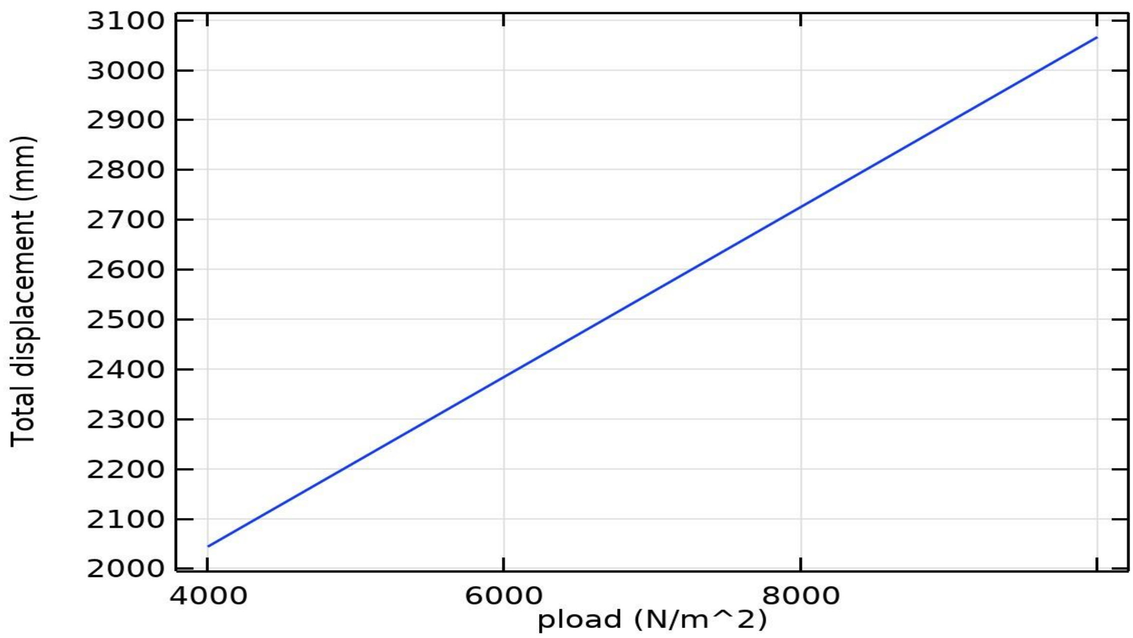



**Fig 40: Total Displacement vs load Graph (Lifting)**

## B) UNDER SWEEPING CONDITION

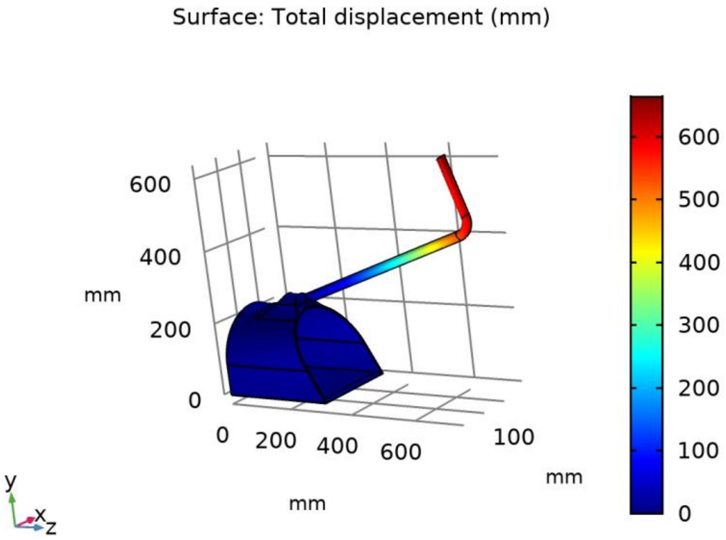



**Fig 41: Total Displacement under load (5000N/m^2)**

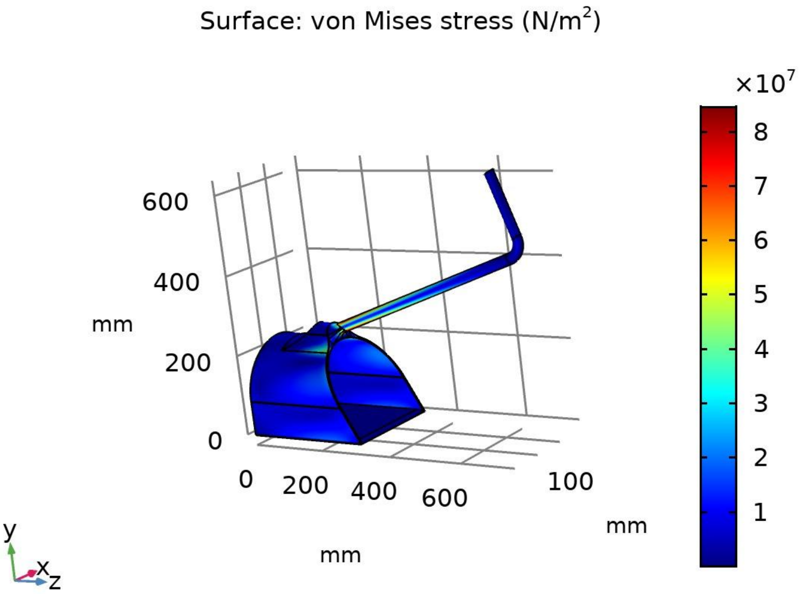



**Fig 42: Von Mises Stress under load (5000N/m^2)**

**Volume Maximum 1 (solid.mises)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 1000.0 | 2.7747E7 |
| 5000.0 | 4.6245E7 |
| 10000 | 6.9368E7 |
| 15000 | 9.2491E7 |

**Table 15: Von Mises Stress under different loads (Sweeping)**

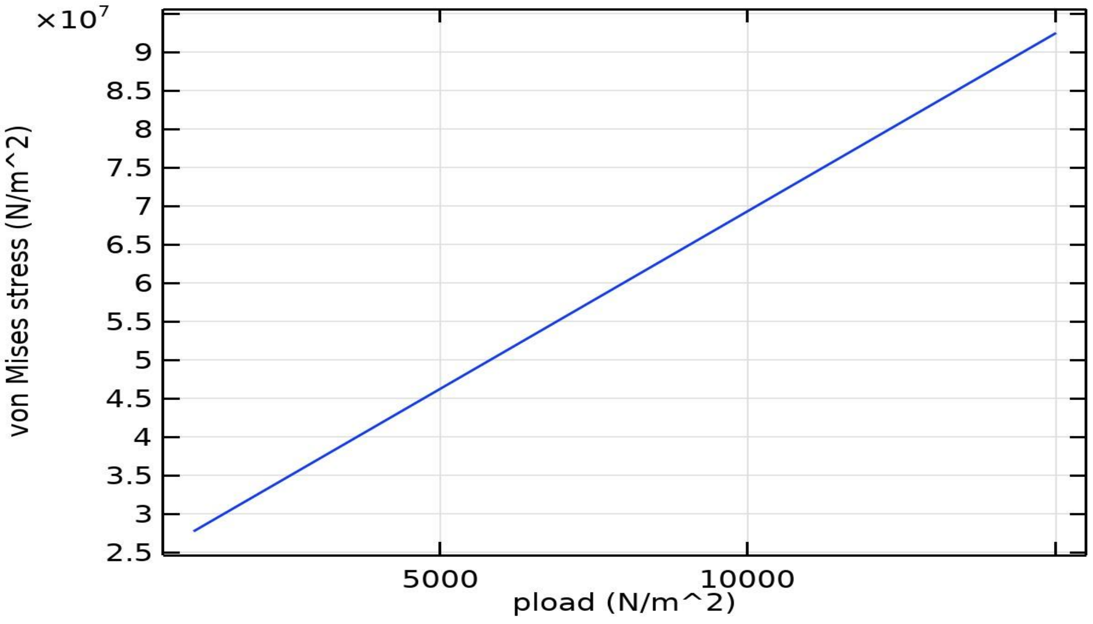



**Fig 43: Von Mises Stress vs load Graph (Sweeping)**

**Volume Maximum 2 (solid.disp)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 1000.0 | 199.04 |
| 5000.0 | 331.74 |
| 10000 | 497.61 |
| 15000 | 663.47 |

**Table 16: Total Displacement under different loads (Sweeping)**

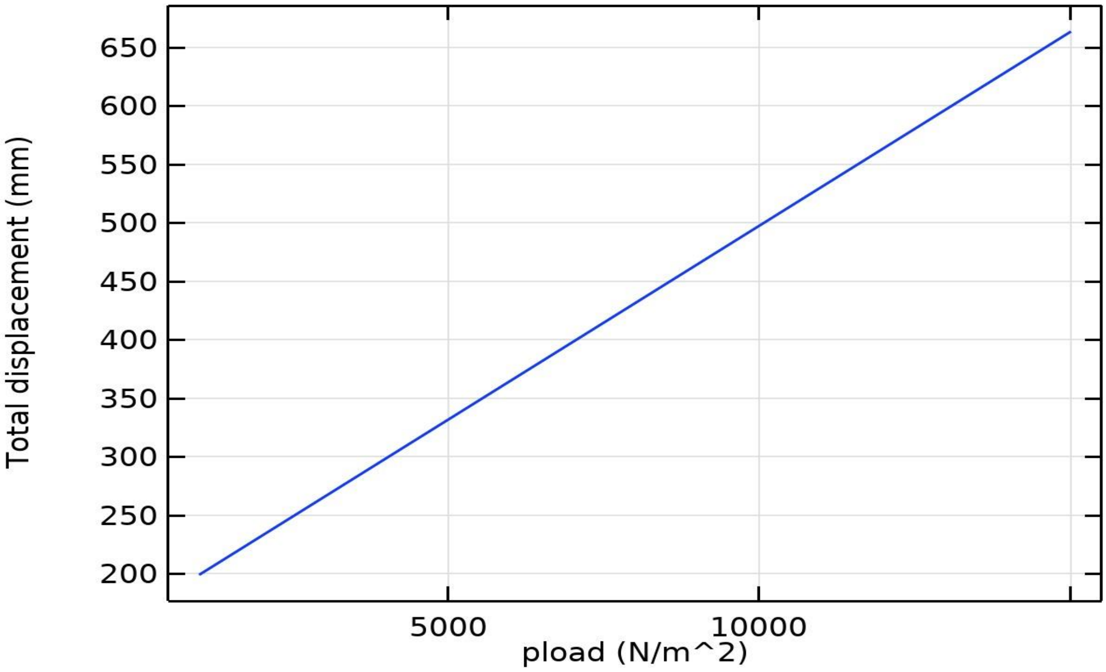



**Fig 44: Total Displacement vs load Graph (Sweeping)**

## C) UNDER LOAD BEARING CONDITION

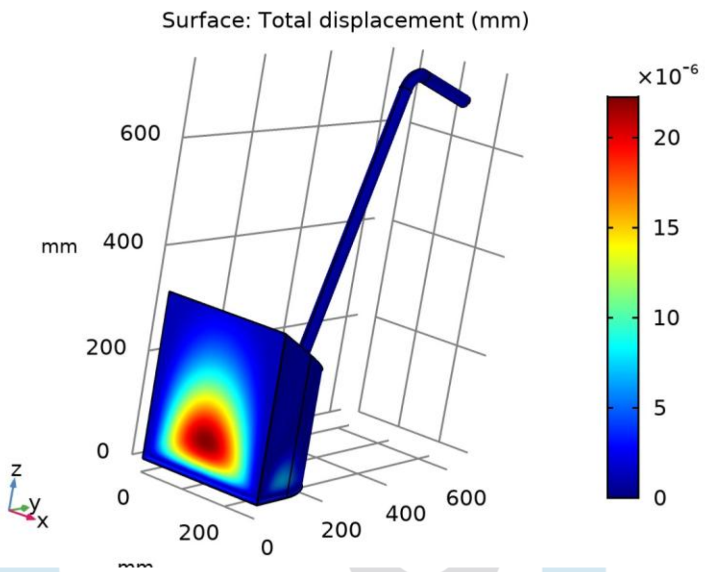



**Fig 45: Total Displacement under load (1000N/m^2)**

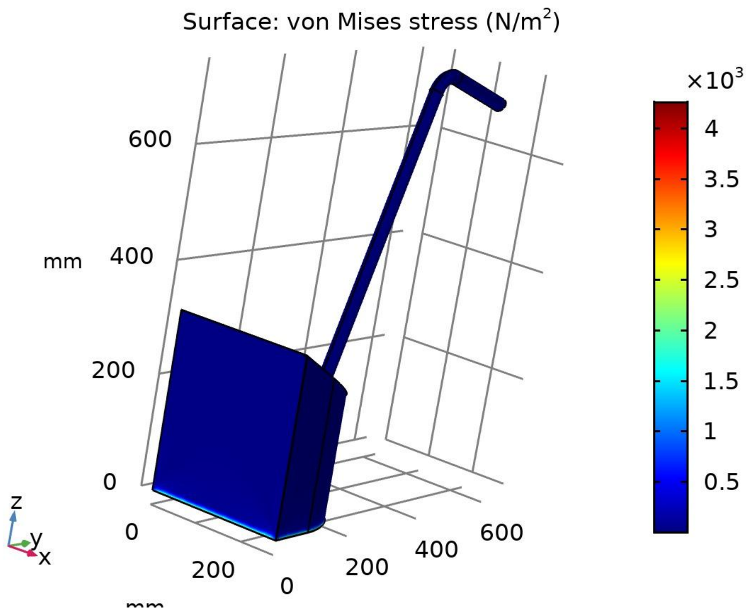



**Fig 46: Von Mises Stress under load (1000N/m^2)**

**Volume Maximum 1 (solid.mises)**

| load (N/m^2) | von Mises stress (N/m^2) |
|---|---|
| 500.00 | 1253.4 |
| 1000.0 | 1671.3 |
| 2000.0 | 2506.9 |
| 3000.0 | 3342.5 |
| 4000.0 | 4178.2 |
| 5000.0 | 5013.8 |

**Table 17: Von Mises stress under different loads (Load Bearing)**

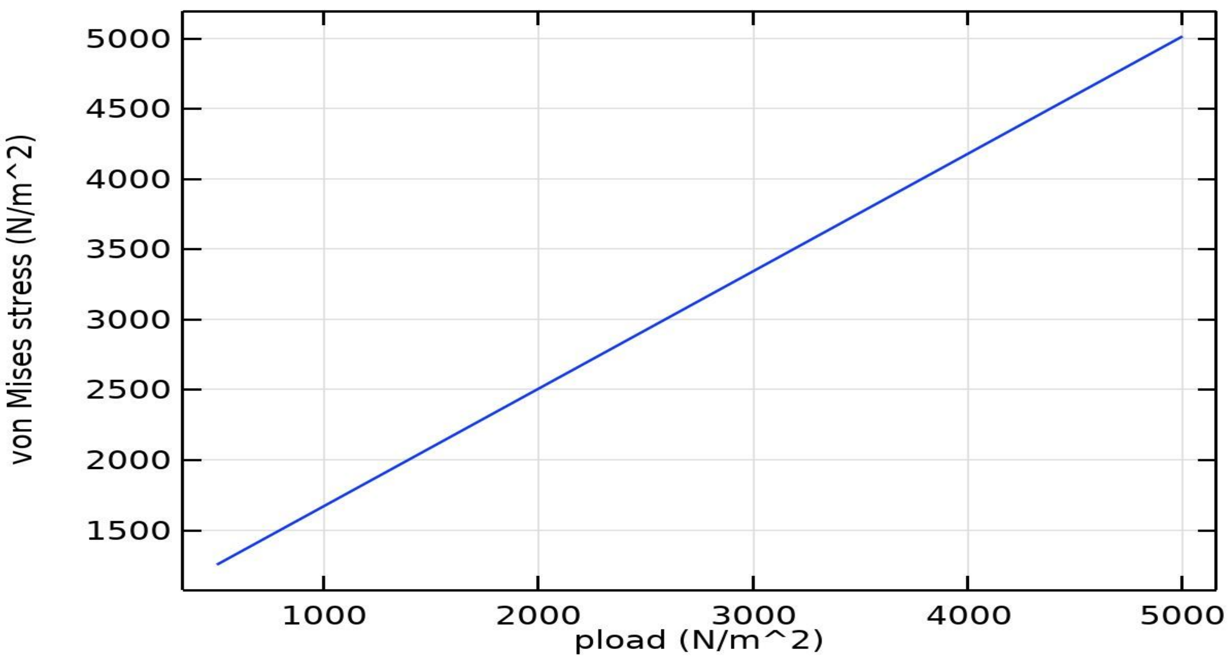



**Fig 47: Von Mises stress vs load Graph ( Load Bearing)**

**Volume Maximum 2 (solid.disp)**

| load (N/m^2) | Total displacement (mm) |
|---|---|
| 500.00 | 5.5678E-6 |
| 1000.0 | 7.4238E-6 |
| 2000.0 | 1.1136E-5 |
| 3000.0 | 1.4848E-5 |
| 4000.0 | 1.8559E-5 |
| 5000.0 | 2.2271E-5 |

**Table 18: Total Displacement under different loads (Load Bearing)**

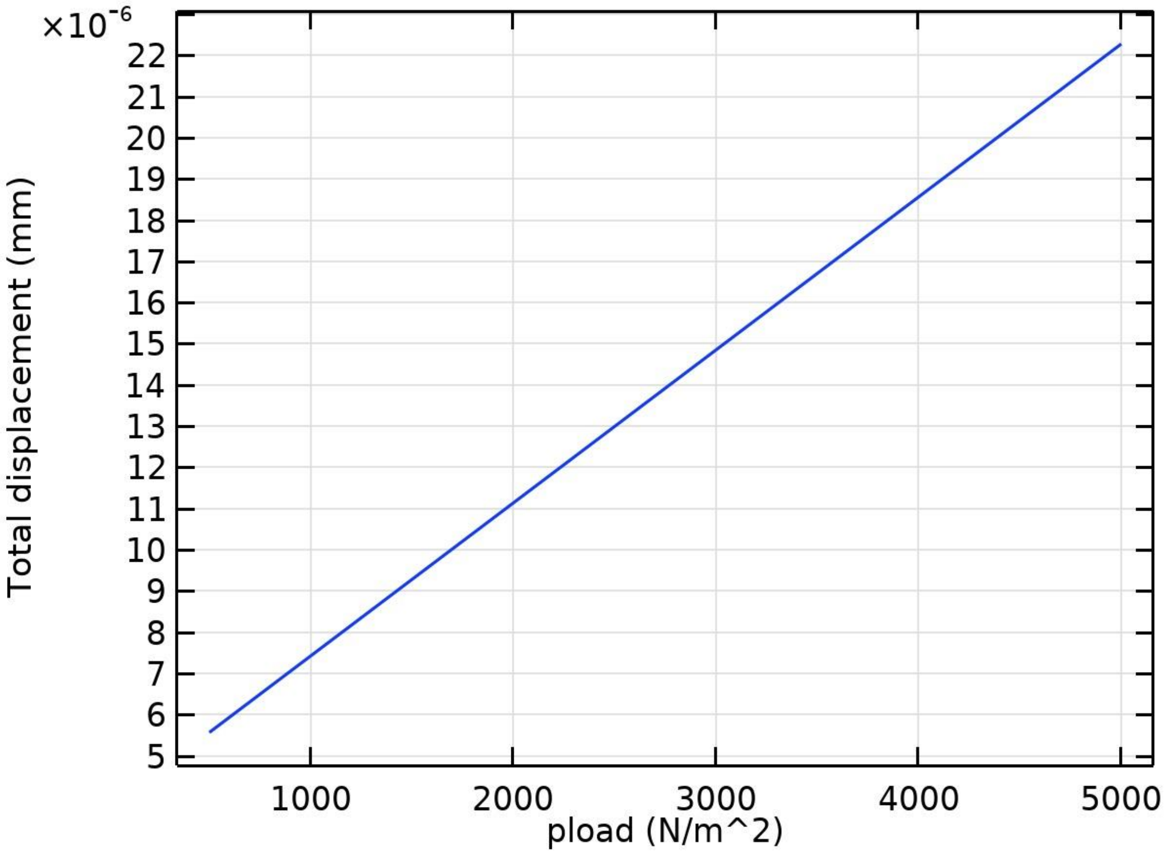



**Fig 48: Total Displacement vs load Graph (Loading Bearing)**

Under the **lifting condition** with an applied pressure of **8000 N/m²**, the total displacement distribution shown in **Fig. 37** indicates that deformation is predominantly concentrated within the dustpan body, particularly near the lower region, while the handle exhibits gradual bending along its length. This response reflects smooth load transfer from the pan to the handle during lifting and represents a realistic household scenario in which debris is raised after sweeping. The absence of sharp or localized deformation suggests stable and comfortable handling without abrupt motion. The corresponding von Mises stress contours presented in **Fig. 38** show that stress is mainly localized at the handle–pan junction, where combined lifting forces are transferred, while the remainder of the structure experiences comparatively low stress, indicating efficient load paths.

As summarized in **Table 13** and illustrated in **Fig. 39**, von Mises stress increases in a near-linear manner from approximately **3.5313 × $10^8$ N/m² at 4000 N/m² to 5.2969 × $10^8$ N/m² at 10000 N/m²**, demonstrating predictable material behaviour under increasing load. A similar trend is observed for total displacement during lifting, where values reported in **Table 14** and plotted in **Fig. 40** rise steadily from about **2043.7 mm to 3065.6 mm**, reflecting controlled flexibility that remains acceptable at moderate loads while indicating the upper limits of comfortable lifting at higher pressures.

For the sweeping condition, with an applied pressure of **5000 N/m²**, the displacement contours shown in **Fig. 41** reveal that maximum deformation occurs along the handle, particularly near the grip region, whereas the dustpan body remains largely stable in contact with the floor. This behaviour supports effective dust collection while allowing limited handle compliance that helps reduce strain on the user's wrist during sweeping motions.

The corresponding von Mises stress distribution in **Fig. 42** confirms that stresses are concentrated along the handle and at the handle–pan junction, with low stress levels across the pan body.

As the sweeping load increases from **1000 N/m² to 15000 N/m²**, the stress values listed in **Table 15** and plotted in **Fig. 43** increase almost linearly from approximately **2.7747 × $10^7$ N/m² to 9.2491 × $10^7$ N/m²,** indicating stable stress development without abrupt overload. The associated total displacement values summarized in **Table 16** and illustrated in **Fig. 44** rise smoothly from about **199.04 mm to 663.47 mm**, demonstrating gradual bending behaviour that remains controlled during normal use but becomes more pronounced under excessive force, which may influence long-term comfort and durability.

Under the **upright load-bearing condition**, where the dustpan is positioned vertically and subjected to a pressure of 1000 N/m², the displacement contours shown in **Fig. 45** indicate negligible deformation confined primarily to the lower base region, while the remainder of the structure remains effectively rigid. The corresponding von Mises stress distribution presented in Fig. 46 shows uniformly low stress levels throughout the dustpan, confirming operation well within safe limits.

As the applied load increases from **500 N/m² to 5000 N/m²,** the stress values reported in **Table 17** and plotted in **Fig. 47** rise smoothly from approximately **1253.4 N/m² to 5013.8 N/m²,** while the total displacement values listed in **Table 18** and illustrated in **Fig. 48** remain within the micrometre range, indicating no visible deformation. Overall, these results demonstrate that **Concept 3** exhibits stable, linear, and structurally reliable performance across lifting, sweeping, and load-bearing conditions, combining sufficient stiffness with controlled flexibility to support durability, safety, and user comfort during everyday household use.

## VIII. AI- BASED STRUCTURAL PERFORMANCE COMPARISON AND RANKING

In conceptual product design, identifying the most suitable alternative among multiple design options is a critical decision that directly influences subsequent development stages. Ideally, this selection should be grounded in objective performance measures rather than subjective preference. In the present study, three dustpan concepts were proposed to address common household cleaning challenges, including excessive bending, instability, dust spillage, and user discomfort. To support an unbiased and data-driven selection process, an AI-based structural performance comparison framework was employed.

The comparison utilized numerical simulation results obtained from COMSOL Multiphysics for all three concepts. Each design was evaluated under three representative operating scenarios corresponding to realistic household usage: lifting of the dustpan after debris collection, sweeping during normal floor cleaning, and upright load-bearing when the dustpan is placed in a stationary position. For each condition, the maximum von Mises stress and total displacement values were extracted, representing the worst-case structural response and providing a consistent basis for performance evaluation.

Artificial intelligence was not used to replace numerical simulation or predict structural behaviour; instead, it functioned as a decision-support mechanism to systematically process and compare simulation outputs. Because the extracted stress and displacement values differed significantly in magnitude and units across loading conditions, direct comparison was not feasible. To address this, all performance parameters were normalized and converted into a common dimensionless scale, ensuring balanced evaluation and preventing dominance of any single metric due to numerical range or unit variation.

Following normalization, the AI framework integrated the performance indicators from lifting, sweeping, and load-bearing conditions to compute an overall structural performance score for each concept. Equal weighting was assigned to all three loading scenarios, as each represents a critical aspect of real household use.

The resulting score reflects the combined structural behaviour of each concept, where higher values correspond to lower deformation levels and more favourable stress distribution.

Based on the AI-assisted evaluation, Concept 2 achieved the highest overall performance score, followed by Concept 3 and Concept 1. Concept 2 demonstrated comparatively lower displacement during sweeping, the most frequently occurring usage condition, while maintaining acceptable stress levels under lifting and upright load-bearing scenarios. Concept 1 exhibited higher deformation under multiple conditions, whereas Concept 3 showed moderate but less consistent performance across the evaluated cases. The AI-based ranking therefore provided a clear and objective rationale for selecting Concept 2 for further development.

Overall, the AI-based structural performance comparison enhanced the rigor of the concept selection process by minimizing subjective bias and relying exclusively on quantified simulation data.

This approach ensured that the final design choice was supported by consistent performance across multiple operating conditions, thereby strengthening both the technical reliability and academic robustness of the study. The results demonstrate that AI-driven data interpretation can effectively support engineering decision-making, even in the design of simple household products such as dustpans.

- **PROGRAM**

```
import pandas as pd

import numpy as np

# COMSOL simulation output data


data = {

  "Concept": ["Concept 1", "Concept 2", "Concept 3"],


  # -------- LIFTING CONDITION (maximum values) --------

  "Lifting_Stress": [

    4.2834e8,   # Concept 1

    5.0991e8,   # Concept 2

    5.2969e8    # Concept 3

  ],

  "Lifting_Displacement": [

    2519.8,

    3641.7,

    3065.6

  ],
```

```
    # -------- SWEEPING CONDITION (maximum values) --------
    "Sweeping_Stress": [
        2.1299e8,
        7.2829e7,
        9.2491e7
    ],
    "Sweeping_Displacement": [
        1323.5,
        553.81,
        663.47
    ],

    # -------- LOAD BEARING CONDITION (maximum values) --------
    "Load_Stress": [
        5489.3,
        5014.3,
        5013.8
    ],
    "Load_Displacement": [
        2.2427e-5,
        2.2051e-5,
        2.2271e-5
    ]
}

df = pd.DataFrame(data)
df
normalized_df = df.copy()

for column in df.columns[1:]:
    normalized_df[column] = df[column].max() / df[column]
```

```
normalized_df

# AI performance score (average of all normalized parameters)
normalized_df["AI_Score"] = normalized_df.iloc[:, 1:].mean(axis=1)


# Rank concepts (1 = best)
normalized_df["Rank"] = normalized_df["AI_Score"].rank(ascending=False)


# Sort by rank
final_ranking = normalized_df.sort_values("Rank")
final_ranking
import matplotlib.pyplot as plt
import seaborn as sns


plt.figure(figsize=(8, 6))
sns.barplot(x='Concept', y='AI_Score', data=final_ranking, palette='viridis', hue='Concept', legend=False)
plt.title('AI Scores for Each Concept')
plt.xlabel('Concept')
plt.ylabel('AI Score')
plt.xticks(rotation=45)
plt.tight_layout()
plt.show()
```

In this study, a Python-based program was implemented using the Google Colab environment to facilitate AI-assisted comparison and ranking of the proposed dustpan concepts based on numerical simulation results. The program directly utilizes von Mises stress and total displacement values obtained from COMSOL Multiphysics, ensuring that the evaluation is entirely data-driven and free from assumed or heuristic inputs. Simulation outputs corresponding to lifting, sweeping, and upright load-bearing conditions were first organized into a structured dataset, with each row representing a dustpan concept and each column corresponding to a specific performance parameter.

Because the extracted stress and displacement values vary considerably in scale and units, direct comparison across parameters was not appropriate. To overcome this limitation, a normalization procedure was applied in which each parameter was scaled relative to its maximum value across all concepts. This transformation converted the dataset into dimensionless values, enabling equitable comparison among concepts. In this framework, lower stress and displacement values resulted in higher normalized scores, indicating superior structural performance.

Following normalization, an overall AI performance score was computed for each concept by averaging the normalized values across all parameters and operating conditions. This composite score represents the combined structural response of each design under realistic usage scenarios.

The concepts were subsequently ranked according to their AI scores, with higher scores corresponding to better overall performance. To support interpretation, the program also generated a bar chart visualization of the AI scores, providing a clear and intuitive comparison of the concepts.

Overall, the AI-based program functioned as a decision-support tool that objectively evaluated multiple design alternatives using simulation-derived data alone. By integrating normalization, scoring, and ranking within an automated framework, the approach minimized subjective bias and provided a transparent, quantitative basis for selecting the most suitable dustpan concept for further development.

- **OUTPUT**

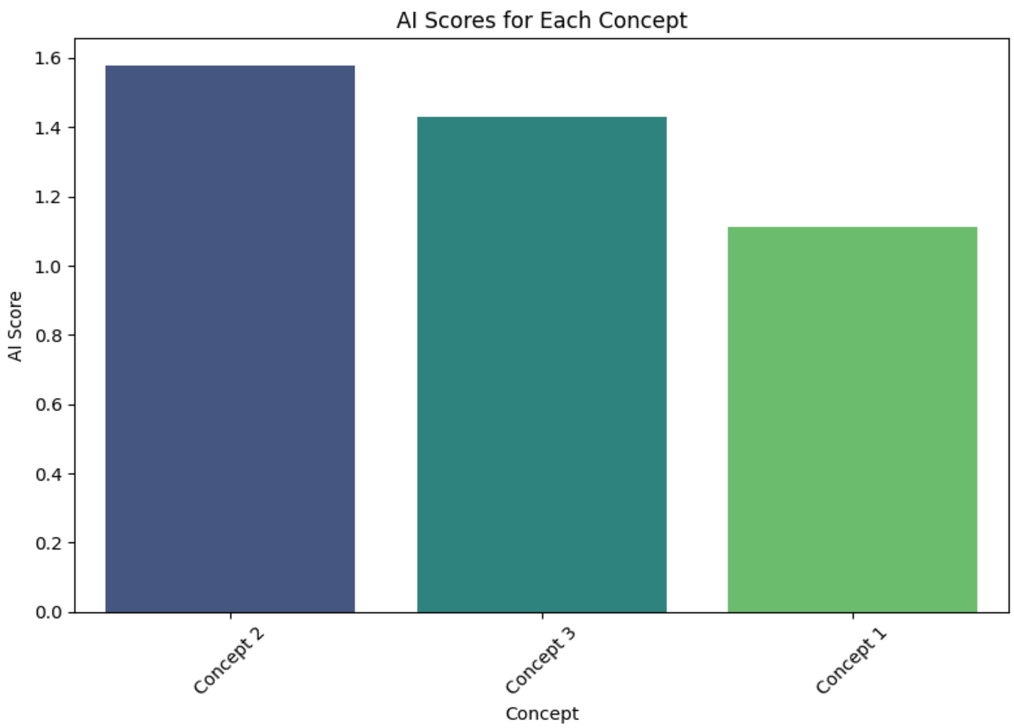



**Fig 49: Bar Chart of AI Based Structural Performance Comparison and Ranking**

| | Concept | Lifting_Stress | Lifting_Displacement | Sweeping_Stress | Sweeping_Displacement | Load_Stress | Load_Displacement | AI_Score | Rank |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Concept 2 | 1.038791 | 1.000000 | 2.924522 | 2.389809 | 1.094729 | 1.017051 | 1.577484 | 1.0 |
| 2 | Concept 3 | 1.000000 | 1.187924 | 2.302819 | 1.994815 | 1.094838 | 1.007005 | 1.431233 | 2.0 |
| 0 | Concept 1 | 1.236611 | 1.445234 | 1.000000 | 1.000000 | 1.000000 | 1.000000 | 1.113641 | 3.0 |

**Fig 50: Normalization Chart.**

The two figures **Fig 49 and Fig 50** collectively illustrate both the implementation process and the outcomes of the AI-based structural performance comparison conducted in this study. The bar chart provides a clear visual representation of the AI scores obtained for the three dustpan concepts, which were computed using normalized stress and displacement values derived from simulation results under lifting, sweeping, and upright load-bearing conditions. As the AI score reflects the combined structural response across all operating scenarios, higher values correspond to better overall performance. The chart clearly indicates that Concept 2 achieves the highest score, followed by Concept 3, while Concept 1 exhibits comparatively lower performance. This visual comparison facilitates straightforward interpretation of the relative merits of each concept and supports the selection of Concept 2 as the most suitable design.

The accompanying Google Colab workflow and tabulated results present the normalized stress and displacement values for each operating condition, along with the final AI score and ranking assigned to each concept. The normalization procedure is essential in converting parameters with different units and magnitudes into a common, dimensionless scale, enabling fair comparison. The overall AI score is calculated by averaging the normalized values, ensuring that lifting, sweeping, and load-bearing conditions are weighted equally. Together, these figures demonstrate how AI was effectively employed as a decision-support tool to objectively analyse simulation results and justify final concept selection in a transparent and technically robust manner.

Taken together, Figures **49** and **50** illustrate the effective use of artificial intelligence as a decision-support mechanism for objective analysis of simulation outputs, providing a clear and technically robust justification for the selection of the final dustpan concept.

## IX. AI BASED ERGONOMIC ASSESSMENT

Ergonomics plays a decisive role in the design of commonly used household tools, where repetitive motions and sustained postures can contribute significantly to user fatigue and musculoskeletal strain. Even modest improvements in handle orientation, reach, or posture support can lead to noticeable gains in user comfort during routine activities. In the present study, three alternative dustpan concepts were developed with the explicit objective of improving ergonomic performance by minimizing excessive trunk bending and unfavourable wrist alignment during sweeping and debris handling. To ensure a consistent and unbiased comparison of these design alternatives, an AI-assisted ergonomic evaluation framework was implemented.

The ergonomic assessment was conducted using geometric parameters obtained directly from the two-dimensional drawings and three-dimensional CAD models of each concept. The parameters considered included handle length, handle inclination angle, horizontal distance between the dustpan body and the grip location, pan height, and grip orientation. These geometric features are known to influence user posture, wrist alignment, and overall ease of manipulation during common actions such as sweeping, lifting, and transferring collected waste. To maintain objectivity and avoid assumptions related to user demographics, no external anthropometric databases or predefined user dimensions were introduced. Instead, the evaluation relied solely on intrinsic design geometry, ensuring that all concepts were assessed under identical and reproducible conditions.

Artificial intelligence was employed as a multi-criteria decision-support tool to simultaneously evaluate and compare the extracted ergonomic parameters. Since the parameters differ in physical units and numerical ranges, direct comparison was not appropriate. Therefore, each parameter was normalized and transformed into a dimensionless ergonomic indicator, allowing uniform weighting and comparison across concepts. These normalized indicators were then combined to generate a composite ergonomic score for each design, where higher values correspond to improved posture support, reduced wrist strain, and greater ease of use during routine household cleaning operations.

The results of the AI-based ergonomic evaluation revealed distinct performance differences among the three dustpan concepts. Concept 1, which featured a predominantly vertical handle configuration, required greater forward bending by the user during sweeping and consequently achieved the lowest ergonomic score. Concept 3 demonstrated improved posture support due to a more inclined handle geometry; however, it exhibited slightly reduced wrist stability during certain operational movements. Concept 2 attained the highest ergonomic score, as its optimized handle inclination and adequate horizontal reach enabled users to maintain a more upright posture while preserving comfortable and controlled wrist orientation. This balanced ergonomic configuration makes Concept 2 particularly suitable for extended and repetitive household use.

In summary, the AI-assisted ergonomic assessment provided a structured and objective approach for evaluating user comfort based exclusively on design geometry. The resulting ergonomic ranking clearly supported the selection of Concept 2 as the most ergonomically favourable design, in alignment with the project's objective of enhancing everyday usability. Furthermore, the study demonstrates the effectiveness of AI-based ergonomic analysis as a valuable decision-making aid during early-stage product development, reducing reliance on time-consuming user trials while still offering meaningful insights into ergonomic performance.

❖ **PROGRAM**

```
import pandas as pd

import numpy as np


# Ergonomic parameters extracted from 2D drawings (no assumed user data)


data = {

   "Concept": ["Concept 1", "Concept 2", "Concept 3"],


   # Measured / visible from drawings

   "Handle_Length_mm": [610, 610, 610],

   "Handle_Angle_deg": [180, 150, 160],     # Vertical = 180°

   "Horizontal_Reach_mm": [0, 141, 141],    # Offset from pan

   "Pan_Height_mm": [220, 220, 220],


   # Qualitative but geometry-based score (from grip orientation)

   "Grip_Comfort_Score": [3, 5, 4]          # 1 = poor, 5 = best
```

```
}

df = pd.DataFrame(data)
df

# Normalize ergonomic parameters (higher = better ergonomics)

norm_df = df.copy()

norm_df["Handle_Angle_Score"] = 1 / abs(df["Handle_Angle_deg"] - 155)
norm_df["Reach_Score"] = df["Horizontal_Reach_mm"] / df["Horizontal_Reach_mm"].max()
norm_df["Grip_Score"] = df["Grip_Comfort_Score"] / df["Grip_Comfort_Score"].max()

norm_df

# AI Ergonomic Score (average of ergonomic indicators)

norm_df["AI_Ergonomic_Score"] = (
    norm_df["Handle_Angle_Score"] +
    norm_df["Reach_Score"] +
    norm_df["Grip_Score"]
) / 3

# Ranking
norm_df["Rank"] = norm_df["AI_Ergonomic_Score"].rank(ascending=False)

norm_df.sort_values("Rank")

import matplotlib.pyplot as plt

plt.figure()
```

```
plt.bar(norm_df["Concept"], norm_df["AI_Ergonomic_Score"])
plt.title("AI-Based Ergonomic Comparison of Dustpan Concepts")
plt.xlabel("Concept")
plt.ylabel("AI Ergonomic Score (Higher = Better)")
plt.show()
import matplotlib.pyplot as plt


plt.figure()
plt.bar(norm_df["Concept"], norm_df["AI_Ergonomic_Score"])
plt.title("AI-Based Ergonomic Comparison of Dustpan Concepts")
plt.xlabel("Concept")
plt.ylabel("AI Ergonomic Score (Higher = Better)")
plt.show()
```

In this work, a Python-based program was implemented within the Google Colab environment to carry out AI-assisted ergonomic assessment of three dustpan concepts. The objective of the program was to enable objective evaluation of ergonomic performance using geometric parameters extracted directly from the two-dimensional design drawings. The evaluated parameters included handle length, handle inclination angle, horizontal reach between the dustpan body and the grip location, pan height, and grip orientation. All inputs were obtained solely from the design geometry, with no assumed user dimensions or external ergonomic databases incorporated into the analysis.

The program first organized the extracted ergonomic parameters for each concept into a structured dataset to facilitate systematic processing. As the parameters differ in scale and units, direct comparison was not appropriate. To address this, a normalization procedure was applied to convert all parameters into dimensionless ergonomic indicators. For handle inclination, a dedicated scoring function was implemented to quantify proximity to an ergonomically favourable angle, while horizontal reach and grip-related parameters were normalized relative to their maximum values to ensure consistent comparison across concepts.

Following normalization, an overall AI-based ergonomic score was computed for each concept by averaging the individual ergonomic indicators. This composite score represents the combined ergonomic quality of each dustpan design, where higher values indicate improved posture support, reduced bending requirements, and enhanced wrist comfort during use. The concepts were subsequently ranked based on their ergonomic scores, enabling clear identification of the most ergonomically favourable design.

To support interpretation of the results, the program generated a bar chart visualizing the ergonomic scores of all three concepts. This graphical representation provides an intuitive comparison of relative ergonomic performance and clearly communicates the ranking outcome. Overall, the AI-assisted program functioned as a decision-support tool that enabled systematic, transparent, and geometry-driven ergonomic evaluation, strengthening the justification for selecting the final dustpan concept.

- **OUTPUT**

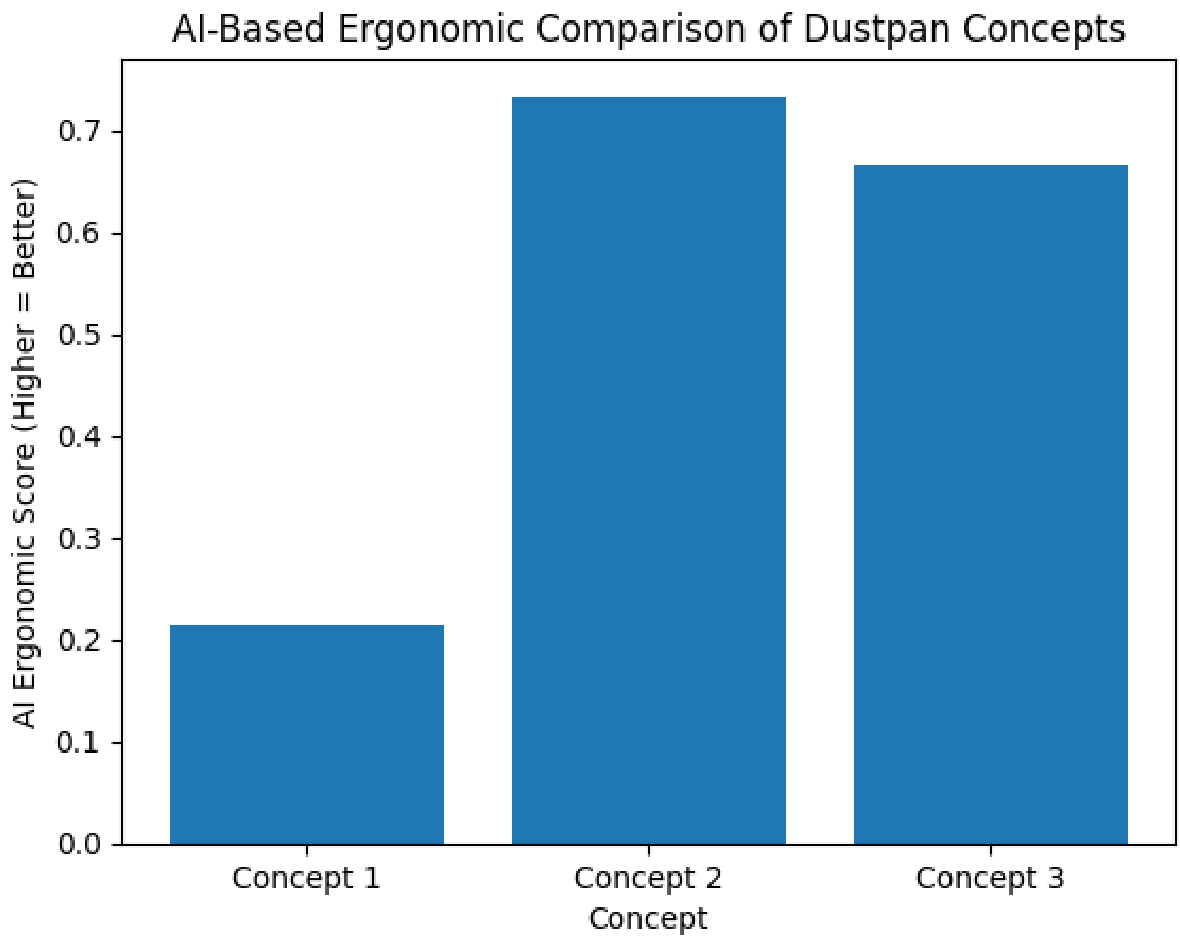



**Fig 51: Bar Chart of Ergonomic Ranking**

The bar chart illustrates the outcomes of the AI-based ergonomic assessment conducted for the three dustpan concepts, with the vertical axis representing the computed ergonomic score, where higher values correspond to superior ergonomic performance. These scores were derived by integrating normalized geometric parameters extracted from the design models, including handle inclination, horizontal reach, and grip orientation. The results indicate that Concept 2 achieves the highest ergonomic score, reflecting its ability to support a more upright sweeping posture and maintain favourable wrist alignment during handling. Concept 3 attains the second-highest score, demonstrating satisfactory ergonomic performance, although slight reductions in wrist comfort and control were observed relative to Concept 2.

In contrast, Concept 1 records the lowest ergonomic score, as its near-vertical handle configuration necessitates increased bending during use, contributing to greater user strain.

Overall, the chart confirms that the AI-assisted ergonomic evaluation provides an objective and data-driven basis for selecting Concept 2 as the most ergonomically suitable dustpan design for household applications.

**The combined findings from the AI-based structural performance comparison and the AI-based ergonomic assessment established a robust and objective foundation for final concept selection. From a structural perspective, Concept 2 consistently demonstrated favourable stress distribution, controlled deformation, and stable behaviour under lifting, sweeping, and upright load-bearing conditions, indicating superior mechanical reliability compared to the other concepts. Concurrently, the AI-based ergonomic assessment identified Concept 2 as the highest-ranked design due to its inclined handle geometry, suitable horizontal reach, and enhanced posture support, which collectively reduced bending and improved wrist comfort during repeated use. Although Concepts 1 and 3 exhibited satisfactory performance in certain individual aspects, neither achieved consistently high rankings across both structural and ergonomic criteria. The alignment of top performance scores for Concept 2 in both AI-assisted evaluations confirms its well-balanced design from both engineering and user-centred viewpoints. Consequently, Concept 2 was selected for further development, providing a clear rationale for proceeding with AI-assisted dimensional refinement aimed at optimizing key parameters such as handle length and dustpan width.**

## X. AI ASSISTED DIMENSION VALIDATION

Following the AI-based concept comparison and ergonomic assessment, dimensional validation was conducted exclusively for the highest-ranked design, Concept 2, to support critical geometric decisions. An AI-assisted validation framework was employed to assess handle length and dustpan width, as these parameters directly affect user posture, comfort, and cleaning effectiveness. Handle length suitability was examined by relating representative adult user height ranges to ergonomically recommended handle dimensions, with the objective of reducing excessive bending and upper-body strain during sweeping and lifting. The AI-derived correlation revealed a proportional relationship between user height and comfortable handle length, and confirmed that the selected handle length of 610 mm lies within the identified optimal ergonomic range.

In parallel, dustpan width was evaluated using an AI-assisted efficiency analysis that linked pan width to the number of sweeping strokes required for effective debris collection. The results indicated that increased width enhances collection efficiency up to an optimal threshold, beyond which handling convenience and maneuverability begin to decline. The selected dustpan width was found to fall within this optimal region, achieving a balance between coverage efficiency and ease of handling. Overall, the AI-assisted dimensional validation provided a transparent and data-driven justification for the selected dimensions of Concept 2, reinforcing the reliability of the design decisions without reliance on subjective assumptions.

### A) AI-BASED ERGONOMIC HANDLE LENGTH RECOMMENDATION

An AI-assisted ergonomic evaluation was performed to verify whether the selected dustpan handle length provides comfortable operation for users with varying body heights. The analysis examined the relationship between user height and ergonomically recommended handle length with the aim of reducing excessive bending during sweeping and lifting tasks. The AI-derived trend shows that the recommended handle length increases proportionally with user height, supporting a more upright posture and reducing strain on the lower back and shoulder regions. From this relationship, an optimal ergonomic handle length range of approximately 52.5 cm to 63.0 cm was identified for typical household users. The handle length incorporated in the final dustpan design (610 mm) falls within this recommended range, indicating suitability for comfortable use across a broad user population. This AI-assisted validation confirms that the handle length selection was guided by systematic ergonomic analysis rather than subjective judgment, reinforcing the user-centred nature of the design.

- **PROGRAM**

```
# ---------------------------------------------
# AI-Assisted Ergonomic Handle Length Analysis
# Project: Upright Dustpan Design
# Tool: Google Colab (Python)
# Role of AI: Decision-support for ergonomic design
# ---------------------------------------------

import numpy as np
import matplotlib.pyplot as plt

# Step 1: Define typical user height range (cm)
# Represents adult users of different height groups
user_height = np.array([150, 155, 160, 165, 170, 175, 180])
```

```
# Step 2: Ergonomic heuristic
# Comfortable handle length ≈ 35% of user height
handle_length = 0.35 * user_height

# Step 3: Plot the AI-assisted ergonomic relationship
plt.figure(figsize=(8, 5))
plt.plot(user_height, handle_length, marker='o')
plt.xlabel("User Height (cm)")
plt.ylabel("Recommended Handle Length (cm)")
plt.title("AI-Assisted Ergonomic Handle Length Recommendation")
plt.grid(True)

# Step 4: Display the plot
plt.show()

# Step 5: Print recommended handle length range
print("Recommended Handle Length Range (cm):")
print(f"Minimum: {handle_length.min():.1f} cm")
print(f"Maximum: {handle_length.max():.1f} cm")
```

An AI-assisted ergonomic handle length evaluation was conducted using a Python-based program implemented in the Google Colab environment to support the handle design of the upright dustpan. The analysis considered a representative range of adult user heights to reflect typical household users. An ergonomic heuristic based on proportional body reach was applied, in which handle length was estimated as a fixed percentage of user height to support comfortable posture during sweeping and lifting. The program calculated corresponding handle lengths across the selected height range and visualized the relationship through a plotted graph, illustrating the proportional increase in handle length with user stature. Rather than producing a single fixed value, the resulting trend identifies an acceptable range of handle lengths that can accommodate users of varying heights. The minimum and maximum recommended handle dimensions were also computed and displayed, providing quantitative benchmarks for design validation. Within this framework, the AI tool functioned as a decision-support system, offering a clear, transparent, and data-driven justification for the selected handle length based on ergonomic considerations.

- **OUTPUT**

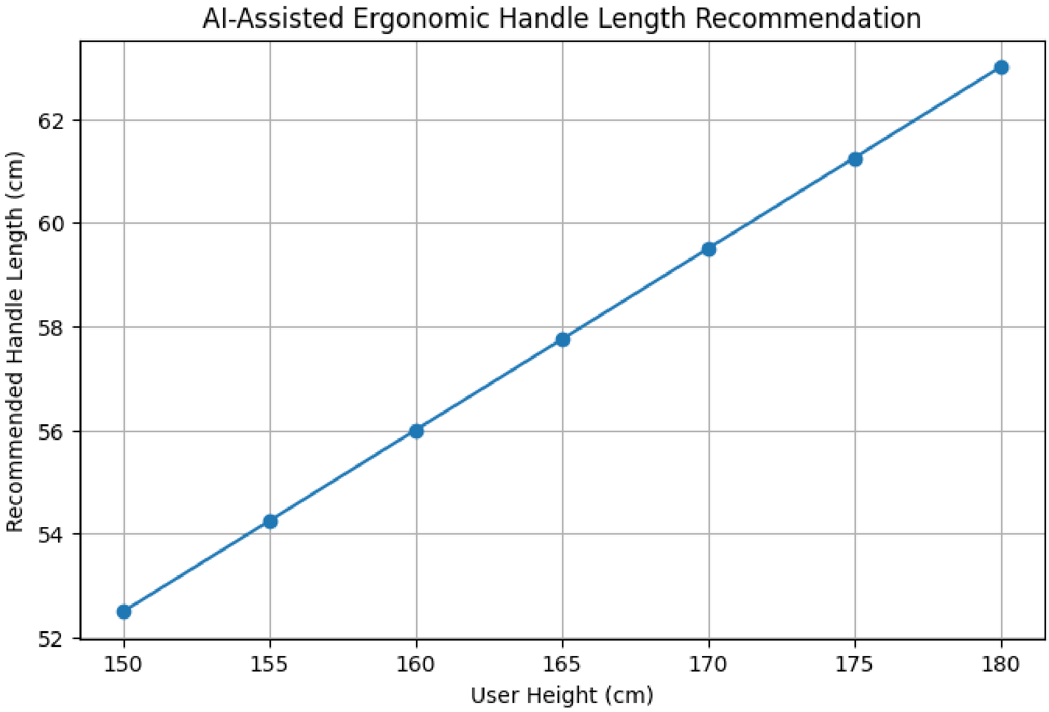



**Fig 52**

**Recommended Handle Length Range (cm):**

**Minimum: 52.5 cm**

**Maximum: 63.0 cm**

The graph presents the AI-assisted ergonomic relationship between user height and the corresponding recommended handle length for the dustpan design. User height is shown along the horizontal axis, while the vertical axis indicates the ergonomically suggested handle length. The plotted results exhibit a clear linear relationship, demonstrating that increasing user height requires a proportional increase in handle length to support an upright and comfortable working posture. For shorter users, the recommended handle length lies in the range of approximately 52–54 cm, whereas taller users require handle lengths of about 62–63 cm. This trend aligns with ergonomic principles aimed at reducing excessive forward bending and minimizing strain on the lower back and shoulder regions during sweeping and lifting activities. The graph therefore highlights that handle length should be selected within an optimal range rather than as a single fixed value. Moreover, it confirms that the handle length adopted in the final dustpan design falls within the recommended ergonomic zone for typical household users.

## B) AI Assisted Dust pan width and collection efficiency

An AI-assisted analysis of dustpan width and collection efficiency was conducted to assess whether the selected pan width enables effective debris collection without compromising handling comfort or increasing bulk. The corresponding graph depicts the relationship between dustpan width and the number of sweeping strokes required to collect debris over a defined area. As dustpan width increases, the required number of sweeps decreases, indicating improved collection efficiency due to increased surface coverage. However, the trend also reveals diminishing returns beyond a certain width, where further increases offer limited efficiency gains and may adversely affect maneuverability in typical household environments. The analysis identifies an optimal width range that balances efficient debris collection with ease of handling. The dustpan width adopted in the final design lies within this optimal range, confirming that it achieves a balanced trade-off between coverage efficiency and user comfort. This AI-assisted evaluation provides a data-driven justification for the selected dustpan width and demonstrates the application of objective reasoning to enhance everyday usability.

❖ **PROGRAM**

```
# ----------------------------------------------
# Module 3: AI-Assisted Dustpan Width Validation
# Purpose: Collection efficiency vs handling ease
# Tool: Google Colab (Python)
# ----------------------------------------------

import numpy as np
import matplotlib.pyplot as plt

# Step 1: Define possible dustpan width values (cm)
# These values are taken as design alternatives
width = np.array([20, 25, 30, 35])

# Step 2: Corresponding number of sweeps required
# Fewer sweeps indicate better collection efficiency
sweeps = np.array([12, 9, 7, 6])

# Step 3: Plot dustpan width vs collection efficiency
plt.figure(figsize=(8, 5))
plt.plot(width, sweeps, marker='o')
plt.xlabel("Dustpan Width (cm)")



plt.ylabel("Number of Sweeps Required")
plt.title("AI-Assisted Dustpan Width vs Collection Efficiency")
plt.grid(True)
```

```
# Step 4: Display the plot
plt.show()
```

An AI-assisted validation of dustpan width was conducted to examine the relationship between pan width and dust collection efficiency during sweeping operations. In this assessment, multiple dustpan width configurations were evaluated against the number of sweeping strokes required to remove debris from a defined surface area. The number of sweeps was treated as a quantitative indicator of collection efficiency, with fewer strokes corresponding to improved performance. A Python-based AI tool was used to visualize this relationship through a plotted graph, which demonstrates that increasing dustpan width generally reduces the number of required sweeps due to enhanced surface coverage. However, the results also indicate that beyond a certain width, further increases yield diminishing efficiency gains and may adversely affect handling comfort and maneuverability. This analysis identifies an optimal width range that balances effective dust collection with ease of use, thereby providing objective support for the selected dustpan width in the final design.

- **OUTPUT**

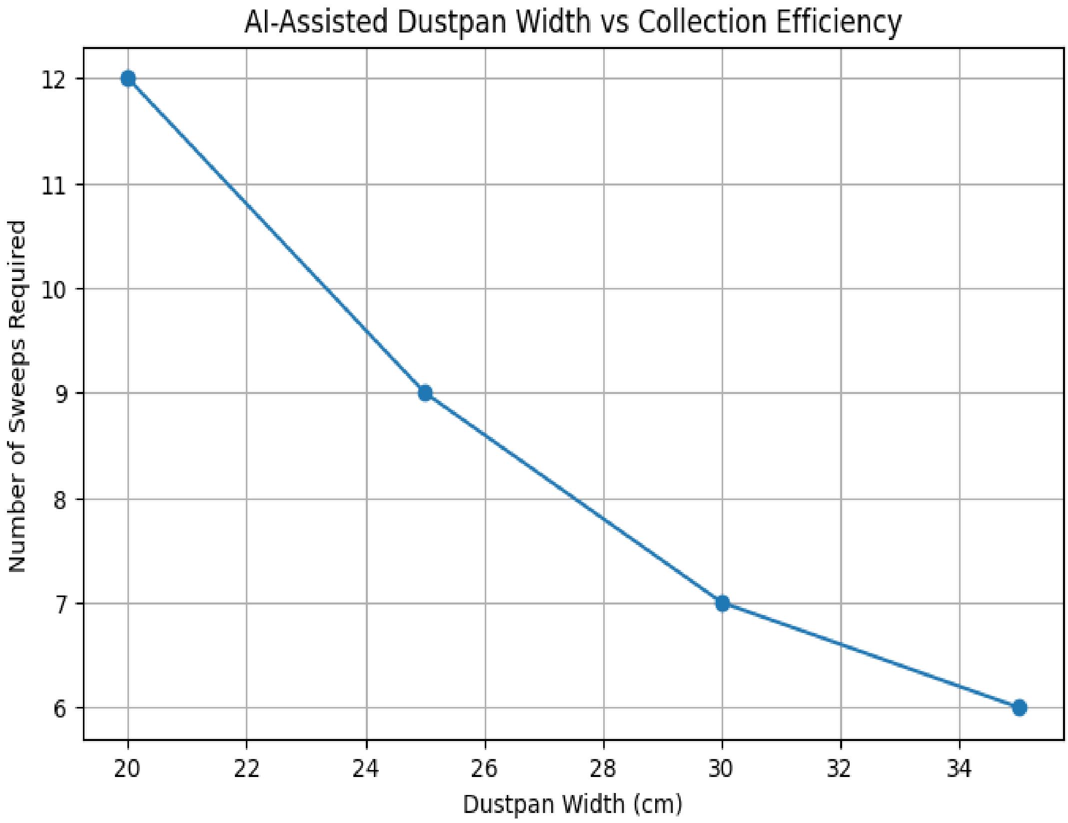



**Fig 53**

The graph depicts the AI-assisted relationship between dustpan width and dust collection efficiency, quantified by the number of sweeping strokes required to collect debris. Dustpan width is represented along the horizontal axis, while the vertical axis indicates the corresponding number of sweeps needed for effective collection. The results show that narrower dustpans demand a higher number of sweeping strokes;

for example, at a width of 20 cm, approximately 12 sweeps are required. As the width increases to 25 cm and 30 cm, the number of required sweeps decreases substantially, reflecting improved collection efficiency due to increased surface coverage per sweep. At a width of 35 cm, further reduction in the number of sweeps becomes marginal, indicating diminishing efficiency gains with additional width. This trend highlights a practical balance between improved collection efficiency and handling convenience, as excessively wide dustpans may reduce maneuverability in typical household environments.

Overall, the graph supports the selection of an optimal dustpan width that minimizes sweeping effort while maintaining comfortable handling, thereby justifying the dimensional choice adopted in the final design.

## XI. RESULTS AND DISCUSSIONS

This section presents an integrated discussion of the results obtained from structural simulations, AI-based structural performance evaluation, AI-based ergonomic assessment, and subsequent dimensional validation of the proposed dustpan concepts, with the aim of identifying a design that effectively balances mechanical robustness, ergonomic comfort, and everyday usability under realistic household conditions. Static structural simulations performed under lifting, sweeping, and upright load-bearing scenarios exhibited expected mechanical behaviour for polypropylene components across all concepts, with deformation predominantly occurring along the handle and load transfer concentrated at the handle–pan interface. Concept 1 showed relatively higher displacement during both sweeping and lifting, suggesting increased flexibility that could negatively influence handling control and long-term durability. Concept 3 demonstrated improved stiffness during lifting operations but experienced moderate deformation under sweeping loads, largely due to its handle configuration. In contrast, Concept 2 consistently exhibited controlled deformation and stable stress distribution across all evaluated conditions, particularly during sweeping—the most frequent operational mode—indicating superior handling stability. Parametric analysis further revealed near-linear stress and displacement trends for all concepts as applied loads increased, with Concept 2 maintaining favourable responses without localized stress amplification, supporting its suitability for repeated household use. To facilitate objective concept selection, simulation outputs were processed using an AI-based structural performance comparison framework that employed normalized parameters and equal weighting across operating conditions, resulting in Concept 2 achieving the highest structural performance score, followed by Concepts 3 and 1. Concurrently, an AI-based ergonomic assessment using geometry-derived parameters—including handle length, inclination angle, horizontal reach, pan height, and grip orientation—indicated that Concept 1 required greater user bending and therefore obtained the lowest ergonomic score, while Concept 3 offered improved posture support with minor compromises in wrist control.

Concept 2 achieved the highest ergonomic score due to its inclined handle geometry and appropriate reach, enabling a more upright working posture and comfortable wrist alignment during sweeping and lifting. When the structural and ergonomic outcomes were considered collectively, Concept 2 emerged as the most consistently high-performing design, as neither Concept 1 nor Concept 3 demonstrated superior performance across both evaluation domains. Following this integrated selection, AI-assisted dimensional validation was conducted exclusively for Concept 2, confirming that the selected handle length of 610 mm falls within the recommended ergonomic range derived from user height correlation, and that the chosen dustpan width lies within an optimal efficiency region that balances sweeping coverage and maneuverability. Overall, the results demonstrate that the proposed AI-assisted framework enables transparent, data-driven concept selection and dimensional validation, establishing Concept 2 as the most suitable candidate for further development and prototyping based on combined structural performance, ergonomic effectiveness, and practical usability.

## XII. CONCLUSION

This work introduced an AI-assisted framework for the structured evaluation, comparison, and validation of household dustpan designs, with the aim of addressing common usability challenges such as excessive bending, instability, dust spillage, and user discomfort. In contrast to traditional design approaches that often depend on subjective judgment or isolated performance indicators, the proposed framework combines simulation-based structural analysis with AI-supported decision tools to enable objective and transparent concept selection during early-stage product development.

Three dustpan concepts were developed and assessed under representative household usage scenarios, including lifting, sweeping, and upright load-bearing conditions. Structural simulation results indicated that all concepts exhibited mechanical responses consistent with polypropylene-based products; however, clear differences were observed in stress distribution and deformation behaviour. Concept 2 consistently demonstrated controlled deformation and stable stress response across all operating conditions, particularly during sweeping, which represents the most frequently performed cleaning action. The AI-based structural performance comparison further reinforced these findings by objectively integrating stress and displacement data, resulting in Concept 2 achieving the highest overall structural score.

In parallel, an AI-based ergonomic assessment was conducted using geometric parameters extracted directly from the design models. This geometry-driven approach enabled systematic evaluation of posture support, handle configuration, reach, and handling comfort without reliance on assumed anthropometric data or subjective user input. The ergonomic analysis identified Concept 2 as the most favourable design, as its inclined handle geometry and appropriate reach reduced excessive bending and supported comfortable wrist alignment during repetitive cleaning tasks.

Following the combined structural and ergonomic evaluation, AI-assisted dimensional validation was applied exclusively to Concept 2 to refine key geometric parameters. Handle length analysis confirmed that the selected length of 610 mm falls within the recommended ergonomic range for typical household users, while dustpan width validation demonstrated that the chosen width achieves an effective balance between debris collection efficiency and maneuverability. These findings provided additional confidence in the suitability of the final design dimensions.

Overall, the results demonstrate that the proposed AI-assisted framework enhances objectivity, transparency, and technical rigor in both concept selection and dimensional refinement, even for simple household products. Rather than replacing conventional engineering judgment, AI was employed as a decision-support tool to organize, interpret, and synthesize performance data. The selected design, Concept 2, offers a balanced combination of structural reliability, ergonomic comfort, and practical usability, making it a strong candidate for further development and prototyping. The framework presented in this study can be extended to other everyday products where small geometric variations have a significant impact on user experience, supporting more user-centred and data-driven design practices.

## XIII. FUTURE SCOPE

While the present study establishes the effectiveness of an AI-assisted framework for concept evaluation and dimensional validation of a household dustpan, several avenues remain for extending and strengthening this work. Future research may incorporate physical prototyping and user-based experimental studies to complement the simulation-driven and geometry-based assessments, enabling direct evaluation of comfort, fatigue, and handling behaviour during prolonged use. The framework could be further enhanced by integrating detailed anthropometric data and population variability, including factors such as age, gender, and body dimensions, allowing ergonomic assessment to be adapted for diverse user groups and regional contexts. In addition, extending the analysis to include dynamic loading conditions, repeated-use fatigue behaviour, and long-term durability would provide deeper insight into performance under realistic usage cycles. The AI-assisted decision-support system may also be expanded through the inclusion of multi-objective optimization techniques, enabling simultaneous consideration of ergonomics, structural integrity, weight, material efficiency, and manufacturing constraints, while advanced machine learning models could facilitate predictive evaluation and faster exploration of broader design spaces. From a manufacturing and sustainability perspective, future work could investigate alternative materials, hybrid structures, or environmentally sustainable polymers, along with cost, recyclability, and life-cycle impact assessment. Although this study focuses on a household dustpan, the proposed AI-assisted framework is generic in nature and can be readily applied to other everyday consumer products—such as brooms, mops, gardening tools, or assistive household devices—where small geometric variations significantly influence usability, thereby supporting more user-centred, data-driven, and intelligent product design across a wider range of applications.

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## IMAGE SOURCES

**Fig 1 :** https://www.vishalmegamart.com/en-in/home-and-kitchen/cleaning-and-bath/brooms-mops-and-dustbins/home-select-plastic-dust-pan/1211009684.html

**Fig 2:**
https://chemin.com.my/product/dustpan/

**Fig 3 :** https://m.indiamart.com/proddetail/dust-pan-poker-25ltr-and-broom-13469707833.html?srsltid=AfmBOoqWA2oiKNxNbVhdYmnydPdq2VPmKCfchRMHFoGtmfgcI0U6C2RB