Sustainable Ergonomic Highchair Design for Toddlers with Environmental Responsibility

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Abstract

Toddler highchairs are essential for parents, restaurants, and daycares to support children's eating activities. However, products on the market have several limitations, including insufficient stability, limited height adjustment, and uncomfortable materials. This study aims to develop a safer, more comfortable, and flexible ergonomic toddler feeding chair using a structured product development approach supported by computer-aided design (CAD) in SolidWorks, digital structural analysis, and considerations of environmental responsibility. The research follows a phased product development methodology: needs identification, concept development, system design, structural analysis, digital validation, and production cost estimation. The chair incorporates an aluminum frame to enhance stability. The seat combines polypropylene and foam for user comfort, while folding and height-adjustment mechanisms ensure adaptability across different conditions. Static simulation in SolidWorks confirmed that the design withstands loads up to 30 kg, with stress, deformation, and safety factor values within acceptable limits. Environmental responsibility was considered at the material level through the selection of recyclable materials (such as aluminum and polypropylene) with anticipated long product life and efficient resource use; no formal life-cycle assessment was conducted. Although digital validation produced promising results, further work is required to develop prototypes and conduct physical user testing to evaluate ergonomics and usability under real conditions. With these improvements, the proposed design shows potential to outperform conventional products and achieve broad applicability, while further environmental validation remains necessary to substantiate sustainability outcomes.

Keywords: ergonomics, environmental responsibility, product development, sustainable design, toddler highchair

1. Introduction

Toddler highchairs are essential for parents to help their children eat, especially as they start to eat independently. For toddlers aged 6 months to 3 years, this period is crucial for the development of fine and gross motor skills, including sitting and chewing (Herdiman, *et al*., 2023). Highchairs provide a safe and comfortable place for toddlers, making it easier for parents to supervise and feed them without constantly holding them (Liu *et al*., 2023). Highchairs have become increasingly common in daily activities to facilitate feeding.

In Padang City, the birth rate increased by 1.5% in 2023, driving higher demand for ergonomic highchairs. Toddlers aged 1 to 5 years are divided into three groups: infants (0–2 years), toddlers (2–3 years), and preschoolers (3–5 years). This period is critical for a child's development, including learning to sit, crawl, walk, and interact with their environment (Cauwenberghe *et al*., 2011). Eating is an essential aspect of toddler life for both nutritional needs and the development of fine motor skills (Chouraqui *et al*., 2025). Therefore, highchairs must be designed to meet toddlers' specific developmental and ergonomic needs.

Data show that the daily use time of highchairs ranges from less than 1 hour to more than 5 hours. Toddlers who need highchairs are typically between 6 months and 3 years old, when they begin to sit independently and interact more actively with their environment, including during meals. Highchairs are designed to support toddlers during this phase by providing safe, comfortable seating, helping them sit correctly, and helping them develop independent eating skills (Gilbert *et al*., 2019). According to the World Health Organization (WHO), proper seating posture during eating is crucial for digestion, spinal alignment, and the prevention of choking hazards (WHO, 2020). Studies indicate that poorly designed highchairs can lead to improper posture, which in turn affects skeletal development and long-term comfort (Zhang *et al*., 2022). The urbanization of parenting in Indonesia, especially in growing cities like Padang, increases the demand for compact, multifunctional, and hygienic feeding solutions. An ergonomic highchair should accommodate rapid growth stages and various body dimensions through adjustable features (Zhang *et al*., 2022). A survey by Susanti *et al*. (2023) on early childhood anthropometry in Padang supports the importance of local data in designing child-specific furniture.

Despite the availability of various commercial products, several ergonomic shortcomings persist. Studies indicate that instability, insufficient adjustability, ineffective restraint systems, and the use of uncomfortable materials remain common issues (Bispo *et al.*, 2024; Zhang *et al.*, 2022). Such deficiencies highlight the broader importance of human-centred design principles in product development. Ergonomics emphasizes aligning product characteristics with human physical and cognitive capabilities to enhance comfort, efficiency, and safety (Ngoc *et al.*, 2022). Evidence from occupational safety research demonstrates that inadequate assessment of physical and mental workload significantly increases accident risk, underscoring the fundamental role of ergonomic evaluation in injury prevention (Triawan *et al.*, 2024). Although derived from an industrial context, this principle is transferable: product designs that fail to accommodate user limitations may elevate risk exposure, particularly among vulnerable populations such as toddlers. Consequently, ergonomic considerations must extend beyond dimensional fitting to include stability, load-bearing capacity, and safe interaction mechanisms. Ergonomics is a discipline that studies how to design equipment and work environments to suit human capabilities and limitations, aiming to increase comfort, safety, and efficiency (Fithri *et al.*, 2024). In the context of toddler dining chair design, ergonomic aspects included safety, comfort, and ease of use for both toddlers and parents.

Research has shown that applying systematic product development approaches improves consumer satisfaction (Bao *et al.*, 2025). Initial surveys indicate that consumer satisfaction with current highchairs is low due to several shortcomings, including toddler discomfort, instability, ineffective safety belts, and limited durability for children weighing more than 20 kg, despite WHO growth charts indicating that toddlers up to 5 years old can weigh 28–30 kg. These issues underscore the need for developing a high chair that addresses health concerns, enhances comfort and efficiency for both parents and children, and incorporates essential structural and ergonomic safety principles (Wulan *et al.*, 2025).

Beyond ergonomic and safety considerations, contemporary product development increasingly incorporates environmental responsibility. The integration of recyclable materials, resource-efficient manufacturing processes, and long product life cycles reduces environmental impact (Lazăr *et al.*, 2023; Mubarokah *et al.*, 2024). Sustainable product development approaches emphasize balancing functional performance, safety, cost efficiency, and ecological impact (Wulan *et al.*, 2025). Advanced digital modelling and structural simulation techniques further enable early validation of safety performance while minimizing material waste during prototyping (Chen *et al*., 2024).

Therefore, this study integrates ergonomic, safety, and environmental considerations within a unified product development framework. The primary objective is to design a high chair that optimally supports toddlers' physical growth and motor skill development, enhances parental comfort and convenience during daily use, and contributes to sustainability efforts through the selection of recyclable materials and the application of efficient, resource-conscious manufacturing methods.

2. Methodology

This study employed a structured product development approach based on Ulrich's stages to formulate design specifications, generate concepts, and select the final design of a toddler dining chair. The process was carried out through six phases as outlined by Sutaguna *et al*. (2023): planning, concept development, system-level design, detail design, testing and refinement, and production preparation.

2.1 Product Planning

Initial research was conducted to understand user needs and market opportunities. A literature study was conducted to analyze the design of existing toddler feeding chairs and identify the necessary ergonomic and safety factors. In addition, surveys and interviews were conducted with parents, restaurants, and daycare providers to identify problems with current products, such as a lack of stability, comfort, and safety features. From this analysis, the initial specifications for an ergonomic dining chair were determined.

2.2 Product Concept Development

Several design alternatives were developed, with ergonomics, functionality, and safety in mind. Some initial concepts were sketched and evaluated. The best concept that met user needs was further developed into a 3D CAD model in SolidWorks for preliminary simulations (Dassault Systèmes, 2025).

2.3 System-level Design

The main elements of the product were further detailed. The primary structure of the chair, including the frame, seat, backrest, and legs, was defined based on its functional needs. Materials were selected based on their strength, safety, cost, and environmental responsibility (Lazăr *et al*., 2023). For example, 6061 aluminum was selected for the chair legs due to its strength and recyclability, while polypropylene was chosen for the seat because of its durability and ease of cleaning. Functional mechanisms, such as folding, height adjustment, and security locks, were also designed during this stage. A preliminary analysis of estimated production and manufacturing costs was conducted to assess the project's feasibility.

2.4 Detailed Design and Digital Testing

The 3D CAD model was refined based on child anthropometric data to ensure ergonomic compliance. After the primary system was finalized, further refinement was done with structural analysis. Digital testing via static simulation in SolidWorks was performed to evaluate durability and to identify critical points in the structure under load (Matwiej *et al*., 2025). This phase provided early validation of structural safety before physical prototyping, consistent with sustainable product development practices (Wulan *et al*., 2025).

2.5 Testing and Validation

At this stage, the design was validated through simulation, which assessed stability, structural safety, and ergonomics. Load tests in SolidWorks confirmed that the chair could withstand a maximum load of 30 kg within safe stress and deformation limits. Since no physical prototype was produced in this study, future physical testing will involve empirical evaluations, including stability, tipping risk, seatbelt effectiveness, and direct user comfort trials. This staged approach aligns with recommendations in sustainable product design, where digital validation precedes physical testing to minimize resource consumption (ISO 14006, 2020).

2.6 Production and Cost Estimation

Estimates of production and manufacturing costs were compiled based on the prices of raw materials and the production processes. Cost analysis considered extrusion for aluminum and injection molding for plastic components to minimize waste and improve efficiency. This approach ensured competitive market pricing and aligned with environmental responsibility by reducing material waste and supporting recyclability (Wulan *et al.*, 2025; ISO 14006, 2020).

3. Results and Discussion

3.1 User Requirement Analysis

Survey data were collected from parents, restaurant operators, and daycare providers, including a questionnaire survey completed by 33 parent/caregiver respondents regarding highchair usage patterns. The findings indicate that many commercially available highchairs exhibit inadequate structural stability, limited storage practicality, and lack height-adjustment features to accommodate children's growth stages. Observations of the 33 toddlers further revealed mismatches between seat dimensions and body proportions, particularly in seating depth and backrest support, which may affect posture and comfort during feeding. Safety concerns, particularly tipping risk and restraint effectiveness, were consistently highlighted by parents and daycare providers as primary considerations. These results confirm that stability, adjustability, and safety mechanisms constitute the most critical design requirements.

3.2 Conceptual Design Outcomes

Alternative chair concepts are initially produced as sketches and assessed for their functionality, ergonomic suitability, and ease of production. The best concepts are then modeled in 3D using SolidWorks to ensure alignment with the design requirements, with all key dimensions derived from toddler anthropometric data (Susanti *et al.*, 2023), as shown in Table 1. Anthropometry, a branch of ergonomics, provided numerical data on human body size used to determine chair dimensions, such as seat height, backrest tilt, and overall dimensions (Iliev *et al.*, 2023). The ergonomic toddler dining chair design outcomes are presented below.

Table 1. Anthropometric measurement results of kindergarten/preschool children

Anthropometric Data	Number of Samples	Average (cm)	Min (cm)	Max (cm)
Shoulder Height	15	29	26	30
Knee Height	15	24	22	27
Hip width	15	26	23	30
Hip-popliteal length	15	24	21	28

3.2.1 Seat Design

The final seat design has overall dimensions of 35 × 33 × 18 cm and provides a comfortable, safe seating area for toddlers. A seat width of 33 cm offers sufficient clearance beyond the maximum hip width of 30 cm, while a seat length of 35 cm exceeds the maximum hip-popliteal length of 28 cm and accommodates both the backrest and foam thickness. These proportions closely align with toddler anthropometric characteristics reported in previous studies, ensuring adequate support and stability during use. The detailed configuration of the seat geometry is illustrated in Figure 1.

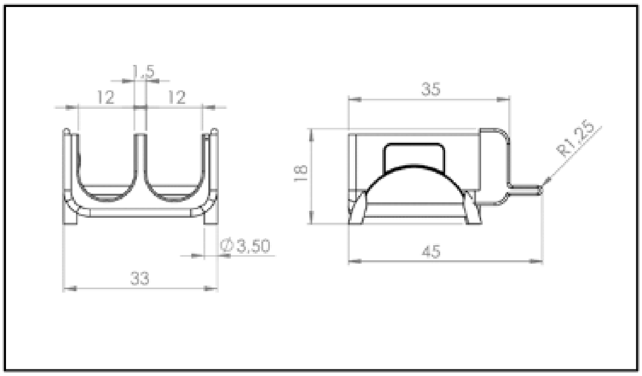

Figure 1. Ergonomic toddler dining chair seat design

3.2.2 Backrest

The dimensions of this backrest are designed according to the anthropometric data shown in Table 1 (Susanti *et al.*, 2023). The backrest is 30 cm wide, which corresponds to the toddler's body width, allowing it to accommodate a maximum hip width of 30 cm. The backrest height of 40 cm is designed to accommodate the toddler's maximum shoulder height of 30 cm. Increasing the backrest height to 40 cm provides full back support, including the neck and head, so that the toddler can sit more stably and comfortably. The overall dimensions of the backrest are 30 × 2 × 40 cm. The backrest is also equipped with a seatbelt to ensure the toddler's safety when sitting in the high chair, and it has hinges so the angle of the backrest can be adjusted. The hinge image is shown in Figure 2, and the backrest design image is shown in Figure 3.

Figure 2. Backrest hinge

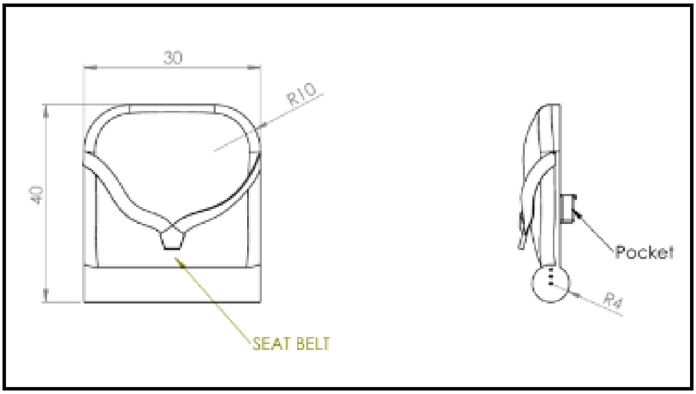

Figure 3. Ergonomic toddler dining chair backrest design

3.2.3 Feeding Tray

The chair tray is dimensioned to align with the ergonomic toddler dining chair seat and support typical feeding activities. It has an overall width of 39 cm and an active surface length of 25 cm, providing a safe, comfortable area for plates, cups, or toys while keeping them within easy reach. The tray corners are curved to enhance safety, reducing the risk of injury from sharp edges and making the surface more toddler-friendly. With overall dimensions of 29 × 39 × 2 cm and a width proportionate to the toddler's body breadth (maximum hip width 30 cm), the tray fits closely around the child without being excessively large or restrictive. The tray also incorporates a cup holder to help stabilize drinking vessels and minimize spills during feeding. The tray configuration is illustrated in Figure 4.

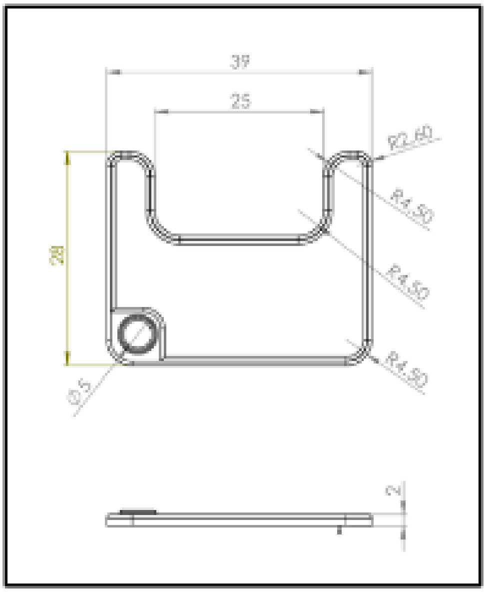

Figure 4. Ergonomic toddler highchair tray design

3.2.4 Chair Legs

The chair legs are configured to achieve a height compatible with typical dining tables (approximately 75 cm), allowing parents and children to sit and eat together comfortably. Each leg consists of three 25 cm segments, providing sufficient length for stability while accommodating height adjustment. The diameters increase from 2.5 cm at the bottom to 2.75 cm in the middle and 3 cm at the top, creating a wider contact area with the seat structure and enhancing sturdiness and load distribution. Height adjustment is secured with a hitch pin mechanism, allowing users to set the chair height to their needs. Anti-slip pads are attached to the lower ends of the legs to improve grip on the floor and maintain the toddler dining chair's stability during use. The configuration of the chair legs is illustrated in Figure 5.

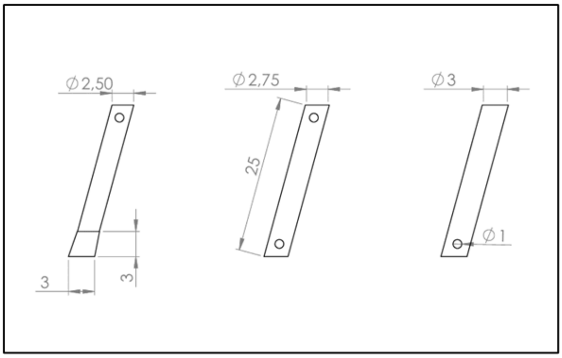

Figure 5. Ergonomic toddler feeding chair leg design

3.2.5 Overall Ergonomic Toddler Dining Chair

The ergonomic toddler dining chair measures 57 × 33 × 100 cm. A length of 57 cm accommodates the seat, backrest, and front tray, providing sufficient space for toddlers to sit comfortably while using the area for food or toys. The 33 cm width offers a balance between stability and comfort, without making the chair excessively wide, so that it can be easily positioned in various household settings. The 100 cm height positions the chair so the seat aligns with a standard dining table height of approximately 75 cm, allowing children to sit at the table with their parents. The elevated backrest supports an ergonomic sitting posture and helps maintain proper toddler body alignment. With these proportions, the chair offers both comfort and safety in daily use and features a folding mechanism to reduce storage space. The assembled chair is shown in Figure 6, and its folded configuration is presented in Figure 7.

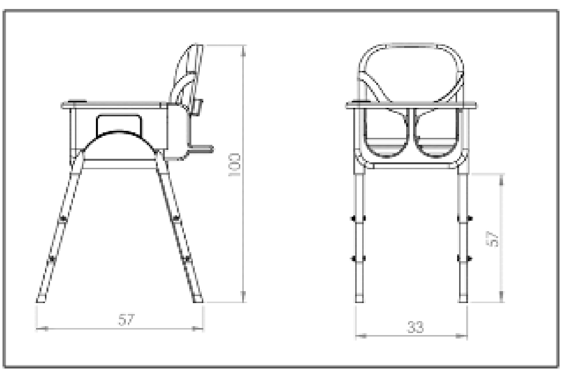

Figure 6. Overall ergonomic toddler dining chair design

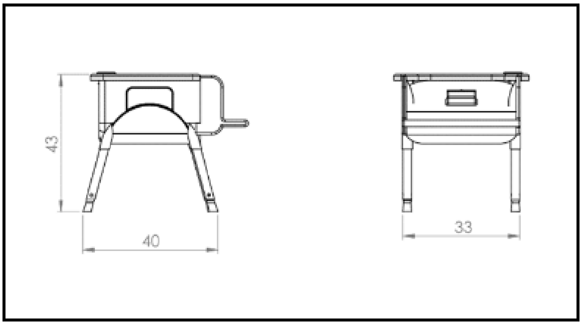

Figure 7. Folded configuration of the ergonomic toddler dining chair

3.2.6 Simulation Results of Ergonomic Toddler Dining Chairs

Finite Element Analysis (FEA) was conducted using SolidWorks Simulation to evaluate the structural integrity of the ergonomic toddler dining chair under static loading conditions. A vertical load of 30 kg (≈ 294.3 N), equivalent to a surface pressure of 350 N/m², was uniformly applied to the seat surface to represent the maximum expected toddler body weight up to 5 years of age, based on WHO growth-chart reference data (approximately 30 kg at the +3 z-score for this age); this value was adopted directly as the upper-bound design load rather than as an additional margin above a lower expected mass. Boundary conditions were defined by fixing the base of the leg supports to simulate ground contact constraints. The static analysis was executed using the standard Linear Elastic Isotropic material models built into the SolidWorks Simulation library. For the seat, Polypropylene properties were assigned (Elastic Modulus $E \approx 1.34$ GPa, Poisson's Ratio $\nu = 0.41$, Tensile Strength ≈ 27.6 MPa), while the leg assembly used Aluminum 6061 ($E \approx 69$ GPa, Poisson's Ratio $\nu = 0.33$, Tensile/Yield Strength ≈ 124 MPa). A standard curvature-based solid tetrahedral mesh was generated with global bonded contact formulations at assembly joints and fixed support constraints at the leg base. However, specific mesh convergence logs, element size iterations, and nonlinear contact formulations were not retained in the initial simulation records; this is acknowledged as a documentation limitation to be systematically expanded in future comprehensive mechanical evaluations.

3.2.7 Seat Structure Analysis

The von Mises stress distribution on the seat structure is presented in Figure 8. Stress concentration is primarily observed at the seat–leg connection interface and tray support region. However, the maximum stress value remains below the yield strength of 6061 aluminum (≈ 276 MPa), resulting in a safety factor greater than 1.5. This confirms that the seat structure satisfies predefined strength requirements.

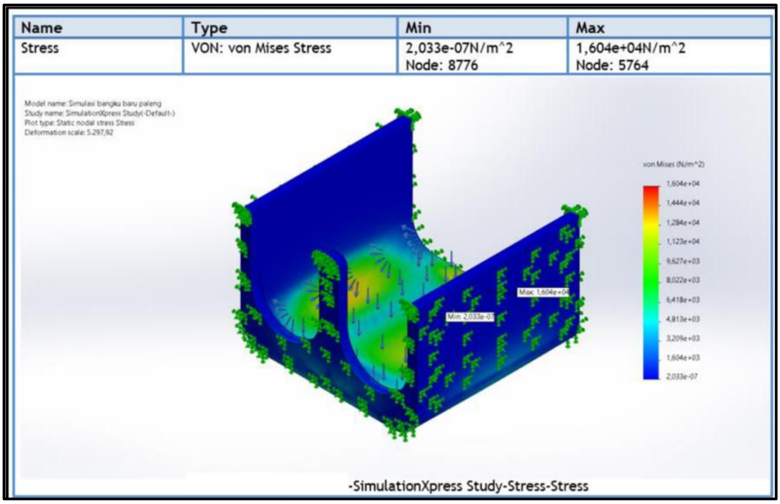

Figure 8. Simulation results of seat stress levels

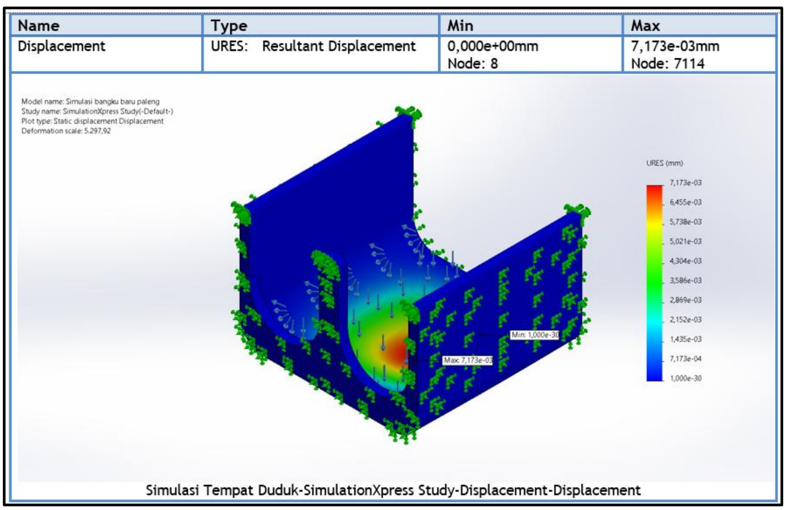

Figure 9. Simulation results of seat displacement levels

The displacement contour of the seat under applied load is shown in Figure 9. Maximum vertical deflection is recorded at approximately 0.0072 mm (7.173×10^{-3} mm) at the central seating area, in agreement with the numeric output in Table 3.

This magnitude of deformation is within acceptable ergonomic tolerance limits and does not compromise user comfort or structural stability.

The deformation profile illustrated in Figure 10 demonstrates uniform load transfer from the seating surface toward the structural supports. No localized buckling or excessive distortion is observed, indicating adequate stiffness and structural continuity.

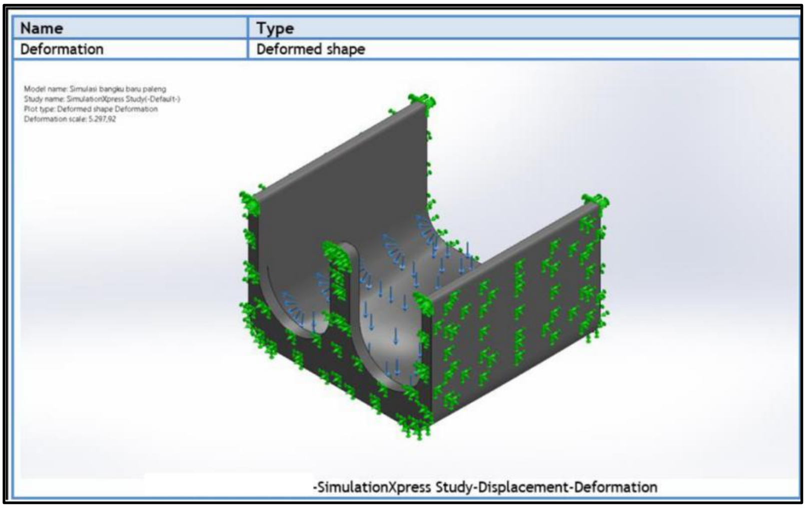

Figure 10. Simulation results of seat deformation shape

3.2.8 Chair Leg Structural Performance

The stress distribution along the aluminum leg assembly under compressive loading is shown in Figure 11. Load transfer occurs progressively from the seat interface to the lower support base. Peak stress values remain below allowable material limits, confirming that the 6061 aluminum structure has sufficient compressive strength.

The displacement contour of the leg assembly is presented in Figure 12. Vertical deformation is minimal and evenly distributed along the telescopic segments. The height-adjustment pinhole interfaces do not exhibit critical localized stress amplification under the applied static vertical load. However, this static simulation only reflects initial load distribution and does not establish the complete mechanical reliability, locking strength, or cyclic fatigue endurance of the adjustable mechanism, which require dedicated dynamic and physical mechanism testing.

The overall deformation shape of the leg structure under load is shown in Figure 13. Under the applied vertical static load, the deformation pattern shows no significant bending or lateral instability at the leg base. This fixed-base boundary condition reflects the static vertical-load simulation only; it does not, by itself, demonstrate resistance to physical tipping, which was not evaluated in this study and is recommended for future physical and simulation-based testing.

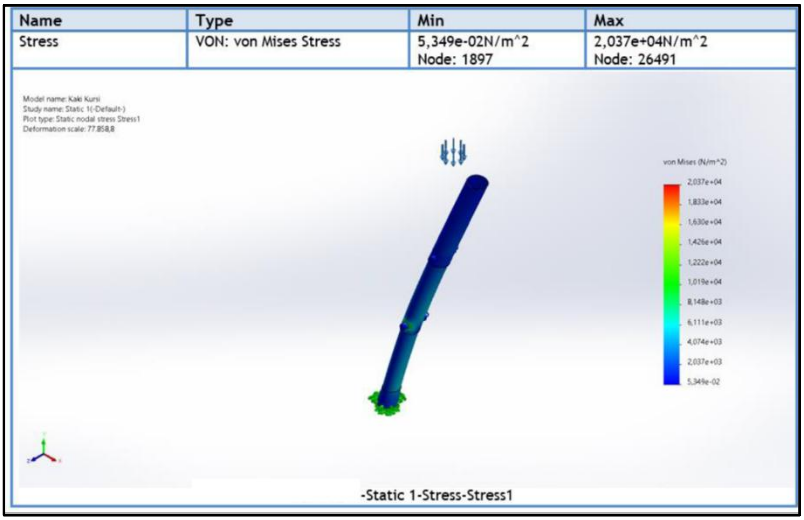

Figure 11. Chair leg stress level simulation results

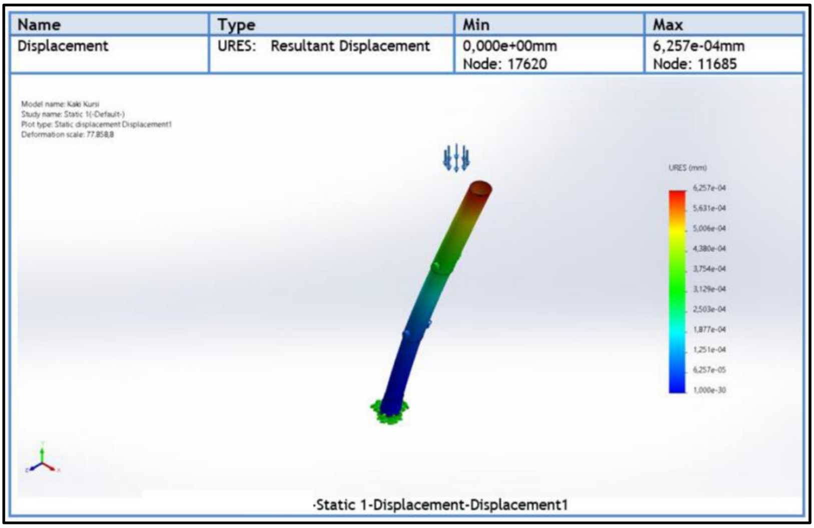

Figure 12. Chair leg displacement simulation results

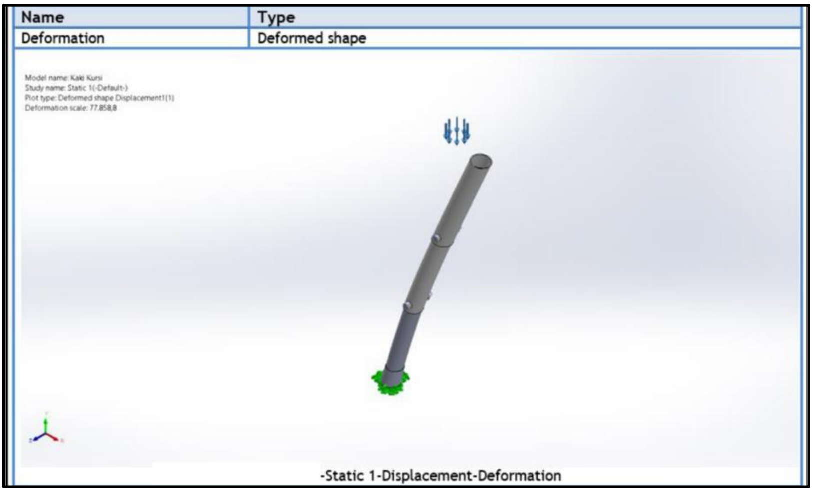

Figure 13. Chair leg stress level deformation shape

3.3 Structural and Material Configuration

The seat also features a folding mechanism, height adjustment, and a nylon three-point restraint proposed as a safety feature; material selection for the restraint was based on tensile strength and durability, while anchorage strength, buckle specification, and entrapment risk were not analyzed and are recommended for future mechanical validation. The material for the ergonomic toddler feeding chair is selected based on engineering and design characteristics that prioritize safety, comfort, durability, and ease of maintenance. Here are the primary materials used, as shown in Table 2.

Table 2. Materials for each design

Design	Materials
Seat	Combining polyurethane foam (PU) and polypropylene plastic (PP) for optimal comfort and durability. Alternatives such as ABS plastic are considered for higher durability.
Backrest	A combination of PP plastic and PU foam for ergonomic support and comfort, with ABS as an alternative for better durability.
Seat Tray	ABS is a sturdy and economical option.
Chair legs	Aluminum 6061 is chosen for its strength and lightweight properties, while mild steel or PP plastic are alternative materials that can help keep costs down.
Seat Belts	Nylon is chosen for its high tensile strength and durability, although polyester can be used for water resistance and ease of maintenance.

The selected materials strike a balance between quality, safety, and competitive pricing. The design was developed with safety considerations to support use by toddlers aged 6 months to 5 years in various environments; no formal compliance testing against a specific product safety standard (e.g., SNI, ASTM, EN) was conducted in this study. Alternative materials are provided to adjust production needs without sacrificing quality.

3.4 Structural Performance Evaluation

Stability, safety, ergonomic, and structural evaluations indicate that the chair performs well under typical usage conditions. Structural performance was quantified using finite element analysis (FEA) in SolidWorks. A vertical load of 30 kg (≈ 294.3 N) was applied to the seat surface to represent the maximum expected toddler body weight up to 5 years of age, consistent with WHO growth-chart reference data. The seat model, made of Polypropylene (tensile strength 27.6 MPa), exhibited a maximum von Mises stress of 16.04 MPa and a maximum displacement of 0.007173 mm, corresponding to a safety factor of approximately 1.72. The leg model, made of Aluminum 6061 (tensile strength 124 MPa), was evaluated independently and exhibited a maximum von Mises stress of 20.37 MPa and a maximum displacement of 0.6257 mm, corresponding to a minimum safety factor of approximately 6.09. Table 3 summarizes these results. Both components remained within safe stress and displacement limits, with the small computed displacements indicating a sufficiently rigid structure and no significant risk of permanent deformation under the applied load.

Table 3. Summary of static FEA results under 30 kg vertical load

Component	Material	Max. von Mises Stress (MPa)	Max. Displacement (mm)	Safety Factor
Seat	Polypropylene (PP)	16.04	0.007173	≈ 1.72
Leg	Aluminum 6061	20.37	0.6257	≈ 6.09

Lateral-load and tipping-resistance simulations were not conducted in this study; only static vertical loading was evaluated for the seat and leg components. Assessment of lateral stability and tipping resistance under active toddler movement is therefore identified as a limitation of the present study and is recommended as a priority for future physical and simulation-based testing prior to prototyping.

The ergonomic evaluation was based on anthropometric conformity analysis rather than direct observation of toddlers; a questionnaire survey of 33 parent/caregiver respondents (Section 3.1) informed the identification of user needs. Anthropometric conformity was assessed by comparing seat width (33 cm), seat depth (35 cm), and backrest height (40 cm) with secondary reference anthropometric data (Susanti *et al*., 2023). Clearance values were calculated by subtracting the maximum body dimensions from the seat dimensions, yielding positive clearance margins of approximately 3–5 cm, indicating adequate dimensional compatibility. These calculations suggest a design-based expectation of improved postural alignment and trunk support during feeding; no quantitative posture or comfort measurement was conducted in this study, and this is recommended as a direction for future work.

The structural frame mass was estimated at approximately 3.5–4.0 kg based on CAD model volume calculations. Compared with a mild-steel configuration of equivalent geometry (estimated at 6.0–7.0 kg), the aluminum structure provides a weight reduction of approximately 35–45%. This reduction was calculated using proportional density comparison (aluminum ≈ 2.7 g/cm^3; mild steel ≈ 7.8 g/cm^3). The lighter mass may contribute to lower transportation energy demand per unit during distribution.

Environmental considerations were assessed qualitatively and partially quantified based on material properties. Aluminum is technically recyclable with industrial recovery efficiencies reported above 90%, while polypropylene (PP) recyclability depends on regional waste management systems. However, the recyclability of individual materials does not by itself establish that the assembled product is environmentally preferable; assembly-level factors such as material separability, adhesives/fasteners, and end-of-life disassembly would need to be assessed to substantiate product-level environmental performance. The applied design load of 30 kg reflects the upper-bound (+3 z-score) growth reference for a 5-year-old child, exceeding typical average body weights (10–22 kg) to ensure accommodating capacity across the toddler's developmental span. It should be noted that this weight differential represents a functional load assumption rather than an engineering safety factor, with structural safety factors (1.72 for seat and 6.09 for legs) derived strictly from material yield/tensile thresholds under finite element analysis.

However, no formal life-cycle assessment (LCA), carbon footprint quantification, or end-of-life recycling rate modeling was conducted. Therefore, conclusions about environmental performance are derived from material characteristics, mass-reduction calculations, and durability assumptions rather than comprehensive environmental impact modeling. Future studies should incorporate standardized LCA methodology, embodied carbon estimation, and recycling rate analysis to quantitatively validate reductions in environmental impact relative to conventional highchair designs.

3.5 Cost and Feasibility Analysis

Production cost analysis, based on current e-commerce prices for raw materials and the assumed fabrication route, indicates an estimated material cost of Rp. 377,800 per ergonomic toddler dining chair, excluding labor and overhead. Using 6061 aluminum for the structural components increases material costs compared with plastic alternatives, but yields clear advantages in structural stability, stiffness, and durability. Scenario evaluations with mild steel or PP as substitute materials show potential to reduce material expenditure, though at the expense of higher weight with mild steel and lower rigidity and service life with PP. These findings highlight an explicit trade-off between safety-related performance and affordability that must be considered in subsequent design and manufacturing decisions.

The results also show that applying Ulrich and Eppinger's product development framework yields a structured translation of user needs into engineering specifications for a toddler feeding chair. Safety and stability emerge as the most critical attributes in the user requirement hierarchy, followed by comfort and ease of use. These priorities are reflected in technical requirements such as the inclusion of a three-point restraint system, limits on allowable deflection under load, and minimum strength criteria for the leg structure. Material selection converges on a combination of 6061 aluminum for load-bearing elements and PP with PU foam for contact surfaces, which improves seating comfort relative to hard-plastic reference products while maintaining adequate structural performance. Height adjustment and folding functions are included not only as product features but also as quantified responses to user needs for adaptability. However, they are also quantified as responses to user needs for adaptability across domestic and public settings, such as homes, restaurants, and daycare facilities.

Structural evaluation using SolidWorks simulations demonstrates that the chair can support a vertical load of up to 30 kg without significant deformation, with maximum stresses remaining below the allowable stress for the seat (Polypropylene) and leg (6061 aluminum) materials. The leg structure exhibits minimal compressive deformation. The folding and height-adjustment mechanisms have been demonstrated at the CAD/design-feasibility level only; locking strength, fatigue/cycling behavior, and pinch-point safety have not been tested and are recommended for future physical evaluation. These results indicate that, at the simulated static load level, the design satisfies the defined structural safety criteria; dynamic and mechanism-level testing remain necessary before the safety and stability criteria can be considered fully validated for typical toddler use.

Overall, the study shows that combining a systematic product development framework with anthropometric data, structural simulation, and cost estimation can yield an ergonomic toddler feeding chair design that meets predefined safety, comfort, and adaptability criteria while explicitly identifying trade-offs between performance and production cost. A key limitation is that all evaluations are based on virtual simulations and cost modeling; no physical prototypes were manufactured or tested. Future work should therefore include prototype fabrication, experimental validation of structural and stability performance, and user trials to obtain empirical data on comfort, perceived safety, and durability in everyday use, enabling further refinement toward a production-ready product.

4. Conclusion and Recommendation

This study successfully developed an ergonomic toddler feeding chair using a computer-aided design (CAD) based product development approach, complemented by static simulation in SolidWorks. Following the product development framework of Ulrich, Eppinger and Yang (2020), as applied through the six phases outlined by Sutaguna *et al*. (2023), the research proceeded through: planning, concept development, system-level design, detail design and simulation, design validation, and production cost estimation. The user needs analysis revealed shortcomings in existing products, including inadequate stability, the lack of height-adjustment features, poor storage convenience, and the use of uncomfortable, hard-to-clean materials. In response, the chair developed in this study was designed with key features: a frame structure made from 6061 aluminum to improve stability, a seating surface made from polypropylene (PP) and polyurethane (PU) foam for enhanced comfort, a folding mechanism for easy storage, and an adjustable height feature to accommodate various dining table types. Static simulation results confirmed adequate structural safety under a maximum vertical load of 30 kg, with minimal deformation and safety factors of approximately 1.72 (seat) and 6.09 (leg), evaluated independently; lateral stability and tipping resistance were not evaluated and remain a limitation of this study. Although the use of aluminum increased production costs, the trade-off resulted in significant benefits in durability and safety. Production efficiency considerations suggest that a combination of injection and extrusion molding can reduce manufacturing costs while maintaining product quality. However, the absence of physical prototype testing remains a limitation. Future work should focus on empirical validation through user trials and real-world testing to comprehensively assess ergonomics, comfort, and usability. Overall, the proposed design shows strong potential to outperform conventional toddler feeding chairs in terms of safety, comfort, and flexibility, and it could be further refined into a competitive, production-ready product.

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