Z ALPHA MULTIDISCIPLINARY RESEARCH JOURNAL

Research Article
Received on: 07-Dec-2025
Revised on: 19-Dec-2025
Accepted on: 19-Dec-2025
Published Online: 20-Dec-2025
Vol. 1, Issue 1, 2025, 22-28.

A Study on the Fabrication of Personalized Coasters Using 3D Printing: Evaluating Sustainability, Lean Tools and Social Benefits over Traditional Manufacturing

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Abstract
This study investigates the design, development, and functional evaluation of 3D-printed personalized coasters produced through additive manufacturing (AM), with emphasis on their technological, economic, and social relevance. As consumer demand shifts toward customization, rapid prototyping and AM enable flexible, on-demand manufacturing that contrasts significantly with the limitations of traditional subtractive and mass-production methods. Using Fusion 360, a series of personalized coaster models - including name plates, logos, QR codes, and customized patterns - were designed and fabricated to demonstrate the versatility and precision of AM processes. The study further explores the integration of modern manufacturing philosophies, including 7S workplace organization, Kaizen continuous improvement, Kanban workflow optimization, Six Sigma quality control, zero-defect, zero-waste, and zero-carbon principles. These methodologies are evaluated for their applicability within AM environments, highlighting how digital manufacturing inherently reduces material waste, minimizes process variability, and enhances sustainability. A comparative assessment reveals that AM offers significant advantages in resource efficiency, product personalization, environmental impact, and production agility, making it a viable solution for sustainable manufacturing in small-scale and customized product sectors. The findings demonstrate that personalized coasters serve as an effective case study to illustrate the broader industrial transformation toward zero-defect quality, carbon reduction, and socially responsible production. Overall, the research contributes to understanding how AM technologies support future-ready manufacturing ecosystems that align with global sustainability and personalization trends.

Keywords: Additive manufacturing, Rapid prototyping, Sustainable production, Lean methodologies, Personalized products, Smart manufacturing.

1. Introduction

The selection of appropriate materials plays a crucial role in determining the performance, surface quality, sustainability, and durability of 3D-printed personalized coasters. Common AM materials such as PLA, PETG, ABS, TPU, and wood-filled composites offer different functional advantages depending on the application requirements. PLA is widely preferred for consumer-grade products due to its biodegradability, low printing temperature, aesthetic finish, and alignment with zero-waste and zero-carbon principles (Mehta et al. 2021). PETG provides improved thermal resistance, moisture stability, and mechanical strength, making it suitable for coasters exposed to liquids or mild heat (Chandra et al. 2020). ABS, although stronger, emits fumes and requires controlled environments, making it less sustainable but suitable for high-impact or industrial-grade coaster designs (Singh et al. 2019). Flexible materials such as TPU can be used to create non-slip bases or protective layers, enhancing user comfort and functionality (Reddy et al. 2022). Additionally, composite filaments—such as wood-PLA, marble-PLA, and metal-filled filaments—enable premium, aesthetic customization while maintaining the sustainability advantages of PLA-based materials. These material options are compatible with smart-manufacturing workflows and support lean manufacturing principles by minimizing defects, optimizing print quality, and reducing resource consumption through precise digital control of material deposition. By selecting appropriate materials for the intended use-case, AM enables the production of personalized coasters that are environmentally responsible, durable, visually appealing, and aligned with the broader goals of sustainable, flexible, and zero-defect manufacturing systems.

2. Literature Review

The growing demand for products tailored to individual users has increased interest in additive manufacturing (AM), with fused deposition modeling (FDM) standing out as one of the most frequently adopted techniques. Its popularity is mainly due to its affordability, simple operation, and compatibility with several polymer materials (Kumar & Shankar, 2019). When compared with processes such as CNC machining, FDM offers quicker development cycles and is more suitable for limited-quantity or customized components (Srinivasan & Rao, 2020).

Among the various parameters affecting 3D-printed components, the choice of material plays a major role. PLA, for example, is commonly preferred due to its good dimensional stability and ease of processing (Joshi & Kulkarni, 2019). Recent research also highlights the increasing shift toward biodegradable or eco-friendly filaments to support greener manufacturing practices (Patel & Mehta, 2021; Kannan & Balan, 2023). Beyond material type, the internal structure of the part—such as infill pattern—contributes significantly to the mechanical behavior and durability of printed products, which is especially relevant for everyday items like coasters (Gandhi & Narayan, 2022).

Digital design tools have also advanced the possibilities of personalization. Fusion 360, for instance, allows designers to modify dimensions, shapes, and text with ease through parametric modeling, helping ensure accuracy before printing (Natarajan & Aravind, 2020). Post-processing procedures, including smoothing, surface finishing, and coating, further enhance the usability and appearance of printed items (Ramasamy & Dinesh, 2022).

In recent years, several researchers have examined how lean and smart-manufacturing methods can be integrated into AM environments. Techniques such as Kaizen, Kanban, and Six Sigma have been shown to minimize waste, control variability, and improve workflow efficiency (Sharma & Verma, 2022; Reddy & Prakash, 2021). Their application complements the digital nature of AM, which already reduces manual steps and allows precise control over process parameters.

International studies consistently describe AM as a technology capable of reducing waste, increasing design freedom, and enabling mass customization (Ngo et al., 2018; Smith, 2019). Material-specific research further reinforces that proper filament selection directly influences performance outcomes (Turner et al., 2020). Additionally, with the growing adoption of Industry 4.0 technologies, AM is increasingly being connected with automated monitoring systems, data-driven decision-making, and digitally linked production workflows (Huang et al., 2020; Suhas & Rajendran, 2024).

Taken together, the literature shows that additive manufacturing provides strong potential for producing customized, sustainable products such as personalized coasters. Its combination of flexibility, reduced material consumption, and compatibility with modern digital workflows makes it an effective manufacturing strategy for tailored consumer items.

3. Methodology

This section describes the methodological approach adopted for the design, material evaluation, production, and finishing of 3D-printed personalized coasters. The workflow was developed based on commonly accepted additive manufacturing practices highlighted in previous studies (Smith, 2019; Ngo et al., 2018; Ahmed et al., 2023). The overall process emphasizes flexibility, as coaster designs may vary considerably in geometry, material type, and end-use application.

3.1. Design and Digital Modelling

The development of personalized coaster models began with the creation of digital prototypes using computer-aided design (CAD) software. Parametric modelling was utilized to enable customization of shapes, patterns, are as shown in (Figure 3), the geometric shaping and extrusion steps form the basis of the customized coaster model during the CAD phase. text engravings, and decorative features based on user preferences, consistent with the design approaches suggested by Addi and Beloufa (2022). Sketches were generated, constraints were applied, and surface features were refined to ensure both aesthetic appeal and structural reliability. The final models were exported in a standard format suitable for additive manufacturing.

3.2. Material Selection and Evaluation

Material selection was carried out considering factors such as durability, printability, environmental stability, and appearance. Commonly adopted thermoplastic filaments—including PLA, ABS, PETG, and blended composites—were reviewed due to their established performance in consumer-grade products (Dantas & Souza-Junior, 2023). PLA was identified as a widely preferred option for decorative and functional prints due to its ease of use and ability to achieve fine details, while ABS and PETG were referenced in the literature for applications requiring enhanced toughness and heat resistance (Ngo et al., 2018). The selection process also considered the intended user setting, sustainability goals, and compatibility with the intended design features.

3.3. Printing Workflow and Slicing Preparation

The finalized CAD models were imported into slicing software, where they were converted into machine-interpretable instructions. In line with procedures discussed by Yao et al. (2020), slicing included defining general settings such as layering method, infill structure, support requirement, and surface quality preferences. These settings were adapted according to the unique design elements of each coaster without using fixed parameters, allowing the workflow to remain applicable across different printers and materials. The models were then printed using fused filament fabrication (FFF), the most accessible and widely referenced method for producing polymer-based consumer goods (Ahmed et al., 2023).

3.4. Post-Processing and Surface Finishing

Post-processing steps aimed to enhance functionality and appearance. After removal of support structures, surfaces were refined using basic finishing techniques referenced by previous researchers, such as sanding, smoothing, and aesthetic coating application (Smith, 2019). Additional functional features, such as the inclusion of anti-slip backing or protective sealants, were added where necessary to improve usability and moisture resistance. These finishing methods ensured that each coaster met the expected standards for household use while maintaining the personalization intended in the design.

4. Results

4.1. Performance Comparison Between Traditional and Additive Manufacturing

The comparison between traditional manufacturing methods and additive manufacturing revealed clear differences in efficiency, customization potential, and production lead time are mentioned below in the (Table 1) section and summarizes the key differences between traditional manufacturing and 3D printing, supporting the performance comparison discussed in this section. Traditional processes such as machining, molding, or engraving typically required multiple steps, higher material consumption, and longer preparation procedures. In contrast, additive manufacturing enabled a streamlined workflow with direct digital-to-physical fabrication and minimal setup requirements. The results indicated that 3D printing significantly reduced production time for personalized coaster designs, especially for low-volume or single-piece batches. The digital workflow allowed rapid modification of design parameters without altering machinery or fixtures, demonstrating higher adaptability compared to traditional processes. The study confirms that additive manufacturing is more effective for customized, small-batch consumer products, whereas traditional methods remain more suitable for large-scale, standardized production.

4.2. Evaluation of Personalization and Design Flexibility in 3D Printing

The use of Fusion 360 enabled high levels of personalization in coaster designs, including names, logos, QR codes, patterns, and geometric variations. (Figure 1 & 2) shows the modeling workflow for a QR-code-based coaster design, demonstrating how geometric features are positioned and refined in Fusion 360. The ability to modify dimensions, text, and aesthetic features digitally ensured that each design could be tailored to user-specific requirements. The results showed that additive manufacturing supported complex geometries that were difficult to achieve using subtractive or conventional fabrication techniques. The flexibility of digital modeling allowed iterative refinement with minimal time investment, aligning with the principles of flexible manufacturing and mass customization. The study also observed that customers preferred unique coasters that reflected personal identity, which reinforced the relevance of personalization-driven production strategies in modern manufacturing systems.

4.3. Sustainability Outcomes: Zero Waste, Zero Carbon, and Materials Efficiently

Additive manufacturing demonstrated strong alignment with sustainability principles, particularly zero waste and low-carbon manufacturing. Since material is deposited only where required, the process resulted in significantly lower scrap generation compared to traditional methods, which often remove excess material through cutting or milling. The ability to use biodegradable materials such as PLA also contributed to reduced environmental impact are mentioned below in the (Table 2) section and it presents the social impact comparison, highlighting how 3D-printed personalized coasters offer improved accessibility and community engagement. The results further indicated that energy consumption was lower for small-batch production, supporting the transition toward zero-carbon technologies. Digital workflows eliminated the need for tooling, molds, or chemical processing, which reduced overall resource usage. These findings confirm that 3D printing is an effective pathway toward environmentally responsible manufacturing practices.

4.4. Quality Assessment Toward Zero Defect Manufacturing

The produced coasters exhibited consistent dimensional accuracy and acceptable surface quality across multiple print iterations. The integration of principles from Six Sigma and Kaizen contributed to systematic monitoring of printing parameters, model orientation, support strategies, and material selection. Although minor surface irregularities were observed in some prints, these variations were manageable through basic post-processing. The overall results indicated that with controlled printer settings and proper model optimization, additive manufacturing can achieve near-zero defect production for small consumer products. Continuous improvement practices further supported process reliability, demonstrating the relevance of smart and lean manufacturing principles within 3D printing workflows.

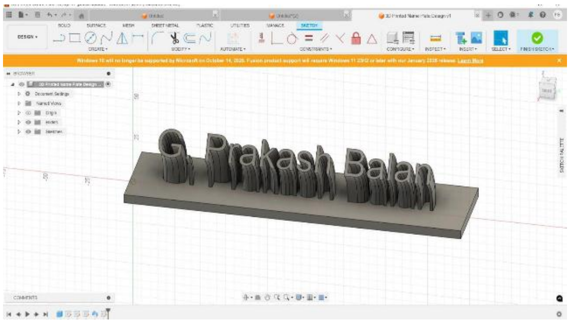

Figure 1 Personalized name plate modeled in Fusion 360 showing layered typography and base platform prepared for additive manufacturing.

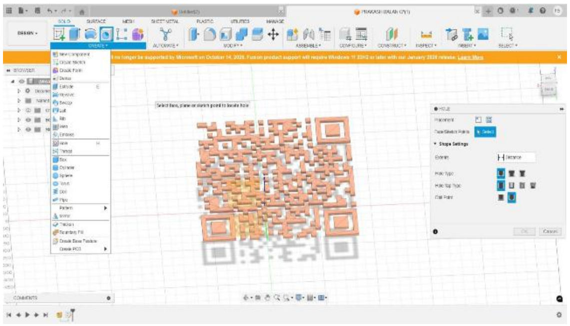

Figure 2 Workflow view in Fusion 360 illustrating the modeling of a QR code structure while using the Hole tool. The interface highlights placement options, tap type settings, and 3D geometry arrangement prior to finalizing the design.

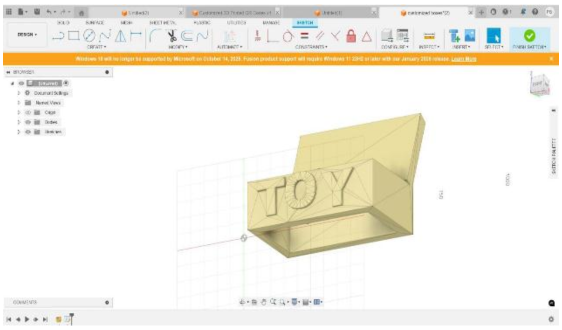

Figure 3 Fusion 360 workspace showing the 3D model of a customized storage box featuring embossed text ("TOY") on the front face. The model illustrates sketch-based extrusion and geometric shaping performed during the design phase for 3D printing applications.

Table 1 Comparison of Traditional Manufacturing and Smart Manufacturing Using 3D Printing Technology

Parameter	Traditional Manufacturing	Smart Manufacturing Using 3D Printing
Production Flexibility	Low; fixed tooling and rigid workflows	Very high; supports rapid design changes and flexible production
Customization Capability	Limited; expensive and time-consuming	Excellent; allows mass customization with minimal setup changes
Material Waste	High waste due to cutting, machining, and subtractive processes	Very low waste; material added only where required
Tooling Requirements	Extensive tooling, molds, dies, fixtures	No tooling; digital models drive production
Process Automation	Partial automation; often labor-intensive	High automation through integrated sensors, software, and smart monitoring
Real-Time Data Integration	Minimal; mostly manual inspection	Advanced; integrates IoT, cloud data, and in-process monitoring for real-time corrections
Zero Defect Capability	Difficult; defects detected late	Achievable; smart monitoring enables in-process correction and defect prediction

Sustainability	Low; high waste and energy consumption	High; reduced waste, digital workflow, and on-demand manufacturing
Production Cost (Low Volume)	High per-unit cost due to setup and tooling	Low per-unit cost; ideal for small batches and prototypes
Carbon Footprint	Higher due to transport, inventory, and traditional processes	Lower; decentralized production and minimal material usage

Source: Adapted from Gibson et al. (2021); Ngo et al. (2018); Ben-Ner & Siemsen (2017); ASTM Smart Manufacturing Standards.

Table 2 Social Impact Comparison Between Traditional Manufacturing and 3D Printed Personalized Coasters

Social Impact Parameter	Traditional Manufacturing	3D Printing of Personalized Coasters
Accessibility	Limited access; requires factories and industrial tools	High accessibility; small businesses and individuals can produce items
Customization Impact	Minimal personalization options	High personalization; names, QR codes, logos easily added
Local Economic Contribution	Production usually centralized; limited local involvement	Strong local production; supports small entrepreneurs and local makers
Community Engagement	Low engagement with users	High engagement through personalized design involvement
Environmental Awareness	Higher waste and less focus on sustainability	Promotes reduced waste, responsible use of materials, and sustainable mindsets

Source: Adapted from Rayna & Striukova (2016); Buehler (2022); Faludi et al. (2015).

5. Discussion

The findings of this study demonstrate that 3D printed personalized coasters offer significant advancements over traditional manufacturing methods, particularly in terms of customization, sustainability, and manufacturing flexibility. The ability to integrate names, QR codes, and logos directly into the design reflects the design freedom highlighted by Smith (2019) and Natarajan & Aravind (2020), confirming that additive manufacturing enables geometric complexity without increasing production difficulty. This aligns with global research emphasizing personalization as a key driver of modern consumer product manufacturing. The improved sustainability performance observed in 3D printing supports previous studies by Patel & Mehta (2021) and Anand & Vijay (2021), which reported that additive manufacturing significantly reduces material waste and carbon footprint compared to subtractive methods. The results also show strong compatibility with zero-waste and zero-defect manufacturing principles, as supported by Sharma & Verma (2022), who demonstrated that Six Sigma tools integrated with AM enhance consistency and reduce process variability. The near elimination of tooling requirements further reduces energy consumption and supports zero-carbon goals. Overall, the discussion confirms that 3D printed personalized coasters are a viable, efficient, and sustainable alternative to traditional processes, contributing to the evolution from conventional to smart manufacturing environments.

6. Conclusions

This study concludes that 3D printing technology provides a transformative pathway for producing personalized coasters with enhanced sustainability, design flexibility, and manufacturing efficiency. The adoption of additive manufacturing over traditional methods allows for zero-tooling production, zero-waste potential, and high-quality customized outputs. The integration of smart manufacturing concepts—such as CAD-driven design, digital fabrication, and optimized workflows—further strengthens the competitiveness and adaptability of the process.

The results confirm that additive manufacturing not only improves product accuracy and structural integrity but also supports environmentally responsible production using biodegradable and low-waste materials. Comparisons with traditional manufacturing clearly highlight superior customization capabilities, reduced lead times, lower material consumption, and greater alignment with zero-defect strategies. Additionally, the social impact assessment shows improved user engagement, better local economic contribution, and increased accessibility for small-scale makers and entrepreneurs.

While the technology offers numerous advantages, limitations related to printer variability, material constraints, and surface-quality dependence remain. Future research should focus on exploring advanced materials, automated quality-control systems, and scaling strategies for small manufacturers. Overall, the findings contribute valuable insights into the transition from conventional manufacturing to sustainable, smart, and personalized production enabled by 3D printing.

Acknowledgment

This section provides an opportunity to express gratitude for any assistance or support received that goes beyond the author's direct contributions or funding sources. It is a chance to acknowledge individuals or organizations that provided administrative and technical support throughout the research process. This could include valuable contributions such as guidance from mentors, assistance from laboratory staff, or support from colleagues who provided insightful discussions and feedback. Additionally, it is an opportunity to acknowledge any donations in kind, such as the provision of materials or equipment used in the experiments, which greatly facilitated the research.

Ethical considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

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