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STRUCTURED PRODUCT DEVELOPMENT IN THE CHILDREN'S SEGMENT: A QFD AND FMEA-BASED APPROACH APPLIED TO A DECORATIVE MDF LAMP

DESENVOLVIMENTO ESTRUTURADO DE PRODUTO NO SEGMENTO INFANTIL: UMA ABORDAGEM BASEADA EM QFD E FMEA APLICADA A UMA LUMINÁRIA DECORATIVA EM MDF

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ABSTRACT

This paper examines the product development process applied to the design and manufacture of a laser-cut MDF decorative lamp for children, the Luminária Decorativa Kids. Following the Rozenfeld et al. (2006) reference model, the study covers all phases from ideation and informational design through prototyping, pilot-batch production, and post-development activities. Tools including brainstorming, Quality Function Deployment (QFD), and Failure Mode and Effects Analysis (FMEA) were applied to translate customer needs into technical specifications and to anticipate and mitigate production risks. The product was conceived around a co-creation premise: delivered unfinished in raw MDF alongside colored markers, it invites children and caregivers to personalize the lamp together, thereby adding emotional and experiential value. A competitive analysis confirmed a significant price advantage over comparable market offerings, reinforcing the viability of the concept. Results demonstrate that a structured, customer-centred development process is a reliable path to market-ready, innovative products, and highlight customization as a meaningful competitive differentiator in children's product design.

Keywords: Product Design and Development; production engineering; QFD; FMEA; Customization.

RESUMO

Este trabalho analisa o processo de desenvolvimento de produto aplicado ao projeto e fabricação de uma luminária decorativa em MDF com corte a laser voltada ao público infantil, a Luminária Decorativa Kids. Seguindo o modelo de referência de Rozenfeld et al. (2006), o estudo percorre todas as fases, desde a ideação e projeto informacional até a prototipagem, lote piloto e pós-desenvolvimento. Ferramentas como brainstorming,

Desdobramento da Função Qualidade (QFD) e Análise dos Modos de Falha e Efeitos (FMEA) foram empregadas para traduzir as necessidades dos clientes em especificações técnicas e para antecipar e mitigar riscos de produção. O produto foi concebido com base em uma premissa de cocriação: entregue em MDF sem acabamento, acompanhado de canetas coloridas, convida crianças e responsáveis a personalizar a luminária juntos, agregando valor emocional e experiencial. A análise competitiva confirmou uma vantagem de preço relevante em relação a produtos similares no mercado, reforçando a viabilidade do conceito. Os resultados demonstram que um processo de desenvolvimento estruturado e centrado no cliente é um caminho confiável para produtos inovadores e viáveis, destacando a personalização como diferencial competitivo no design de produtos infantis.
Palavras-chave: Projeto e Desenvolvimento de Produto; Engenharia de Produção; QFD; FMEA; Personalização.

1. INTRODUCTION

Launching a new product is rarely a routine activity for most organisations. It typically results from a substantial collective effort spanning virtually every department, generating commercial demand and ensuring the company's long-term viability. Although alternative solutions may emerge throughout the process, the fundamental choices regarding materials, processes, and technical specifications are made in the earliest phases of product development, and their effects reverberate through cost and quality long after production begins (Rozenfeld et al., 2006).

Rapid technological change has intensified competitive pressure: customers are better informed, enjoy access to a wider range of alternatives, and global competitors continuously release new offerings designed to outpace evolving needs. Under these conditions, companies must go beyond competitive pricing; they must stay ahead of rivals by understanding the target audience in depth, tailoring products to customer desires, and adopting efficient, evidence-based development methodologies (Rozenfeld et al., 2006).

The southern region of Brazil accounts for the second largest share of the country's GDP, with Rio Grande do Sul as the primary contributor. The state had a population of approximately 11.3 million people and a monthly per-capita household income of BRL 1,843 in 2019 (IBGE, 2019). On a national scale, the children's market has expanded notably: over six years, Brazilian sales of children's products grew from BRL 2.7 billion to BRL 3.9 billion, a 45.6% increase (Olivette, 2018). Research into children's product design further confirms that this segment rewards well-executed, user-centred approaches: Hua (2024) demonstrates the effectiveness of sensory-based methods in translating children's emotional responses into product requirements, while Phuah et al. (2025) show that structured usability evaluation of children's furniture yields meaningful insights that improve both function and acceptance.

Given this market context, the authors identified the children's segment as a promising niche and chose it as the focus of this product development project. The guiding research question was: How can a product be developed to capitalise on the potential of the children's market through an object that stimulates creativity?

The general objective of this paper is to document the development and manufacture of a decorative lamp with a children's theme, produced from laser-cut MDF (Medium Density Fiberboard). The product concept invites parents and children to paint and personalise the lamp together using coloured markers, so that beyond its core function of illuminating a room it also provides a moment of play, creative expression, and family bonding. Specific objectives included: defining the product concept; building a physical prototype; producing a pilot batch of ten units; carrying out sales and delivery of those units; and conducting a customer satisfaction assessment.

The development followed all classical phases of structured product development: brainstorming for idea generation and concept definition; informational design with QFD and competitive benchmarking; detailed design; cost estimation; material procurement; prototyping; pilot-batch production; price confirmation; and post-development activities covering marketing, distribution channels, and logistics.

2. THEORETICAL BACKGROUND

This section presents the conceptual foundations underpinning the product development process applied in the study.

2.1. Product Development

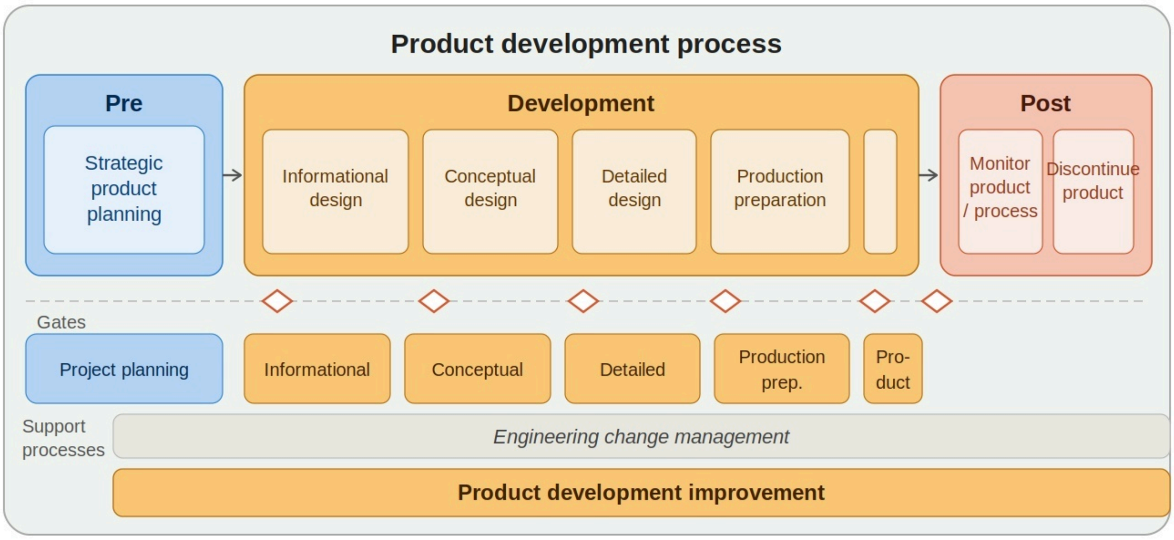
New products arise when market opportunities make them attractive to consumers, whether through entirely novel functionalities or through incremental and disruptive innovations (Barbosa Filho, 2009). Product development is a structured set of activities that transforms market needs and technological possibilities into detailed engineering specifications, taking into account the company's competitive strategies and production capabilities. The process extends beyond the launch itself to encompass post-market monitoring and planning for product discontinuation, integrating lifecycle considerations from the outset (Rozenfeld et al., 2006).

Because new product development (NPD) activities influence and are influenced by virtually every organisational function, effective coordination and inter-functional communication are critical. Typical NPD activities follow an iterative Design–Build–Test–Optimise cycle that may apply equally to concepts, specifications, or tolerances of either the product or its production process (Rozenfeld et al., 2006). More recent scholarship reinforces this systemic view: Chiu et al. (2022) identify the principal risk factors in NPD projects and stress the need for proactive risk management from the earliest phases, while Relich, Nielsen, and Gola (2022) show that design-stage decisions directly shape final product costs, underscoring the strategic importance of early, well-informed choices.

2.2. Reference Models

For the NPD process to be both effective and efficient, it must be governed by reference models that provide structure, traceability, and control. The Rozenfeld et al. (2006) model, widely adopted in Brazilian industry and academia, organises the process into three macro-phases: pre-development, development, and post-development. Each macro-phase is subdivided into phases and activities, as illustrated in Figure 1.

Figure 1: *Product Development Process*



Source: Adapted from Rozenfeld et al. (2006).

Although the Rozenfeld model provides a solid structural foundation, it can be complemented by additional decision-support tools. Altubaishe and Desai (2023) propose integrating multicriteria methods such as AHP and PROMETHEE with FMEA to enable more robust decisions throughout development. Thomas (2025) further argues that FMEA itself must be rethought to remain relevant in today's innovation-intensive manufacturing environments, while Piloto, Lima, and Severino (2024) demonstrate how parameter modelling applied within FMEA supports risk management in complex industrial projects. Combining these approaches with the Rozenfeld framework creates a more resilient development process capable of anticipating and responding to both technical and market uncertainties.

2.3. Brainstorming

Brainstorming, sometimes described as a "storm of ideas", is a group creativity technique that suspends critical judgment to maximise the quantity and diversity of ideas generated. Participants from varied specialties produce unrestricted suggestions, each of which may in turn spark further ideas from colleagues. Evaluation and selection occur only after the session concludes (Pahl et al., 2005; Rozenfeld et al., 2006).

In the NPD context, brainstorming is particularly valuable in the early ideation stage, where openness to radical solutions is most productive. Zou et al. (2024) examine how design teams retrieve and use precedents during brainstorming sessions, finding that exposure to diverse prior examples broadens the solution space and improves the originality of concepts generated, an insight directly relevant to consumer product design projects such as the one reported here.

2.4. Risk Management In Product Development

Uncertainty and unpredictability are inherent to NPD. The greater the likelihood of undesirable events and the fewer the available remedies, the higher the project's risk exposure, with direct consequences for cost, schedule, and quality. Effective risk planning seeks an equilibrium between the need to reduce uncertainty and the equally pressing need to pursue innovation, which by its nature introduces instability (Rozenfeld et al., 2006; Gehlen et al., 2018).

Chiu et al. (2022) systematically identify key risk factors across NPD projects and provide a framework for prioritising them from the concept stage onwards. Their findings reinforce the importance of embedding risk assessment into the earliest design decisions rather than treating it as a downstream corrective activity.

2.5. Informational Design

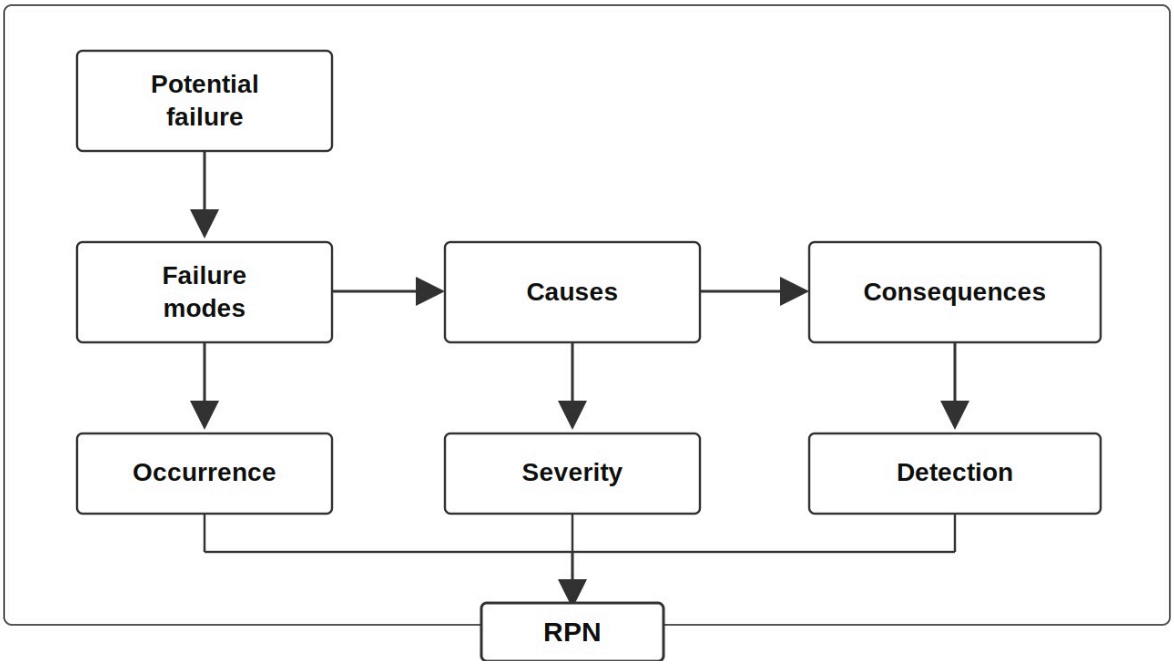
The informational design phase translates the project plan into product meta-specifications, that is, the set of requirements and qualitative information that the engineering activities aim to achieve. Key outputs include: the product scope (a preliminary description of requirements); a lifecycle map; customer needs (raw, often overlapping statements of desire); customer requirements (structured and categorised needs); product requirements (characteristics with target values); and supplementary qualitative information (Rozenfeld et al., 2006).

This phase also provides the criteria against which subsequent design decisions are evaluated. Relich, Nielsen, and Gola (2022) demonstrate that design-stage choices account for a disproportionate share of total product cost, making the informational phase a critical leverage point for economic viability. Ince et al. (2025) further show that combining QFD, FMEA, and lean principles during informational and conceptual design can simultaneously improve economic and environmental performance, a finding particularly relevant to wood-based product development.

2.6. FMEA: Failure Mode And Effects Analysis

FMEA is a systematic, proactive technique for identifying potential failures in a product or process, analysing their causes and effects, and defining corrective actions before those failures materialise in production or in the field. As illustrated in Figure 2, the analytical logic of FMEA maps potential failures to their failure modes, which in turn connect to causes and consequences; these three dimensions feed into the indices of occurrence, severity, and detection, whose product yields the Risk Priority Number (RPN) (Barbosa Filho, 2009).

Figure 2: FMEA structure



Source: Adapted from Barbosa Filho (2009).

Application follows five structured steps: (1) plan objectives and scope; (2) list failure modes, causes, and effects; (3) prioritise failure modes by severity, occurrence, and detectability; (4) define and implement corrective actions; and (5) monitor outcomes (Barbosa Filho, 2009; Gehlen et al., 2018). The RPN, calculated as Severity × Occurrence × Detection (each rated 1 to 10), allows the development team to rank failure modes objectively and concentrate improvement efforts where risk exposure is greatest. Design FMEA (DFMEA) addresses potential failures inherent to the product design itself, while Process FMEA (PFMEA) focuses on the manufacturing and assembly process (Gehlen et al., 2018). This distinction is strategically important: decisions taken during the design phase disproportionately determine final product cost and quality, making early-stage risk analysis a high-leverage activity (Relich, Nielsen, & Gola, 2022).

The power of FMEA grows considerably when integrated with complementary methodologies. Its most established pairing is with QFD, a combination that closes the loop between customer requirements and technical risk: QFD translates customer needs into engineering specifications, while FMEA stress-tests those specifications against potential failure scenarios. Jugend and Silva (2013) describe this integration as a foundation for structuring development activities around user expectations, ensuring that quality targets are pursued consistently from concept through production. Frizziero et al. (2022) apply this combined approach in the development of a full-electric sports sedan, showing that the simultaneous use of QFD and virtual prototyping enables early identification of design vulnerabilities that would otherwise surface only during costly physical testing. Ginting et al. (2025) extend this logic further, integrating QFD, reverse engineering, and 3D printing in the development of a prosthetic device, demonstrating that systematic requirements analysis and failure anticipation are equally applicable in high-stakes, safety-critical contexts where any failure mode carries severe consequences for the end user.

The integration of FMEA with lean manufacturing principles has also yielded measurable results. Ince et al. (2025) apply a fuzzy QFD approach supported by FMEA within a lean framework in the outdoor wood furniture industry, achieving concurrent improvements in economic performance and environmental sustainability. Their findings are particularly relevant to the present study, which shares the same material domain, MDF-based wood products, and a similarly cost-sensitive market positioning. Tiewtoy, Moocharoen, and Kuptasthien (2024) arrive at comparable conclusions in a different sector, showing that user-centred QFD combined with structured failure analysis produces designs better matched to real operational conditions, even in low-cost, resource-constrained production environments. Both studies reinforce the argument that FMEA delivers the greatest value not as a standalone checklist but as an embedded component of a broader quality and decision framework.

The integration of FMEA with multicriteria decision methods represents a further frontier of methodological development. Altubaishe and Desai (2023) couple FMEA with AHP and PROMETHEE, enabling more transparent and auditable prioritisation of supply-chain risks, an approach that improves upon traditional RPN-based ranking by accounting for the relative importance of different failure dimensions. Amine, Hmina, and Sallaou (2024) demonstrate that combining FMEA with behaviour-model accuracy assessment and physical prototyping strengthens design decisions, particularly in early development phases where uncertainty about component behaviour is highest. This finding aligns with the broader evidence that risk identification embedded from the earliest project stages consistently improves NPD outcomes (Chiu et al., 2022).

Quality-improvement frameworks that draw on FMEA logic have also shown applicability across product improvement cycles. Siwiec, Pacana, and Gazda (2023) propose a QFD-based method that incorporates circular economy principles alongside failure analysis, showing that systematic risk anticipation can simultaneously serve quality, sustainability, and lifecycle objectives. Ulewicz, Siwiec, and Pacana (2023) extend this perspective with a pro-quality decision model that integrates customer requirements into ongoing product improvement decisions, using FMEA-derived risk data as an input to continuous refinement rather than a one-time pre-launch exercise. Together, these contributions reframe FMEA as a living analytical instrument that accompanies the product throughout its lifecycle, rather than a gate to be passed before production begins.

Piloto, Lima, and Severino (2024) reinforce this view by applying parameter modelling within FMEA to manage risks in large-scale industrial operations, demonstrating the tool's adaptability to complex, multi-variable environments where failure interdependencies are difficult to capture through conventional analysis alone. Thomas (2025) synthesises these developments into a broader argument: FMEA must be fundamentally reconceived for today's innovation-intensive manufacturing landscape. While its core logic, identify, prioritise, act, remains sound, its application must evolve to accommodate faster development cycles, greater product complexity, and a more demanding regulatory and sustainability environment. Far from signalling obsolescence, this call for renewal affirms FMEA's continued centrality in product and process risk management.

Taken together, the evidence positions FMEA not as a static compliance tool but as a dynamic analytical framework whose value compounds when applied iteratively, integrated with complementary methods, and revisited across the full arc of product development and post-launch improvement.

2.7. QFD: Quality Function Deployment

QFD is a methodology that systematically converts customer needs into technical product requirements. Through the House of Quality matrix, qualitative customer expectations are mapped against engineering characteristics, enabling the development team to identify which technical parameters most strongly influence customer satisfaction. The methodology can cascade from product characteristics through manufacturing processes to quality-control plans, ensuring that customer-derived requirements are consistently pursued across all stages of production (Jugend & Silva, 2013).

Ince et al. (2025) demonstrate the power of QFD when integrated with FMEA and lean principles in the furniture industry, reporting measurable gains in both environmental sustainability and economic efficiency. This integration is particularly relevant to the present study, which targets a wood-based consumer product where cost and environmental impact are key concerns.

2.8. Process Flow Diagram

The process flow diagram details the manufacturing sequence and the resources required at each step, including machines, materials, labour, and physical space. Decisions about production flow made during early design phases have a direct and lasting impact on product cost, making the flow diagram a critical planning tool (Rozenfeld et al., 2006). Relich, Nielsen, and Gola (2022) confirm that cost-reduction opportunities are greatest when addressed at the design stage, before production commitments are made.

2.9. Detailed Design

Detailed design produces the complete technical documentation required for manufacturing: drawings with dimensional tolerances, part lists, and update-controlled revision records. This documentation is essential to avoid production defects and is the foundation for formal production-part approval processes (Gehlen et al., 2018). Muminović et al. (2024), working in the furniture manufacturing sector, illustrate how precision in dimensional documentation, supported by advanced measurement tools, reduces assembly errors and waste.

2.10. Prototyping

The prototype translates design intent into a physical artefact that can be evaluated against technical specifications, assessed for visual and ergonomic qualities, and used to identify discrepancies before full-scale production (Jugend & Silva, 2013). Ahmed, Irshad, and Demirel (2021) situate prototyping at the heart of human-centred product development in the Industry 4.0 era, emphasising its role in reconciling user requirements with engineering constraints. Erichsen et al. (2021) show that early-stage physical prototypes in engineering projects serve primarily as learning artefacts, generating knowledge that cannot be obtained through purely computational means.

Beyond the physical object, prototyping is increasingly understood as a knowledge-generation activity. Goudswaard et al. (2023) document how prototyping produces distinct types of knowledge, about the product, the process, and the user, and argue that managing this knowledge explicitly improves downstream development decisions. Santos et al. (2021) demonstrate that prototypes used to involve users during development yield substantial benefits in terms of requirement validation and stakeholder alignment.

In the context of customer co-creation, Song and Wei (2024) show that prototype design choices influence customers' willingness to participate in iterative product refinement, reinforcing the strategic importance of prototype fidelity and presentation in customer-facing development processes.

2.11. Pilot Batch Production

The pilot batch is produced using final production equipment and follows the same sequence as future series production, even when volumes are low. Its purpose is to validate the production process, identify latent issues not apparent in prototype testing, and confirm that quality targets can be met under real manufacturing conditions. Pilot production may occur in new or existing facilities and may require shared use of equipment with existing product lines (Rozenfeld et al., 2006).

2.12. Product Customization And Co-creation

Mass customization, understood as the ability to offer individually tailored products at near-standard costs, has emerged as a significant source of competitive differentiation. Li, Yang, and Xu (2022) demonstrate that mass customization positively influences consumers' perceived brand value, a finding with direct implications for the positioning of customizable children's products. Lyu et al. (2024) show that structured consumer participation in product co-design, when properly managed within a service-oriented manufacturing system, generates superior outcomes for both customer satisfaction and product relevance.

In the furniture and home-decoration sector specifically, Manavis et al. (2024) present evidence that digital customization capabilities enhance consumer engagement and perceived product value, themes that extend naturally to the analogue personalization approach adopted in the present study. The children's product domain adds a further dimension: Hu et al. (2023) demonstrate that structured product development methods applied to infant and toddler products produce designs better aligned with developmental needs and parental expectations, while Hua (2024) shows that Kansei engineering provides a systematic route from children's emotional responses to concrete product design requirements.

2.13. Post-development: Launch, Distribution, And Marketing

The post-development macro-phase encompasses all activities that support the product's commercial life: market launch, distribution, customer service, and technical assistance, as well as the eventual planning of product discontinuation (Rozenfeld et al., 2006). Logistics in this phase spans demand management, order fulfilment, and delivery tracking, all of which contribute to the customer's perception of service quality (Arbache et al., 2011).

Marketing activities leverage communication channels to make the product's benefits visible to the target audience, create desire, and drive purchase decisions. Digital channels and social-media-based campaigns have become central to consumer product launches, especially for niche and novelty items targeting younger demographics (Jansen, 2015). Customer satisfaction research conducted after launch provides feedback that can inform future product improvements and new development cycles (Ferreira et al., 2011).

3. RESEARCH METHODOLOGY

This study is applied research, aimed at generating knowledge directed at solving a specific practical problem: the development and manufacture of a commercially viable children's decorative product (Prodanov & Freitas, 2013). In terms of objectives, it is exploratory, relying on literature review and empirical investigation to deepen understanding of the phenomenon under study.

The methodological approach is qualitative, interpreting meaning and significance rather than quantifying variables (Yin, 2015). With respect to technical procedures, the study combines bibliographic research, drawing on previously published materials, combined with action research, in which the investigators participate actively in both the investigation and the resolution of the problem (Yin, 2015). This dual approach allows for continuous interaction between theory and practice throughout all development phases. The empirical activities reported here were carried out between March and December 2020, as part of a Product Design and Development course in the Industrial Engineering undergraduate programme at Universidade Feevale, Nova Hamburgo, Rio Grande do Sul, Brazil. The course provided the institutional framework within which the full NPD cycle was applied, from initial ideation through pilot-batch production and post-development planning, under academic supervision.

The work method followed a structured roadmap: (1) theoretical foundation; (2) opportunity identification and idea selection; (3) concept and scope definition; (4) QFD elaboration and competitive analysis; (5) detailed design; (6) cost estimation and material procurement; (7) process sequence definition; (8) PFMEA elaboration; (9) prototype construction; (10) pilot-batch production; (11) price confirmation and critical review; and (12) post-development planning. Each phase fed into the next, creating an iterative and traceable development record.

4. RESULTS

This chapter presents the outcomes of each phase of the Luminária Decorativa Kids development process, demonstrating the application of the tools and methods described in the theoretical background.

4.1. Opportunity Identification And Idea Selection

The initial phase focused on selecting a product concept within the children's segment. MDF was chosen as the primary material on account of its versatility, suitability for laser cutting, and local availability. The brainstorming sessions, structured to defer judgment and encourage radical ideas in line with Pahl et al. (2005) and Rozenfeld et al. (2006), converged on a thematic lamp featuring laser-cut silhouettes that project light through decorative cutouts, combining visual appeal for children with practical lighting functionality.

Zou et al. (2024) note that exposure to diverse design precedents during brainstorming broadens the solution space; accordingly, the team surveyed existing decorative lighting products before and during sessions to enrich the generative process. The primary selection criteria were structural resistance, competitive cost, and visual attractiveness for the target age group.

4.2. Product Concept, Process And Project Scope, And Target Price

The product concept, Luminária Decorativa Kids, was defined around co-creation: the lamp is delivered unfinished in raw MDF, accompanied by a set of coloured markers, inviting children and their caregivers to personalise the piece together. This approach draws on the insights of Lyu et al. (2024) and Song and Wei (2024), who demonstrate that active consumer participation in product customization generates emotional investment and increases perceived value. Li, Yang, and Xu (2022) further support this positioning, showing that mass-customization strategies are positively associated with consumers' perceived brand quality.

The project scope specified a lamp shade (chapéu) in 6 mm MDF with laser-cut decorative cutouts, a supporting stem (haste) fixed to a structured base, and no top cover, a deliberate decision that facilitates bulb replacement, reduces weight, and improves light diffusion. The process scope established seven manufacturing steps:

Table 1: *Manufacturing Process Steps*

Step	Description
10. Receive Material	Receive, inspect, and identify materials.
20. Store	Store and protect materials according to specifications.
30. Cut	Cut MDF using laser cutting machine.
40. Assembly 1	Assemble MDF parts using adhesive.
50. Assembly 2	Install lamp socket, wire, male plug, and fix base plate.
60. Inspect	Perform visual inspection and test electrical components.
70. Pack/Ship	Package, label, and ship to customer according to requirements.

Source: Developed by the authors.

A brainstorming session for risk analysis identified four primary risks that could affect development. Risk assessment principles from Chiu et al. (2022) informed the discussion. An initial target selling price of

BRL 34.90 was set based on preliminary market research, subject to revision following the full cost analysis.

4.3. QFD Elaboration And Competitive Analysis

The QFD matrix was built to convert customer needs into prioritised technical specifications. The main customer requirements identified were: effective light projection through the cutout patterns; electrical safety; affordable price (targeting income classes A through D); vertical structural stability; accessible bulb-change mechanism; resistance to disassembly during handling; aesthetic appeal; and adequate luminosity.

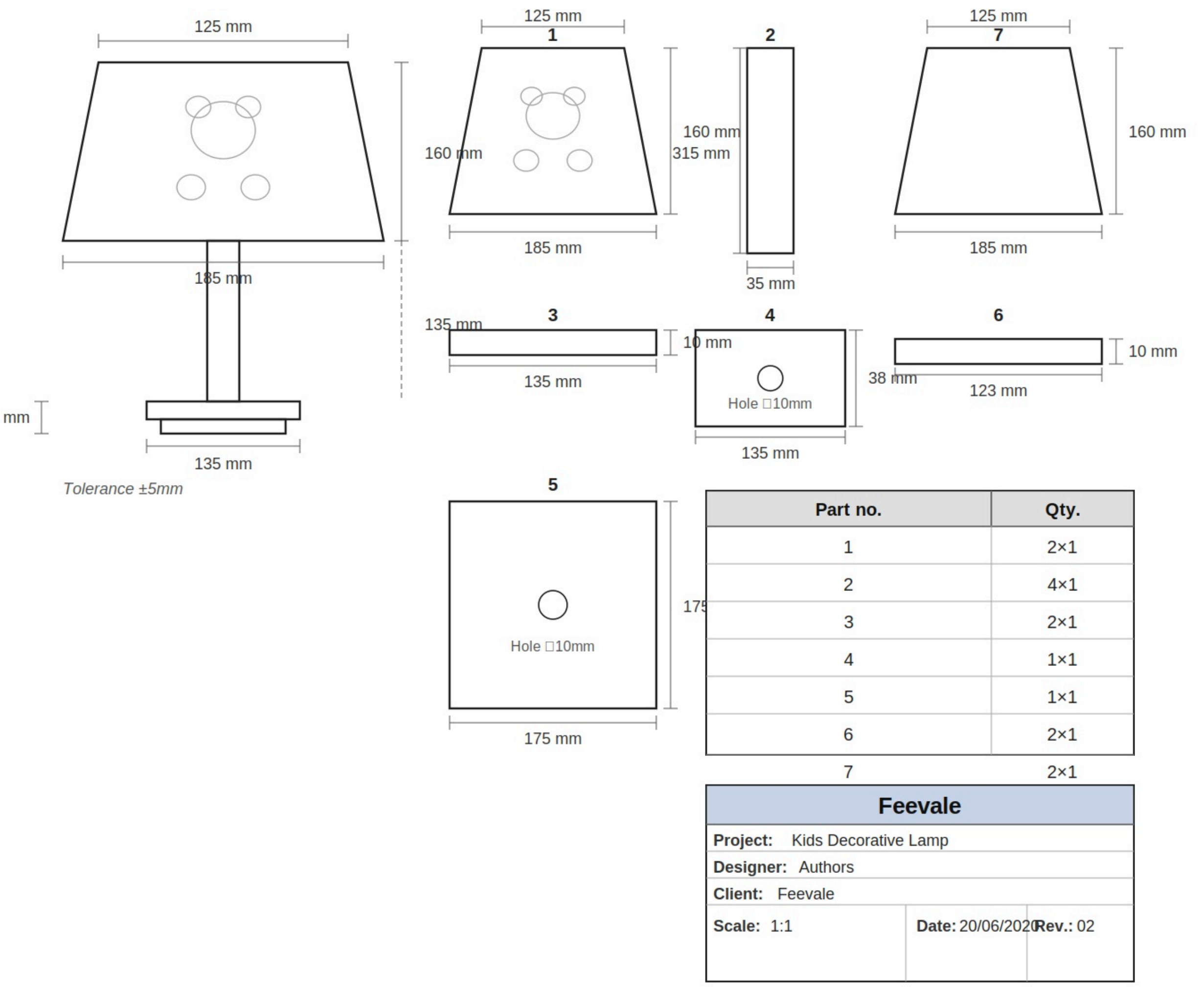
These were translated into the following technical specifications: 1.5 mm^2 electrical wire cross-section; 6 mm MDF base with structural reinforcement; overall lamp height of 285 mm; and dimensioned light-diffusion apertures in the shade. QFD correlation analysis identified three critical engineering priorities: base reinforcement (to prevent tipping), wire sizing (for electrical safety), and elimination of the top cover (to facilitate maintenance and improve luminosity, while simultaneously reducing cost and weight). This integrated approach aligns with the QFD–FMEA–lean framework proposed by Ince et al. (2025) for the wood furniture industry.

The competitive analysis revealed that comparable products from key market competitors (Precious Baby and Grão de Gente) were priced between BRL 49.90 and BRL 109.90 including shipping, compared to the proposed BRL 34.90, a meaningful price advantage that could be leveraged as a key market differentiator. This finding is consistent with the cost-based differentiation strategy discussed by Chiu et al. (2022) and Relich, Nielsen, and Gola (2022).

4.4. Detailed Design

Dimensional parameters were defined with the children's target audience in mind, aiming for a product of intermediate size relative to existing market alternatives, consistent with benchmarking and trend-analysis practices recommended by Jugend and Silva (2013). The detailed technical drawing specified seven part types, each with its own dimensions, tolerances (±5 mm), and required quantities for one complete lamp assembly (Figure 3).

Figure 3: *Detailed Design Drawing*



Source: Developed by the authors (2020).

Following pilot-piece production, two design adjustments were incorporated: Part 6, a base component, was reduced by 12 mm after a dimensional mismatch was identified during assembly; and Part 7 was revised to remove the bear-silhouette cutout from the interior of the shade panel, as this detail added disproportionate laser-cutting time without a commensurate quality benefit. The revised drawing also specified the exact quantity of each part per assembly, facilitating laser-cutting programming. These adjustments reflect the value of the prototype as a knowledge-generation and error-detection tool, as documented by Goudswaard et al. (2023).

4.5. Cost Estimation, Procurement Planning, And Material Acquisition

Cost estimation followed a bottom-up approach: quotations were gathered for each material, waste percentages were estimated for each production step, and all inputs were consolidated into a five-section cost spreadsheet:

- Section 1: Structural raw materials (MDF 6 mm, assembly adhesive)
- Section 2: Electrical components (socket, complete extension cord)
- Section 3: Personalisation kit (coloured markers)
- Section 4: Packaging materials
- Section 5: Production processes (laser cutting, assembly labour)

For MDF, purchased by the square metre, each part was itemised individually with its area and expected waste factor, enabling an accurate total consumption calculation. This level of detail is consistent with the systematic cost-planning approach advocated by Barbosa Filho (2009) and aligns with Relich, Nielsen, and Gola's (2022) evidence that design-stage cost decisions have the greatest impact on final product economics.

4.6. Process Sequence Definition

The manufacturing sequence was planned during the product design phase, drawing on the team members' prior experience with furniture manufacturing. The planned sequence required minor adjustments during prototype production, primarily due to supply-chain disruptions caused by the COVID-19 pandemic, which limited access to materials and third-party services.

4.7. PFMEA: Process Failure Mode And Effects Analysis

With the detailed design, bill of materials, and process sequence in place, the team elaborated the Process FMEA covering all seven manufacturing steps, from raw material receipt through shipping. The analysis identified 19 potential failure modes, 15 potential effects, and 21 possible causes, of which seven presented high RPN values requiring corrective action. The main results are summarised in Table 2.

Table 2: Process FMEA (PFMEA): Selected high-priority failure modes

Process step	Failure mode	Effect(s)	Cause(s)	Current controls	Recom nde action
				Preventio n / Detection	
Step 10 Receive	Failure to receive	Productio n	Transport failure;	Shipment tracking /	Quali alterna

material	raw material	shortage; order	supplier cancellatio	Purchase order	suppli to redu

⚠ Esta tabela possui muitas colunas e foi cortada para impressão. Para visualizá-la completa, acesse o artigo original em: https://revistatopicos.com.br/artigos/structured-product-development-in-the-childrens-segment-a-qfd-and-fmea-based-approach-applied-to-a-decorative-mdf-lamp?noblockage

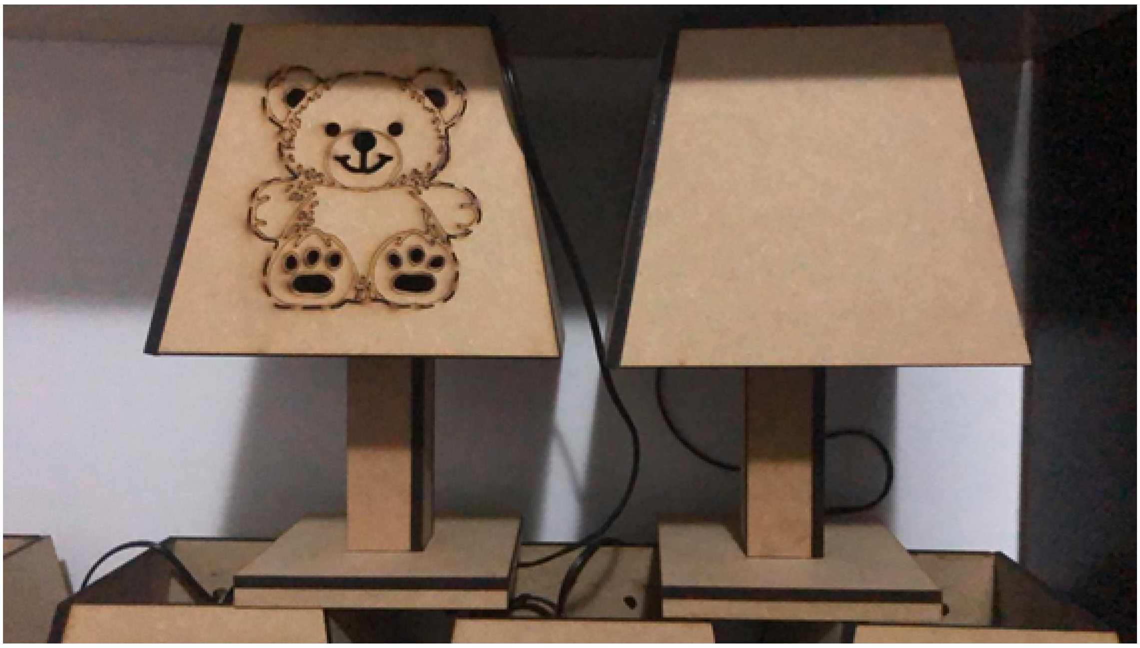
Source: *Developed by the authors.*

Two failure modes were particularly significant. In Step 10 (Receive Material), the risk of supply disruption was elevated due to the pandemic; the corrective action was to qualify alternative suppliers, reducing dependency on a single source. In Step 50 (Assembly 2, electrical installation), the risk of electric shock or fire due to faulty wiring connections was rated critically high; the adopted solution was to source pre-assembled electrical cables, removing manual connection steps from the process. These interventions are consistent with the risk-priority framework described by Piloto, Lima, and Severino (2024) and with Thomas's (2025) assertion that FMEA remains an indispensable tool for managing innovation risk in manufacturing.

4.8. Prototype Construction

Laser cutting of the MDF parts was outsourced to a specialised supplier, following the recommendation by Pahl et al. (2005) to select technologies appropriate to the project's level of detail and complexity. Remaining materials, namely adhesive and electrical components, were then procured. Assembly proceeded sequentially: the base was assembled first, during which a minor dimensional error was identified and corrected manually with a handsaw. The stem and shade were then assembled without incident, and the three sub-assemblies were joined and fitted with the electrical system to produce a functional prototype (Figure 4).

Figure 4: Prototype of the Luminária Decorativa Kids



Source: Developed by the authors (2020).

Ahmed, Irshad, and Demirel (2021) argue that human-centred prototyping in the Industry 4.0 context serves as a critical bridge between user requirements and engineering solutions. The prototype confirmed that the design met its functional requirements, while the assembly experience provided valuable process knowledge consistent with the knowledge-generation model described by Goudswaard et al. (2023). Santos et al. (2021) further underscore that prototypes used to engage users and stakeholders yield broader benefits in validation and alignment, a principle that would inform subsequent sales and satisfaction assessment activities.

4.9. Pilot Batch Production

The pilot batch targeted ten units. Due to COVID-19 restrictions on movement and access to services, laser cutting and raw material acquisition were completed for all ten sets upfront; however, full assembly was completed in two sub-batches. Pilot Batch I comprised four fully assembled units; Pilot Batch II completed the remaining six.

Both sub-batches followed the same assembly sequence as the prototype: base assembly, stem attachment, shade construction (assembled in two lateral halves before final joining), electrical installation, and quality inspection. No significant deviations from the planned process were observed in either sub-batch, validating the process sequence and confirming that the design adjustments identified during prototyping had been effectively incorporated. This outcome aligns with the pilot-batch validation principles described by Rozenfeld et al. (2006), and with the evidence from Erichsen et al. (2021) that early physical prototyping generates the process knowledge needed to ensure reliable scaled production.

4.10. Price Confirmation And Critical Development Review

The initial target price of BRL 34.90 was reviewed in light of the QFD competitive analysis, which revealed that this estimate was below the average market range. The price was accordingly adjusted upward to align with prevailing market levels, maintaining a competitive advantage while reflecting a more accurate assessment of value. The final price was calculated by summing all material costs, process costs, production losses, and an estimated profit margin; tax implications were noted as requiring inclusion once the company's tax regime was defined, per the approach outlined by Ferreira et al. (2011) and Altubaishe and Desai (2023).

The overall critical review confirmed that all NPD phases had been completed as planned and that the product met its objectives. The FMEA had correctly anticipated the failure modes encountered in practice, and the corrective actions taken proved effective. The cost structure provided a realistic and defensible basis for pricing.

4.11. Post-development

The post-development plan addressed three commercial pillars. For distribution channels, the team selected specialised children's furniture and décor stores as the primary retail channel, complemented by a dedicated e-commerce platform, a choice motivated by the sustained growth of online retail in Brazil and by the lower cost structure of digital channels relative to physical stores (Olivette, 2018; Rozenfeld et al., 2006).

For marketing, the plan centred on Instagram and Facebook, with paid promotion managed by a specialist digital agency, channels well matched to the product's target demographic of parents with young children. This approach is consistent with contemporary digital marketing practice as discussed by Jansen (2015) and Jugend and Silva (2013). Logistics would be managed through regional carriers selected by coverage area, following the efficiency and flexibility principles described by Arbache et al. (2011).

Customer satisfaction data collection, planned as a formal post-sales survey, was not completed within the scope of the present study, representing a limitation and an opportunity for future research.

5. FINAL CONSIDERATIONS

This study set out to develop and manufacture a children's decorative lamp through a structured product development process, and that objective was fully achieved. The Luminária Decorativa Kids proved attractive to its target audience and embodied a meaningful competitive differentiator: the co-creation premise, in which customers personalise the product themselves using coloured markers, transforms a simple lamp into a shared creative experience between parents and children. This approach is grounded in evidence that consumer participation in product customization generates emotional investment and enhances perceived value (Lyu et al., 2024; Song & Wei, 2024; Li et al., 2022).

Every phase of the NPD process was executed according to plan and contributed distinctly to the final result. The brainstorming sessions, guided by principles documented by Pahl et al. (2005) and enriched by diverse design precedents (Zou et al., 2024), produced a focused and viable product concept. The process flow diagram provided an integrated view of manufacturing steps and resource requirements. QFD translated customer needs into actionable engineering specifications, revealed three critical technical priorities, and enabled a rigorous competitive analysis. PFMEA identified seven high-RPN failure modes; corrective actions were taken proactively, notably the qualification of alternative suppliers and the adoption of pre-assembled electrical cables, and all anticipated failure modes were subsequently encountered and resolved during production, confirming the analytical validity of the tool (Piloto et al., 2024; Thomas, 2025; Altubaishe & Desai, 2023).

Prototyping served a dual role: it validated the design against technical specifications and generated process knowledge that directly improved the pilot-batch production sequence (Ahmed et al., 2021; Goudswaard et al., 2023; Santos et al., 2021; Erichsen et al., 2021). The detailed cost analysis enabled a transition from initial price estimates to a grounded, defensible final price, one that remained significantly below the competition while reflecting actual costs and a sustainable profit margin.

The evidence from this case study confirms that the systematic and integrated application of NPD tools, namely brainstorming, QFD, FMEA, detailed design, cost planning, and structured prototyping, enhances product quality, reduces costs, standardises production processes, and supports schedule compliance. These outcomes translate into a more efficient organisational environment and higher levels of end-customer satisfaction. The study also demonstrates the value of customization as a strategic competitive differentiator in children's product development, consistent with broader trends documented in the literature (Li et al., 2022; Manavis et al., 2024; Hua, 2024; Phuah et al., 2025; Hu et al., 2023).

Future work should address two gaps identified during this project: the completion of formal customer satisfaction research to validate perceived value and identify improvement opportunities; and an exploration of how digital customization tools could complement the current analogue personalisation approach, potentially broadening the product's market reach.

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