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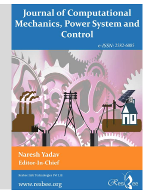

Application of Finite Element Analysis in Assessing Mechanical Chair Design

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Abstract: This research explores the design of a steel chair addressing the crucial need for adaptability in modern living spaces. Advanced engineering techniques, specifically Finite Element Analysis (FEA), are employed to meticulously analyze and enhance the structural performance of this versatile furniture piece. The traditional approach to chair design often lacked adjustable features and adequate lumbar support, leading to discomfort and poor posture. With advancements in technology, there is a growing demand for chairs that are not only aesthetically pleasing but also ergonomic and structurally sound. The study focuses on simulating various scenarios using FEA to ensure that the chair meets stringent ergonomic standards, providing user safety and comfort in both seatingp and table configurations. The integration of FEA in Fusion 360 offers a systematic and comprehensive method to optimize chair designs, ensuring durability, safety, and ergonomic efficiency. The research methodology encompasses problem definition, ideation, concept visualization, and verification, followed by detailed FEA simulations and design optimization. Key aspects such as material properties, meshing parameters, and result analysis are thoroughly explored to provide a deep understanding of the chair's structural performance under various loads and conditions. The outcomes of the research include safety factors, stress distribution, displacement analysis, reaction forces, and strain evaluations, all of which contribute to making informed design decisions. The study not only focuses on improving the specific chair design but also lays the groundwork for better ways of designing furniture and structures in general, with a strong emphasis on sustainability, user comfort, and safety. This research aims to bridge the gap between traditional chair design methods and modern, technology-driven approaches, highlighting the importance of FEA in enhancing structural integrity, optimizing materials, and creating furniture that meets the evolving needs of users in today's dynamic environments.

Keywords: Stress Analysis, Finite Element Analysis (FEA), Autodesk Fusion 360, Designing, CAD/CAM – Computer-Aided Design and Computer-Aided Manufacturing,

Nomenclature

Abbreviation	Expansion
FEA	Finite Element Analysis
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
FMEA	Failure Mode Effects Analysis
NDT	Non-Destructive Testing

1. Introduction

In this technology-driven era, chairs are one of the necessities that influence the productivity of any human being. A chair is something that is used in places like homes, offices, public workspaces, and more. They are available in various shapes and sizes [30]. For a long time, people used traditional chairs because at that time they were the only option. The problem with these chairs was that they often lacked adjustable features and adequate lumbar support, leading to discomfort and poor posture over time [29][27]. As technology improves, people are interested in more comfortable and ergonomic designs [19]. The integration of FEA in Autodesk Fusion 360 offers a streamlined approach to optimizing chair designs, ensuring durability, safety, and ergonomic efficiency [17]. This study explores how FEA in Fusion 360 enhances chair design processes, with implications for broader advancements in furniture Engineering and Sustainability. Fusion 360 is a robust CAD/CAM software known for its parametric

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modeling capabilities, integrated CAM features, and versatility in synchronously incorporating advanced technologies like FEA [2][4][9]. The choice of Fusion 360 is grounded in its collaborative workflows, cost-effectiveness, and efficient design iteration, offering an ideal environment for a comprehensive examination of the chair's mechanical behavior [18]. FEA serves as a cornerstone in Engineering disciplines, allowing for a detailed understanding of structural responses under various conditions. In the context of chair design, FEA enables precise simulations of stress distribution, displacement, and other critical factors, providing invaluable insights into the chair's performance [16]. The paper focuses on elucidating the procedural aspects of FEA within Fusion 360, emphasizing its role in validating and enhancing the structural integrity of the chair [1] [4]. Unlike generative design, FEA directly simulates the impact of loads and constraints on the chair's components, providing engineers and designers with quantitative data to make informed decisions about the design's robustness and safety [13].

In the past, designers mainly used traditional methods to improve chair designs. These methods were good but had limits in understanding how chairs work under different conditions. Now, FEA is changing this. FEA is like a detailed microscope for chairs, showing exactly how they handle different forces and situations [21]. This shift to using FEA is important because it helps create chairs that not only look good and work well but also are safer and more durable [26][20].

The reason for focusing on this problem is because it has many benefits. A well-designed chair not only makes people more comfortable but also helps save materials by making designs more precise [29][28]. This is important for the environment. Also, in today's world, where people spend a lot of time sitting, having chairs that are good for your body can prevent injuries and keep people healthy in the long run [32]. So, resolving these issues with a convertible chair is made with ergonomic design and comfort[27][25]. In addition, the chair can be converted to a table by rotating it. Its unique design makes it feasible for homes, offices, and other places.

These goals work together to show the use of FEA in Fusion 360 to make sure a chair is strong and reliable [23][22]. The hope is this will not only help with understanding this chair but also lead to better ways of designing furniture and structures in general. The main objectives of this research paper include:

- Learn how to use FEA in Autodesk Fusion 360, understanding each step in detail.
- Record the step-by-step process from drawing in 2D and 3D to creating realistic images, testing in simulations, and figuring out the cost – all within Fusion 360.
- Show and explain the outcomes of the FEA process using different tools like pictures, tables, and graphs for a better understanding.
- Examine the results from FEA closely, paying attention to things like how stress is spread, how much things move (displacement), and other important factors for how the chair holds up.
- Use the detailed FEA results to make sense of how the chair performs under different situations and restrictions.
- Take useful lessons from the FEA analysis that can help design not just this chair but also other furniture and structures, contributing to better ways of making things strong and safe.

This paper contains five sections, starting with an introduction, Section 2 covers the literature review, Section 3 explains the methodology, Section 4 mentions the result, and Section 5 concludes the paper.

2. Literature Review

FEA is a method used in fusion to conduct strength, durability, thermal, and other analyses for materials. For strength analysis of a chair beyond FEA, there are several other methods:

- Hand Calculations: Traditional engineering calculations based on material properties, dimensions, and loading conditions can provide initial estimates of strength, stress, and safety factors [33].
- Failure Theories: Utilize theories like Von Mises, Tresca, or Mohr-Coulomb to predict failure modes such as yielding, fracture, or buckling under different loading scenarios [34].
- Material Testing: Conduct physical tests on chair components or similar materials to determine mechanical properties like tensile strength, compression strength, and flexural strength [35][31].
- Digital Prototyping: Use virtual prototyping tools to simulate and test different design iterations for strength and performance under various loads [36].
- Structural Load Testing: Apply controlled loads to the chair and measure deflections, strains, and stresses using sensors and instrumentation to assess structural integrity [37].
- FMEA: Systematically analyses potential failure modes, their effects, and criticality to prioritize design improvements for strength and reliability [38].

- NDT: Employ techniques like ultrasonic testing, radiography, or magnetic particle inspection to detect internal defects or weaknesses without damaging the chair [39].
- Dynamic Analysis: Evaluate dynamic loads such as impact or vibration to assess the chair's durability and fatigue resistance over time [40].

These methods offer a comprehensive approach to understanding the strength characteristics of the chair, encompassing theoretical analyses, real-world testing, and failure mode assessments. The comparison between the different approaches is explained in Table 1.

Table 1. *Comparisons between different types of methods*

Method	Methodology	Advantages	Disadvantages
Hand Calculations [33]	Basic calculations based on data	Quick estimates	Limited accuracy especially for complexity.
Failure Theories [34]	Using theoretical failure models	Predicts failure under different loads	Simplified assumptions may miss nuances.
Material Testing [35][31]	Physical tests for material strength	Direct data on material properties	Time-consuming can be destructive.
Digital Prototyping [36]	Virtual simulations of designs	Rapid testing of multiple scenarios	Requires accurate modeling.
Structure Load Testing [37]	Applying controlled loads	Real-world performance data	Expensive and needs specialized equipment.
FMEA [38]	Systematic failure mode analysis	Identifies critical failure points	Relies on assumptions and data quality.
NDT [39]	Non-destructive defect detection	Detects hidden weaknesses	Limited to surface defects.
Dynamic Analysis [40]	Assessing dynamic loads	Evaluate durability over time.	Complex and needs accurate load modeling

2.1 Research Gap

Identifying issues within current methods for chair strength analysis is crucial for enhancing the design process toward creating more resilient and enduring chairs. There are some potential drawbacks associated with each of the eight methodologies mentioned earlier, which are listed below.

- Hand Calculations: Hand calculations, although beneficial for initial estimations, often lack precision when dealing with intricate geometries or materials exhibiting non-linear behaviors. This limitation can result in oversimplified analyses of real-world conditions, potentially leading to either overly cautious or overly optimistic conclusions [33].
- Failure Theories: The applicability of failure theories heavily relies on accurate material data and idealized assumptions. However, practical scenarios frequently involve non-uniform material behaviors or unexpected failure modes that may not be adequately addressed by these theories [34].
- Material Testing: Physical testing offers valuable insights but is hindered by its time-consuming, expensive, and limited-scope nature. Variability in material properties and environmental conditions further challenges the reliability of test outcomes [35][31].
- Digital Prototyping: Virtual simulations are potent tools requiring precise input parameters and modeling assumptions. However, the complexity of simulations often demands substantial computational resources and specialized expertise for accurate results [36].
- Structural Load Testing: While controlled load testing provides valuable insights, it may not fully replicate real-world usage scenarios. Ensuring precise calibration of instruments and meticulous load application procedures is imperative for deriving meaningful and reliable results [37].
- FMEA: It aids in prioritizing design improvements but may overlook rare failure modes or fail to consider interactions among multiple failure mechanisms, potentially resulting in design oversights [38].
- NDT: This technique offers non-intrusive assessments but can be limited in detecting subsurface defects or anomalies in complex structures. Skillful interpretation of findings is crucial for deriving meaningful insights [39].
- Dynamic Analysis: Dynamic testing plays a vital role in evaluating fatigue resistance but can be resource-intensive and may not encompass the entire range of dynamic loading conditions experienced throughout the chair's lifespan [40].

Addressing these challenges involves refining methodologies, combining different approaches for a thorough assessment, improving material characterization techniques, enhancing simulation accuracy, and carefully considering real-world usage scenarios.

FEA emerges as a superior method for structural analysis and design compared to traditional techniques due to several distinct advantages. Firstly, FEA provides precise predictions of stress, strain, and deformation across intricate geometries, overcoming the limitations of methods like hand calculations or simplified failure theories that might overlook subtle nuances and localized effects. Its capacity to handle complex geometries, non-linear material behaviors, and varied loading conditions makes it versatile and applicable to a broad spectrum of design scenarios.

Cost and resource efficiency further highlight FEA's superiority. While FEA simulations can be computationally demanding, they often prove to be more cost-effective than extensive physical testing or dynamic analyses, particularly for iterative design refinements. Additionally, FEA integrates structural, thermal, and dynamic considerations into a unified simulation environment, offering a holistic analysis platform that surpasses methodologies like FMEA.

FEA's support for iterative design processes is another notable advantage. Engineers can rapidly test multiple design iterations and evaluate their performance under diverse conditions, leading to optimized and efficient designs [32]. This iterative capability is constrained by techniques such as hand calculations or failure theories, which lack the same level of adaptability and optimization. Overall, FEA's precision, ability to handle complexity, cost-effectiveness, comprehensive analysis capabilities, and support for iterative design and optimization establish it as the preferred choice for structural analysis and design across engineering applications. Table 2 mentions the advantages and disadvantages of the FEA.

Table 2. *Comparison of FEA*

Advantages of FEA	Disadvantages of FEA
Precision	Computational complexity
Versatility	Accuracy limitations
Cost-effectiveness	Model simplification
Comprehensive analysis	Interpretation challenges
Iterative design support	Validation requirements

3. Methodology

3.1 Procedure for FEA and Design Optimization

The methodology begins with defining the problem and ideation, progressing through idea conceptualization, visualization, and subsequent verification. Once conceptually solidified, chair design is digitally articulated using software [3]. The generated prototype then undergoes FEA, a critical step in ensuring structural integrity and optimal performance [1]. The design process begins with identifying a problem or gap, leading to idea generation, conceptualization, visualization, and conceptual verification [10]. The detailed flow procedure for FEA is explained in Fig 1.

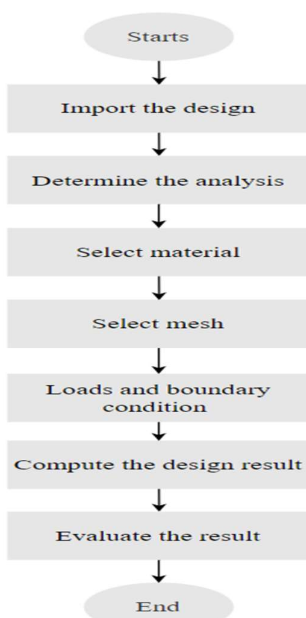

Fig. 1. *Procedure in the toolbar of Finite Element Analysis (FEA)*

Following the FEA, The design approach (Fig. 2) of various outcomes is obtained, including stress distribution, mass, displacement, and strength of the chair. These outcomes serve as crucial metrics for evaluating the chair's structural performance under different conditions. The design optimization process is categorized into early, medieval, and end stages, encompassing imagination, idea generation, conceptualization, sketching, 3D modeling, and final outcome selection [11][12][14].

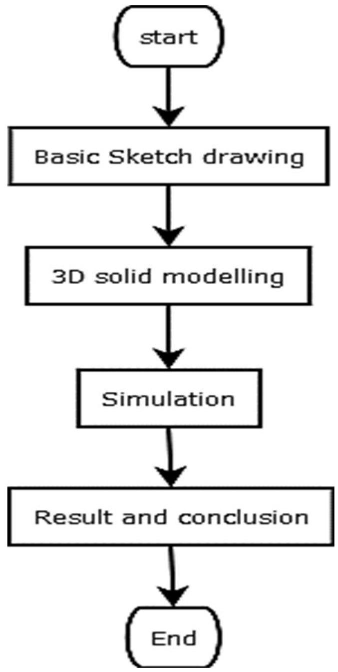

Fig. 2. *Design Approach*

3.2 Applying Finite Element Analysis in Chair

The specific chair component under consideration is introduced, and the initial design as seen in Fig. 3is presented for FEA. The goal is to optimize the design for enhanced structural performance and usability.

Fig. 3. *Design of the chair*

3.2.1 Finite Element Analysis Defining Procedure

To initiate the FEA process in Fusion 360, begin by launching the software and opening the designated design file. Once within the Fusion 360 environment, seamlessly navigate to the simulation workspace, where the analytical procedures will take place. In the simulation workspace, commence the FEA by selecting "New Study" or "New Material Study". Specify the analysis type as "Static Stress" to assess the structural behavior under static loads.

Next, designate the material for the study, opting for steel in the case of a chair design. Ensure accurate representation by assigning appropriate material properties like Young's modulus and Poisson's ratio. Simulate real-world conditions by applying constraints and fixing the positions of the chair's bases using structural constraints. Introduce external forces through the application of loads; for instance, apply a vertical structural load to the chair's seating area. Specify load magnitude by converting weight to Newtons, considering gravitational acceleration [5].

Include the effects of gravity by applying a downward load based on the gravitational acceleration of 9.8 m/s^2 in Fig. 4. Conduct a thorough review of the applied loads and constraints to validate their fidelity to the intended physical scenario. Subsequently, initiate the analysis by clicking on the "Solve" button, prompting Fusion 360 to employ the Finite Element Method for calculating the chair structure's response under the specified conditions.

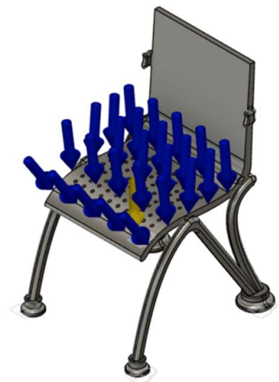

Fig. 4. *Structural load*

Throughout the analysis process, diligently monitor Fusion 360 for any warning messages or errors. Once the analysis is complete, review the results, examining stress distribution, displacement, and other pertinent data. Interpret these results within the context of the design, identifying areas of concern such as high stress, deformation, or potential failure. If necessary, implement design iterations based on the analysis findings to enhance structural performance.

Fig. 5. *Structural constraints*

Thoroughly document each step of the FEA process, including material properties, applied loads, constraints, and results. Enhance the documentation with screenshots and visualizations that effectively communicate key aspects of the analysis. Finally, compile a comprehensive report summarizing the FEA analysis, emphasizing key findings, and providing recommendations for design improvements if warranted. Following this systematic approach ensures a detailed and well-documented record of the finite element analysis conducted in Fusion 360. It is represented in Figure 5.

4. Result and Discussion

4.1 Stress Analysis

The Fusion 360 analysis for the static stress of the chair design gave us useful insights into how the structure behaves under specific conditions. The study, which focused on a 1:1 simulation model, employed steel as the material. Steel has a density of 7.850E-06 kg/mm^3, a Young's modulus of 210,000.00 MPa, a Poisson's ratio of 0.30, and a yield strength of 207.00 MPa. These material properties help us understand how the chair responds to different forces and loads [6][7].

4.2 Mesh

Configuring the mesh parameters in Fusion 360 is crucial for gaining a comprehensive understanding of how the chair responds to stress. The average element size, designated as 10% of the overall model size, plays a key role in determining the analysis's level of detail and precision. That is explained in Table 3. Maintaining a consistent mesh size for all parts of the chair through the scale mesh size per part ensures uniformity across the entire model. The utilization of parabolic elements contributes to a more accurate representation of deformations.

Table 3. *Brief description of mesh outcome*

Average Element Size (% of model size)	
Solids	10
Scale Mesh Size Per Part	No
Average Element Size (absolute value)	-
Element Order	Parabolic
Create Curved Mesh Elements	Yes
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20

The inclusion of curved mesh elements becomes integral to capturing the intricate curves and complex shapes of the chair, enhancing the realism of the simulation. Allowing curves to bend up to a maximum of 60 degrees during mesh creation adds flexibility, especially in areas with pronounced curves. The control of the difference in size between neighboring mesh elements (max adjacent mesh size ratio) at 1.5 facilitates a smooth transition between various mesh densities. Limits on the aspect ratio, capped at a maximum of 10, prevent elements from stretching or distorting excessively. In Fig.10the minimum element size, established at 20% of the average size, prevents the creation of overly small elements that could compromise analysis accuracy. In this analysis, adaptive mesh refinement is not utilized, as indicated by the zero refinement steps.

Table 4. *Adaptive Mesh Refinement*

Number of Refinement Steps	**0**
Results Convergence Tolerance (%)	20
Portion of Elements to Refine (%)	10
Results for Baseline Accuracy	von Mises Stress

The convergence tolerance for results is set at 20%, ensuring the analysis concludes when results are within this percentage of convergence. In a scenario involving mesh refinement, 10% of the elements would undergo refinement based on the results. Prioritizing von Mises stress as the baseline accuracy parameter acts as a primary indicator of potential material failure under applied loads.

4.3 Material

The material specifications (Table 5) utilized in the Fusion 360 analysis, particularly for the chair design, play a crucial role in understanding the structural response to stress.

The unique properties of the selected steel material include a density of 7.850E-06 kg/mm³, Young's Modulus of 210,000.00 MPa, Poisson's Ratio of 0.30, yield strength of 207.00 MPa, ultimate tensile strength of 345.00 MPa, thermal conductivity of 0.056 W / (mm°C), thermal expansion coefficient of 1.200E-05 / °C, and specific heat of 480.00 J / (kg°C).

Table 5. *Steel properties*

Density	**7.850E-06 kg / mm^3**
Young's Modulus	210000.00 MPa
Poisson's Ratio	0.30
Yield Strength	207.00 MPa
Ultimate Tensile Strength	345.00 MPa
Thermal Conductivity	0.056 W / (mm C)
Thermal Expansion Coefficient	1.200E-05 / C
Specific Heat	480.00 J / (kg C)

These characteristics are essential inputs for the FEA, defining how steel behaves under diverse conditions. They impact mass, elasticity, deformation under stress, resistance to permanent deformation, maximum stress endurance, and the material's response to temperature changes. Ensuring accuracy in these material properties enhances the precision of the simulation, offering valuable insights into the chair's structural integrity and performance when subjected to static stress conditions.

4.4 Contacts

4.4.1 Bonded

Within the Fusion 360 analysis of the chair design, the inclusion of bonded connections stands as a fundamental aspect, serving to facilitate the simulation of interactions among distinct structural elements. Specifically denoted as [S] Bonded117, [S] Bonded118, and [S] Bonded119 in the context of Simulation Model 1:1 and Component1:1, these labels uniquely identify and characterize the bonded connections, emphasizing a cohesive structural linkage between the specified components are represented in Table 6.

Table 6. *Brief description of Bonds*

Name
[S] Bonded117 [Simulation Model 1:1||Component1:1]
[S] Bonded118 [Simulation Model 1:1||Component1:1]
[S] Bonded119 [Simulation Model 1:1||Component1:1]

The term "bonded" conveys a state in which these components collaboratively share loads and resist deformation, ensuring a synchronized response to externally applied forces. These bonded connections assume a pivotal role in faithfully representing the physical integrity of the chair throughout the FEA. Their significance lies in offering valuable insights into the inter-component relationships and their collective impact on the overall structural behavior when subjected to static stress conditions.

4.4.2 Mesh

The meshing process utilized an average element size of 10% of the model size for solids, resulting in 173,929 nodes and 105,916 elements. The study, set for static stress analysis, incorporated contact tolerances of 0.10 mm and gravitational effects with a magnitude of 9.807 m/s² in the downward direction.

4.5 Load Case1

4.5.1 Constraints

In Fusion 360 analysis, Load Case1 involves fixed constraints denoted as Fixed1, aiming to replicate immobility within structural elements. These constraints are set as Fixed in the X, Y, and Z directions.
The imposition of these constraints in the FEA ensures an accurate portrayal of static stress conditions, enabling a realistic simulation of the chair's response to applied loads. This methodology enhances analytical precision, facilitating a comprehensive exploration of structural integrity and potential stress points inherent in the design.

4.5.2 Loads

4.5.2.1 Gravity

In Fig. 16,a Gravity load of 9.807 m/s² is applied to simulate the impact of gravitational forces on the chair structure. Specified as acting in the negative Z-direction, this load type accurately represents the acceleration due to gravity. The gravitational load table 7 describes the load of the gravity.

Fig. 6. *Selected entity for gravity*

Table 7. *Brief description ofgravitational load*

Type	Gravity
Magnitude	9.807 m / s^2
X Value	0.00 m / s^2
Y Value	0.00 m / s^2
Z Value	-9.807 m / s^2

This inclusion in the FEA ensures a realistic assessment of the chair's response to external forces, contributing to the precision of the simulation under static stress conditions. By mimicking real-world gravitational effects, this approach enhances the overall accuracy of the analysis, providing valuable insights into the structural behavior of the chair when subjected to varying loads.

4.5.2.2 Force1

In the Fusion 360 analysis, a Force1 load is implemented to simulate a vertical force on the chair's sitting area as seen in Table9 with a magnitude of 1176.80 N and directed on the negative Z-axis, this force mimics an external load acting downward [2] and is illustrated in Figure 7.

Fig. 7. *The selected entity of applied force*

Table 8. *Brief description of applied force*

Type	Force1
Magnitude	1176.80 N
X Value	0.00 N
Y Value	-87.02 N
Z Value	-1173.578 N
Force Per Entity	No

The X and Y values are set to zero, signifying no force in those directions. The Force Per Entity parameter is configured as No, indicating that the entire force is applied as a single unit rather than distributed. This Force1 input in the FEA ensures a precise assessment of the chair's structural response to applied loads, enriching the simulation's accuracy under static stress conditions.

4.6 Result Summary

The results obtained from the Fusion 360 analysis provide comprehensive insights into the structural performance of the chair under static stress conditions. The chair is applied in the 1176.80 N force download direction for stress and strength analysis. In Fig. 8, the safety factor, a critical indicator of structural robustness, ranges from 9.756 to 15.00, ensuring a satisfactory margin of safety[8].

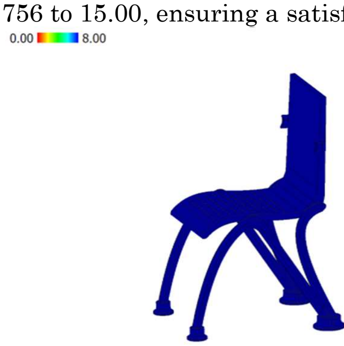

Fig. 8. *Safety Factor (Per body)*

In Fig. 9, stress analysis, represented by von Misess tress and principal stresses, reveals the distribution of forces within the chair's structure. In Fig. 9, blue denotes minimal stress, and red signifies high pressure (up to 21.219 MPa). The seating area displays a distinct cyan mix, indicating a moderate stress level. This visual representation highlights stress patterns for effective analysis [8].

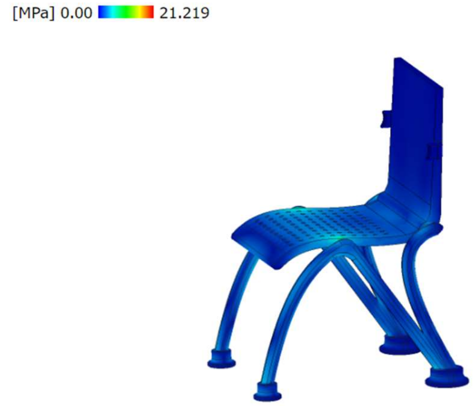

Fig. 9. *Von stress*

Fig. 10. *1st Principal*

Fig. 10 illustrates 1st Principal stress ranging from -4.351 to 16.939 MPa. In Fig. 10, blue indicates minimum stress and red indicates maximum stress. The chair's cyan color signifies overall stress, which signifies less stress than the median, while green in the seating area indicates heightened stress concentration in that specific region.

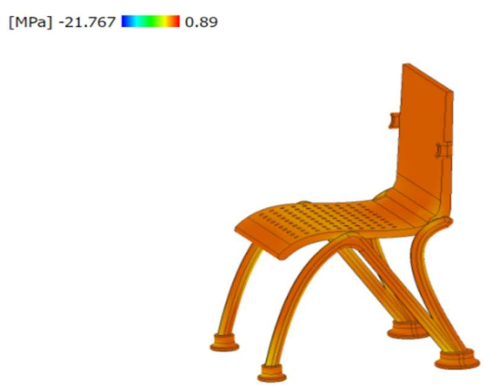

Fig. 11. *3rd Principal*

In Fig. 11 3rd Principal stress value ranges from -21.767 MPa (minimum) to 0.89 MPa (maximum), as in the figure tables shown in a mixture of red and yellow indicates a stress level less than maximum making the table's color orange.

In Fig. 12, Displacement values indicate the degree of deformation, with total displacement ranging from 0.00 mm to 0.034 mm in various directions.

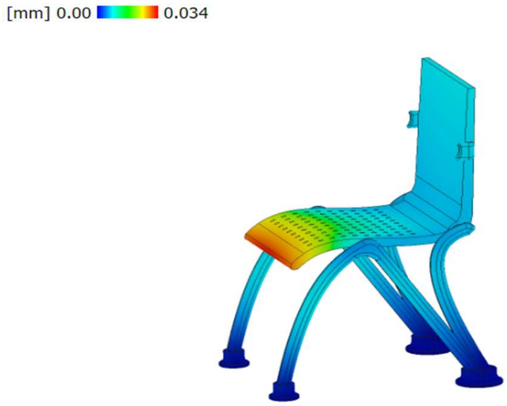

Fig. 12. *Displacement*

In Fig. 12, the front part of the seat area is marked red, indicating maximum displacement when applying pressure. As moving inward, the color transitions to yellow, green, cyan, and blue, signifying progressively less displacement in the chair structure.

Table 9. *Brief description of the resulting outcome*

Name	Minimum	Maximum
	Safety Factor	
Safety Factor (Per Body)	9.756	15.00
	Stress	
Von Mises	4.426E-05 MPa	21.219 MPa
1st Principal	-4.351 MPa	16.939 MPa
3rd Principal	-21.767 MPa	0.89 MPa
Normal XX	-7.769 MPa	5.42 MPa
Normal YY	-20.627 MPa	13.214 MPa
Normal ZZ	-8.172 MPa	5.759 MPa
Shear XY	-7.002 MPa	6.741 MPa
Shear YZ	-9.393 MPa	8.604 MPa
Shear ZX	-8.15 MPa	7.072 MPa
	Displacement	
Total	0.00 mm	0.034 mm
X	-0.005 mm	0.005 mm
Y	-0.007 mm	0.005 mm
Z	-0.033 mm	0.002 mm
	Reaction Force	
Total	0.00 N	7.569 N
X	-2.075 N	1.904 N
Y	-1.173 N	3.521 N
Z	-4.178 N	7.005 N
	Strain	
Equivalent	3.270E-10	1.611E-04
1st Principal	2.020E-10	1.138E-04
3rd Principal	-1.608E-04	1.429E-08
Normal XX	-1.664E-05	2.373E-05
Normal YY	-8.976E-05	5.027E-05
Normal ZZ	-3.375E-05	4.176E-05
Shear XY	-8.669E-05	8.346E-05
Shear YZ	-1.163E-04	1.065E-04
Shear ZX	-1.009E-04	8.756E-05
	Contact Pressure	
Total	0.00 MPa	8.127 MPa
X	-3.073 MPa	2.125 MPa
Y	-4.819 MPa	7.252 MPa
Z	-6.741 MPa	5.199 MPa
	Contact Force	
Total	0.00 N	337.673 N
X	-66.967 N	52.155 N
Y	-130.458 N	85.223 N
Z	-335.646 N	221.364 N

The results detailed in Table 9 offer a thorough insight into how the chair performs under various loads, providing essential information about its structural integrity. The safety factor, ranging from 9.756 to 15.00, indicates a robust design that can withstand applied loads with a significant safety margin. A higher safety factor indicates a stronger design, which is crucial for ensuring the chair's durability and safety over time. Analyzing the Von Mises stress, which ranges from 4.426E-05 MPa to 21.219 MPa, is crucial for assessing the material's strength. These values, along with the 1st and 3rd principal stresses, normal stresses, and shear stresses, reveal how stress is distributed within the chair's components. Areas with negative principal stresses indicate compression zones, guiding designers to reinforce critical areas for enhanced stability. The displacement values, ranging from 0.00 mm to 0.034 mm, show how much the chair deforms under different loads. Analyzing this data across the X, Y, and Z axes provides insights into the direction and magnitude of deformations, helping refine the design for optimal performance. Understanding reaction forces along the X, Y, and Z axes at different points of the chair reveals its load-bearing capacity and response to external forces. This information is crucial for identifying potential stress concentration areas and optimizing the chair's structural layout. The analysis of strain, including equivalent, principal, and normal strains, is essential for evaluating material deformation under load. Interpreting contact pressure values (ranging from 0.00 MPa to 8.127 MPa) and contact forces along different axes helps pinpoint critical contact points and address potential failure risks. In summary, these detailed numerical findings empower designers to make informed decisions to enhance the chair's structural performance and reliability. Leveraging this data, designers can iteratively refine the design, optimize material usage, and ensure the chair meets stringent safety and durability standards.

4.6 Deformation

Analyzing deformation in chair design is crucial for ensuring structural integrity, user comfort, and safety. It helps optimize materials and design elements, informs design iterations, and ensures chairs meet safety standards while minimizing discomfort and risks of failure. Deformation in chair design resulted in five images: "Actual," in Fig 13(a) “Adjusted 0.5x,” in Fig 13 (b) “Adjusted,” in Fig 13 (c) “Adjusted 2x,”in Fig 13 (d) and “Adjusted 5x.” in Fig 13 (e).These visuals illustrate how the chair responds to different levels of deformation. In Figures 13(b), (d), and (e), as deformation increases from 0.5X to 5X, noticeable changes emerge. The chair exhibits a downward bend, indicating its response to different deformation levels. These visualizations offer a crucial understanding of how the chair structure behaves under varying conditions, informing design decisions, and highlighting potential areas for reinforcement or optimization to ensure stability and structural integrity [7].

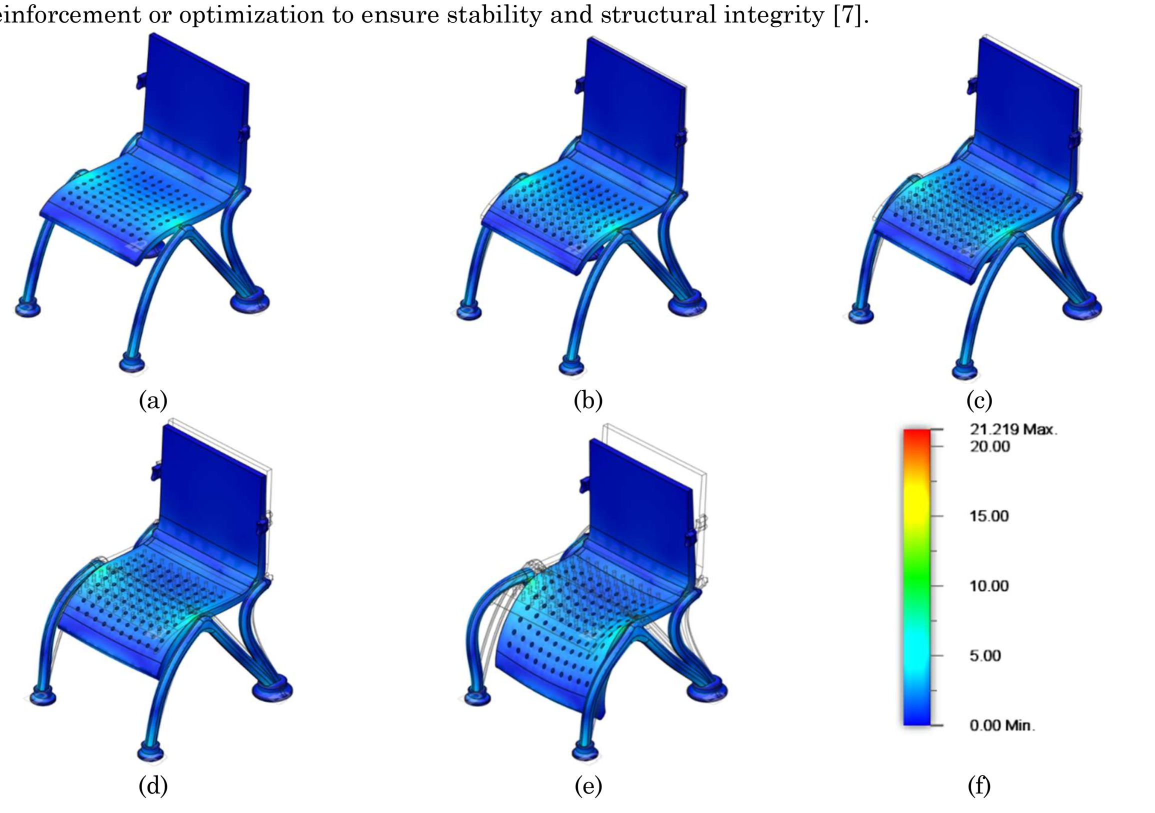

Fig. 13. *Deformation*

5. Conclusion

Successfully applied FEA in Autodesk Fusion 360 to optimize the structural performance of a steel chair. Integration of FEA in chair design using Autodesk Fusion 360 enhances structural optimization and ergonomic efficiency. Achieved safety factors ranging from 9.756 to 15.00, affirming the structural robustness and providing a considerable margin of safety. Von Mises stress ranged from 4.426E-05 MPa to 21.219 MPa, unveiling forces within the structure and aiding in pinpointing areas of stress concentration. Documented reaction forces from 0.00 N to 7.569 N and strains ranging from 3.270E-10 to 1.611E-04, providing a comprehensive understanding of the chair's response to external loads. Established Load Case1 with fixed constraints (Fixed1) and applied gravity and Force1 loads to simulate real-world scenarios and assess the chair's response. Configured meshing parameters, including average element size, parabolic elements, and curved mesh elements, ensure precise stress distribution analysis. The research analyzed the chair's changes when pushed or pulled. As the pushing or pulling increases from 0.5x to 5x, the chair visibly bends downward. These observations help to make important decisions about how to improve the design, focusing on areas that might need strengthening. The parameters of the selected material, steel, play a critical role in understanding the chair's structural behavior under various conditions. By accurately simulating these factors in FEA, it makes smart design choices to make the chair strong and reliable.FEA analysis in Fusion 360 yielded quantitative insights into safety factors, stress distribution, displacement, and component interactions, informing an iterative design process. The numerical outcomes serve as a foundation for precise design improvements, contributing to the creation of structurally sound and adaptable furniture for modern living spaces. User-centric design principles, including lumbar support, seat comfort, and adjustability, are emphasized for an improved user experience. Technology-driven approaches like FEA in Fusion 360 revolutionize chair design, contributing to a healthier, more comfortable, and more sustainable future. In summary, this paper concludes that the application of FEA in Autodesk Fusion 360 has significantly optimized the structural performance of a steel chair. Safety factors ranging from 9.756 to 15.00 affirm the chair's robustness, while Von Mises stress values from 4.426E-05 MPa to 21.219 MPa reveal critical areas of stress concentration. Reaction forces, strains, and displacement analyses provide a comprehensive understanding of the chair's response to external loads. The study demonstrates that FEA, compared to other methods, is highly suitable for assessing chair strength and flexibility, leading to informed design decisions and structurally sound furniture for user comfort and sustainability.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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