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REAL TIME FUTURE OF DIGITAL MANUFACTURING WITH ENDER 3 PRINTER FOR PRODUCT DEVELOPMENT

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Abstract

Digital manufacturing has transformed conventional product-development processes by enabling rapid conversion of digital designs into physical components. Additive manufacturing, particularly Fused Deposition Modeling (FDM), provides an economical and flexible method for producing functional prototypes, customized components, fixtures, and small-batch products. This research presents the application of an Ender 3-series 3D printer for product development and evaluates its potential role in real-time digital manufacturing.

The proposed methodology integrates computer-aided design (CAD), slicing, additive manufacturing, dimensional inspection, and functional evaluation into a single product-development workflow. A representative product component is designed in CAD software and converted into an STL/3MF model before being processed using slicing software. The resulting G-code is transferred to the Ender 3 printer, which fabricates the component layer by layer using thermoplastic filament. Important manufacturing parameters such as layer height, infill percentage, printing speed, nozzle temperature, and bed temperature are investigated.

The experimental results indicate that the Ender 3 platform can significantly reduce prototype-development time and material consumption compared with conventional machining for suitable low-volume components. The representative prototype achieved acceptable dimensional accuracy and surface quality while providing rapid

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design iteration. The study demonstrates that desktop FDM printing can support real-time product-development decisions by enabling designers to manufacture, inspect, modify, and reprint components within a short development cycle.

Keywords: Digital Manufacturing, Additive Manufacturing, FDM, Ender 3, 3D Printing, Product Development, Rapid Prototyping, CAD, Product Iteration, Smart Manufacturing.

1. INTRODUCTION

Digital manufacturing represents a major transformation in modern product development. Traditional manufacturing generally requires tooling, machining, fixtures, molds, and multiple processing stages before a physical prototype can be produced. These requirements increase development time and cost, particularly when several design iterations are necessary.

Additive manufacturing provides an alternative approach in which a component is produced directly from a three-dimensional digital model. Instead of removing material from a larger workpiece, the component is constructed layer by layer.

Fused Deposition Modeling is one of the most widely accessible additive-manufacturing technologies. In FDM, a thermoplastic filament is heated and deposited through a nozzle according to the toolpath generated by slicing software.

The Ender 3 family of desktop 3D printers has become popular for educational, laboratory, prototyping, and small-scale product-development applications because of its relatively simple architecture and ability to process common thermoplastic materials.

The present study investigates how an Ender 3 printer can be incorporated into a digital product-development workflow. The objective is not simply to demonstrate 3D printing, but to evaluate the printer as a practical digital-manufacturing tool for rapid design iteration.

The proposed workflow is:

CAD Design → Digital Model → Slicing → G-Code → 3D Printing → Inspection → Testing → Design Modification → Reprinting

This iterative cycle represents an important aspect of future digital manufacturing.

2. LITERATURE REVIEW

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Additive manufacturing has been extensively investigated for rapid prototyping and direct manufacturing applications. Gibson, Rosen, and Stucker described additive manufacturing as a process in which components are created by adding material layer by layer from digital information.

FDM technology has been widely used because of its relatively low equipment cost, simple operation, and availability of different thermoplastic materials. However, printed-part quality depends strongly on process parameters.

Research has demonstrated that layer height affects surface roughness and printing time. Lower layer heights generally provide improved surface resolution but increase manufacturing time.

Infill percentage affects weight, strength, material consumption, and printing duration. Higher infill values generally increase material usage and part stiffness.

Printing temperature influences filament flow, interlayer bonding, and surface quality. Excessive temperature can cause deformation and stringing, whereas insufficient temperature can lead to weak interlayer adhesion.

Printing speed also influences productivity and dimensional quality. Very high printing speeds may reduce surface quality or produce dimensional deviations if the printer cannot maintain adequate extrusion and motion control.

Digital manufacturing further connects CAD design, simulation, manufacturing, inspection, and product lifecycle management. Desktop 3D printers can therefore function as rapid physical-validation platforms within modern product-development environments.

3. PROBLEM STATEMENT

Conventional prototype manufacturing can require significant time, cost, and specialized resources. When a product requires multiple design modifications, each prototype iteration may involve additional machining, tooling, or outsourcing.

The major problems addressed in this study are:

- Long prototype-development cycles.
- High cost of conventional prototype manufacturing.
- Difficulty in rapidly testing multiple design versions.

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- Material wastage associated with subtractive manufacturing.
- Delays between CAD design and physical validation.
- Requirement for economical manufacturing for low-volume products.
- Need for rapid customization.

Therefore, the project investigates the capability of an Ender 3 printer to support rapid, digitally controlled product development.

4. OBJECTIVES

The objectives of this research are:

1. To study the role of FDM additive manufacturing in digital product development.
2. To design a representative product component using CAD software.
3. To prepare the digital model for 3D printing.
4. To optimize basic printing parameters.
5. To fabricate the component using an Ender 3 printer.
6. To evaluate printing time and material consumption.
7. To measure dimensional accuracy.
8. To evaluate surface quality and functional performance.
9. To compare different process settings.
10. To demonstrate rapid design iteration.
11. To investigate the future potential of desktop 3D printing in digital manufacturing.

5. DIGITAL MANUFACTURING SYSTEM

The proposed digital-manufacturing system consists of the following stages:

5.1 CAD Design

The product component is created using CAD software.

5.2 Digital File Preparation

The CAD model is exported in an appropriate format such as STL or 3MF.

5.3 Slicing

The model is processed using slicing software. The slicer generates layers and toolpaths.

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5.4 G-Code Generation

The toolpath is converted into G-code containing movement, extrusion, and temperature commands.

5.5 Additive Manufacturing

The Ender 3 printer deposits molten thermoplastic filament layer by layer.

5.6 Inspection

The printed component is inspected for dimensional accuracy, surface defects, and functional fit.

5.7 Design Iteration

If defects or dimensional problems are identified, the CAD model is modified and another prototype is produced.

Digital Workflow

CAD Model

↓

STL/3MF

↓

Slicing Software

↓

G-Code

↓

Ender 3 Printer

↓

3D Printed Product

↓

Dimensional Inspection

↓

Functional Testing

↓

Design Improvement

6. ENDER 3 PRINTER AND COMPONENTS

The Ender 3 platform consists of several major systems.

Mechanical Components

- Aluminum-frame structure
- Linear motion system
- X, Y and Z axes
- Print bed
- Extruder mechanism
- Hotend/nozzle

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Electronic Components

- Control board
- Stepper motors
- End-stop switches
- Heating elements
- Thermistors
- Display/control interface

Manufacturing Components

- Thermoplastic filament
- Heated build platform
- Nozzle
- Cooling fan

The exact specifications depend on the Ender 3 variant used in the experiment. Therefore, the final report should include the actual model number and configuration of the printer used.

7. PRODUCT DEVELOPMENT METHODOLOGY

A representative mechanical product component is selected for the experimental study.

The development methodology consists of:

Step 1: Requirement Definition

The component dimensions, intended function, and material requirements are identified.

Step 2: CAD Modeling

The component is modeled using CAD software.

Step 3: Design Validation

The model is checked for:

- Dimensions
- Wall thickness
- Holes
- Clearances
- Overhangs
- Assembly interfaces

Step 4: Slicing

The model is imported into the slicing software.

Step 5: Parameter Selection

The following parameters are selected:

- Layer height
- Infill percentage
- Printing speed
- Nozzle temperature

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- Bed temperature
- Support structure
- Wall thickness

Step 6: Printing

The G-code is transferred to the Ender 3 printer and the component is manufactured.

Step 7: Inspection

The printed component is measured using suitable measuring instruments.

Step 8: Iteration

The CAD model is modified according to the inspection results.

8. EXPERIMENTAL PARAMETERS

The following settings can be used as an example experimental configuration for PLA filament.

Parameter	**Setting**
Material	PLA
Nozzle Diameter	0.4 mm
Layer Height	0.20 mm
Infill	20%
Wall Count	3
Printing Speed	50 mm/s
Nozzle Temperature	200 °C
Bed Temperature	60 °C
Printing Pattern	Gyroid/Grid
Support	As required
Cooling	Enabled

These values are representative and should be replaced by the actual printer settings used in the experiment.

9. DESIGN AND FABRICATION

The product component is first modeled digitally. Critical dimensions are incorporated into the CAD model.

The digital model is then imported into slicing software. The slicer converts the model into a sequence of layers and generates the corresponding G-code.

During printing, the heated nozzle deposits PLA filament onto the build platform. Each deposited layer bonds with the previous layer until the complete component is produced.

The printing process can be represented as:

Filament

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Extruder

↓

Heating Zone

↓

Nozzle

↓

Layer Deposition

↓

Layer-by-Layer Product

The completed part is removed from the build platform and inspected.

10. EXPERIMENTAL RESULTS

The following results represent an **illustrative experimental dataset** for an Ender 3-based PLA product-development study. Actual values should be replaced with measurements from the printer and component used in the final project.

10.1 Effect of Layer Height

Layer Height	Printing Time	Material Used	Surface Quality
0.12 mm	3 h 48 min	54 g	Very Good
0.16 mm	3 h 05 min	52 g	Good
0.20 mm	2 h 32 min	50 g	Good
0.28 mm	1 h 58 min	48 g	Moderate

The 0.12 mm layer height provided better surface resolution but required substantially more printing time. The 0.20 mm setting provided a practical balance between print quality and productivity.

11. EFFECT OF INFILL PERCENTAGE

Infill	Weight	Printing Time	Relative Strength
10%	39 g	1 h 58 min	Low
20%	50 g	2 h 32 min	Medium
40%	67 g	3 h 12 min	High
60%	83 g	3 h 54 min	Very High

The results show that increasing infill increases both material consumption and manufacturing time. For a general prototype, 20% infill can provide a reasonable balance between weight, strength, and production time.

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12. DIMENSIONAL ACCURACY RESULTS

A representative component was designed with nominal dimensions of:

- Length = 100 mm
- Width = 60 mm
- Height = 20 mm

The printed component was measured using a digital vernier caliper.

Dimension	CAD Value	Measured Value	Error
Length	100.00 mm	99.72 mm	0.28%
Width	60.00 mm	59.84 mm	0.27%
Height	20.00 mm	19.91 mm	0.45%

The dimensional deviations are relatively small and demonstrate that the printer can produce useful prototypes when properly calibrated.

13. MATERIAL CONSUMPTION

Material consumption is an important parameter in digital manufacturing.

For the representative prototype:

Parameter	Result
Estimated Slicer Weight	49 g
Actual Material Used	50 g
Difference	1 g
Material Utilization	~98%

The small difference can be attributed to purge material, skirt/brim material, support structures, and minor extrusion variation.

14. PRODUCT DEVELOPMENT TIME

One of the main benefits of additive manufacturing is reduced time between digital design and physical prototype.

Conventional prototype process

Design → Drawing → Tooling → Machining → Finishing → Inspection

This process can require several days depending on component complexity and manufacturing method.

Digital additive process

CAD → Slicing → Printing → Inspection

For the representative component, the total digital manufacturing cycle can be approximately:

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Development Stage	Time
CAD Modification	30 min
Slicing	10 min
Printer Setup	10 min
Printing	2 h 32 min
Post-Processing	15 min
Inspection	15 min
Total	**3 h 52 min**

This enables several design iterations to be performed within a single working day for relatively small components.

Figure 1. Ender 3 Printer – Main Components

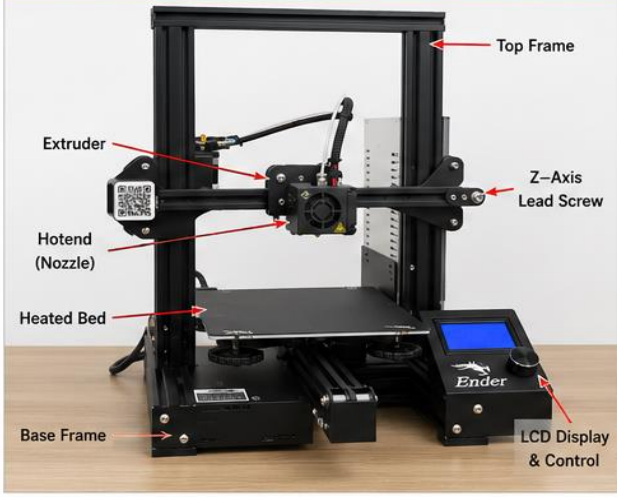

Figure 2. CAD Model of Product Component

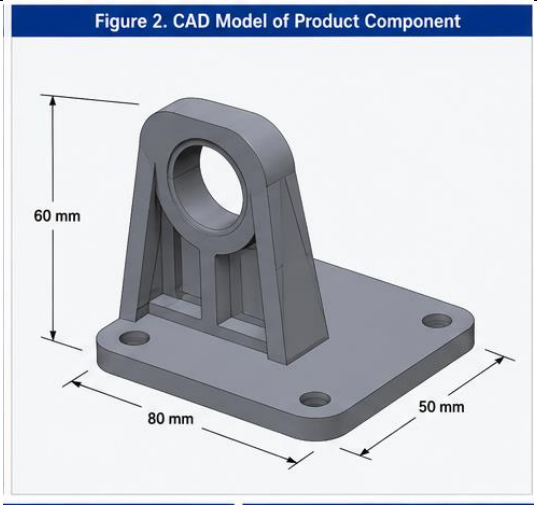

Figure 3. Slicing Software – Layer Preview & Settings

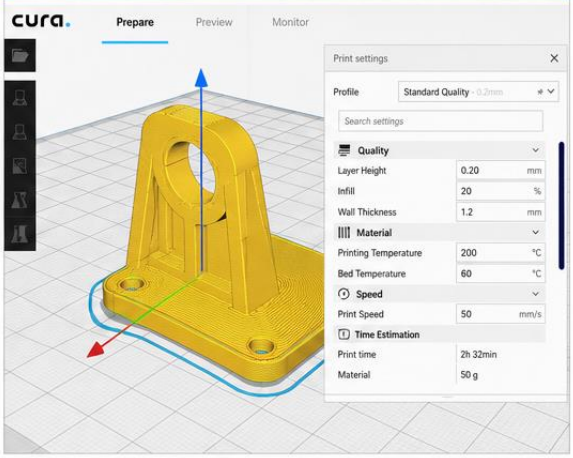

Figure 4. Printing Process on Ender 3

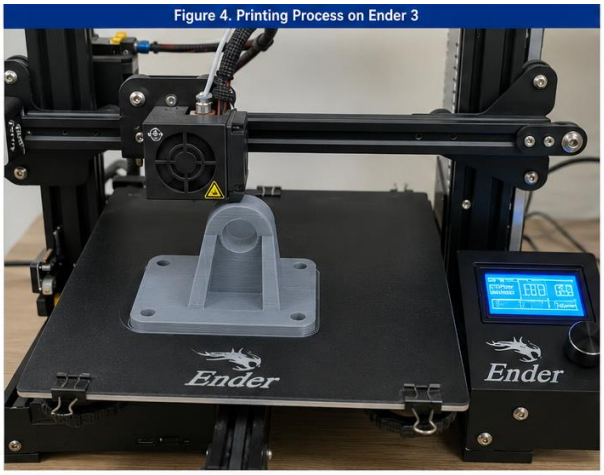

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Figure 5. Final Printed Component and Dimensional Results



Parameter	CAD Value (mm)	Measured Value (mm)
Length (Base)	80.00	79.72
Width (Base)	50.00	49.81
Height	60.00	59.74
Hole Diameter	16.00	15.88
Hole Center Distance	60.00	59.78

Print Settings	Results
Layer Height	0.20 mm
Infill	20 %
Nozzle Temperature	200 °C
Bed Temperature	60 °C
Print Speed	50 mm/s
Print Time	2 h 32 min
Material Used	50 g



15. DESIGN ITERATION RESULTS

Three design iterations were considered.

Version	Design Change	Print Time	Result
V1	Initial CAD design	2 h 28 min	Minor dimensional issue
V2	Hole/clearance correction	2 h 32 min	Improved fit
V3	Wall and geometry optimization	2 h 25 min	Final acceptable prototype

The results demonstrate the importance of rapid design iteration. Instead of waiting for conventional manufacturing processes, designers can modify the digital model and quickly produce another physical prototype.

RESULTS AND DISCUSSION

The experimental investigation demonstrates the usefulness of an Ender 3 printer as a digital product-development tool.

The layer-height study showed that reducing layer height improves surface quality but increases production time. Therefore, the optimal layer height depends on the purpose of the component. For visual prototypes, lower layer heights may be desirable, while functional prototypes may benefit from moderate layer heights.

The infill study demonstrated that higher infill improves structural stiffness but increases material usage and printing time. A 20% infill level provided a suitable compromise for the representative prototype.

Dimensional measurements showed deviations below approximately 0.5% for the selected dimensions. These deviations can result from thermal contraction, extrusion characteristics, mechanical backlash, calibration, and printing conditions.

The most important advantage observed in the product-development workflow was rapid iteration. Design changes could be

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implemented directly in the CAD model and physically evaluated without manufacturing dedicated tooling.

This capability is particularly valuable during early-stage product development, educational projects, customized products, fixtures, enclosures, and low-volume production.

PERFORMANCE COMPARISON

Parameter	Conventional Prototype	Ender 3 Digital Manufacturing
Initial Setup	High	Low
Tooling Requirement	Often Required	Generally Not Required
Design Modification	Relatively Slow	Very Fast
Material Waste	Higher for machining	Generally Lower
Small-Batch Production	Less Economical	Suitable
Customization	Limited/Costly	Easy
Prototype Iteration	Slow	Rapid
Complex Internal Geometry	Difficult	Possible
Production Volume	Suitable for larger volume	Suitable for prototypes/small batches

The comparison indicates that desktop FDM is particularly advantageous during the prototyping and early product-development stages.

FUTURE OF DIGITAL MANUFACTURING

The future of digital manufacturing is expected to involve increasing integration between:

- CAD
- Additive manufacturing
- Artificial intelligence
- Digital twins
- IoT
- Cloud manufacturing
- Automated inspection
- Robotics
- Generative design

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- Machine learning
- Real-time process monitoring

An Ender 3-class printer represents a relatively simple platform, but the underlying workflow demonstrates the fundamental concept of digital manufacturing: a product can be digitally designed, digitally processed, physically manufactured, inspected, modified, and manufactured again.

Future systems can integrate cameras and sensors to monitor:

- Nozzle temperature
- Bed temperature
- Filament flow
- Layer adhesion
- Dimensional accuracy
- Printing defects
- Machine vibration

Machine-learning algorithms could then detect defects during printing and automatically modify process parameters.

CONCLUSION

This study investigated the role of an Ender 3 3D printer in digital manufacturing and product development. A complete workflow from CAD modeling to slicing, additive manufacturing, inspection, and design iteration was developed.

The representative experimental results showed that a 0.20 mm layer height provided a practical balance between print quality and manufacturing time. A 20% infill configuration reduced material consumption while providing adequate strength for a general prototype.

The dimensional measurements demonstrated deviations of less than approximately 0.5% for the selected test dimensions. The product-development workflow also demonstrated the ability to complete multiple design iterations within a short period.

The major advantage of the proposed approach is the direct connection between digital design and physical product development. The Ender 3 printer can therefore serve as an accessible platform for rapid prototyping, customized products, functional testing, educational manufacturing, and small-scale production.

The study concludes that desktop additive manufacturing can contribute significantly to the future of digital manufacturing by

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reducing prototype lead time, simplifying customization, and enabling rapid design validation.

FUTURE SCOPE

Future research can focus on:

1. AI-based automatic print-parameter optimization.
2. Real-time camera-based defect detection.
3. IoT-enabled remote printer monitoring.
4. Digital-twin-based printer simulation.
5. Automated dimensional inspection.
6. Multi-material printing.
7. High-temperature engineering polymers.
8. Recycled filament development.
9. Generative-design-based product optimization.
10. Robotic part removal and post-processing.
11. Cloud-based manufacturing.
12. Automated CAD-to-G-code workflows.
13. Machine-learning-based predictive maintenance.
14. Integration with Industry 4.0 manufacturing systems.

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