

Development and Fabrication of a Three-Dimensional Human Facial Model via Fused Deposition Modelling

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ABSTRACT:

Additive manufacturing (AM) is emerging as an advanced fabrication paradigm capable of transforming the traditionally labour-intensive construction sector. Large-scale three-dimensional (3D) printing technologies enable automated, computer-controlled deposition of construction materials to fabricate structural and architectural elements with high geometric precision. This study investigates the technological capabilities, operational advantages, and practical constraints associated with the integration of 3D printing systems in construction applications. The implementation of additive construction methods facilitates significant reductions in material consumption, construction time, and on-site labour requirements while improving process efficiency and structural consistency. Furthermore, automated layer-wise fabrication enhances design flexibility, enabling the production of complex geometries that are difficult to achieve through conventional construction techniques. However, the widespread adoption of this technology is influenced by regional economic factors, infrastructure readiness, and workforce availability. Effective deployment requires specialized technical expertise for system operation, maintenance, and process optimization. Overall, additive construction technologies present a promising pathway towards sustainable, efficient, and digitally driven construction practices.

KEYWORDS:

FDM, Bambu Studio, 3D Printer, Infill Density, Geometric Accuracy

INTRODUCTION

Three-dimensional (3D) printing, commonly referred to as additive manufacturing (AM), has emerged as a transformative technological advancement with significant potential to modernize the traditionally labour-intensive construction industry. Rapid urbanization and continuous global population growth have increased the demand for efficient, sustainable, and cost-effective construction methodologies. It is

projected that the global population will reach

approximately 9.7 billion by 2050, creating substantial pressure on housing and infrastructure development. Conventional construction practices are often associated with high material consumption, extended project durations, and significant dependence on manual labour. In contrast, additive construction technologies offer an automated, digitally controlled manufacturing approach capable of fabricating complex architectural geometries with improved efficiency and reduced material waste. By employing computer-aided design (CAD) models and automated deposition

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layer-by-layer fabrication of structural components directly from digital data, thereby enhancing design flexibility and structural precision.

Inconstructionapplications,large-scale3Dprintingssystemstypicallyutilizegantry-basedmechanisms or robotic arm printers equipped with controlled extrusion nozzles to deposit specially formulated cementitiousmaterialsinsuccessivelayers.Theprintablematerialmustexhibitoptimizedrheological and mechanical properties, including adequate flowability, extrudability, buildability, and controlled setting behaviour to ensure structural stability during the printing process. Various additive construction techniques have been developed, including Contour Crafting, concrete extrusion printing, and binder-jetting technologies such as the D-Shape process. These methods enable the fabricationofstructuralelements,residentialbuildings,bridges, andinfrastructure componentswith improved construction speed, reduced labour requirements, and enhanced worker safety. Despite these advantages, challenges remain related to material formulation, equipment cost, process optimization,andlarge-scaleimplementation.Consequently,continuedresearchisrequiredto refine printable material compositions, optimize printing parameters, and improve system reliability. The integration of advanced additive manufacturing technologies therefore represents a promising pathway toward achieving sustainable, efficient, and digitally driven construction practices.

the feasibility of producing accurate and reliable facial models using FDM, thereby expanding its potential for biomedical, forensic, and educational applications.

METHODOLOGY

The methodological framework implemented in this investigation employs a **systematic digital reconstruction and additive manufacturing pipeline** for the fabrication of a three-dimensional anthropomorphic facial model using **Fused Deposition Modelling (FDM)** technology. The process beginswiththeacquisitionofhigh-resolutionfacialimageryundercontrolledilluminationandviewing conditionstoensureaccuraterepresentationofmorphologicalcharacteristics.Theseimagesserveas primaryreferencedatasetsforsubsequentthree-dimensionalgeometricreconstruction.Thecaptured images are imported into the **Blender computational modelling platform**, where they are spatially aligned within orthographic projection planes to establish a precise coordinate reference system for digital model development.

Followingimagealignment,thefacialgeometryis generatedusing**polygonalmeshmodelling,digital sculpting, and parametric surface reconstruction techniques**. Detailed attention is provided to anatomically significant regions such as the ocular cavity, nasal structure, oral geometry, and overall facialcurvaturetoensuregeometriccontinuityand anatomicalrealism.Thepreliminarydigitalmodel undergoes **topological refinement and mesh optimization**, which includes vertex smoothing, polygonalrestructuring,removalofnon-manifoldelements,andcorrectionofgeometricirregularities. These procedures enhance model integrity, structural consistency, and manufacturability within additive fabrication constraints.

Subsequently, the optimized model is exported in **Standard Tessellation Language (STL)** format to

ensure compatibility with additive manufacturing workflows. The STL file is then imported into **Bambu Studio slicing software**, where essential printing parameters such as layer thickness, extrusion temperature, infill density, printing velocity, and build orientation are systematically configured. The slicing algorithm converts the three-dimensional geometry into discrete cross-sectional layers and generates corresponding **G-code toolpath instructions**.

The generated instructions are executed using an **FDM-based additive manufacturing system**, where thermoplastic filament is extruded through a heated nozzle and deposited sequentially to construct the physical model. Post-fabrication procedures, including support removal and surface finishing, are performed to improve dimensional precision and surface morphology.

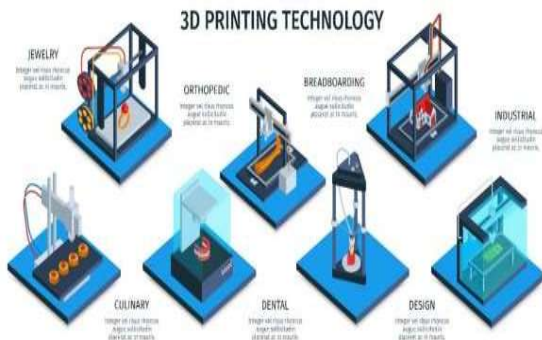


Fig.1. Step-by step involved in the human face formulation

RESULTS AND DISCUSSION

The fabricated facial model demonstrates satisfactory dimensional accuracy and surface fidelity when compared with the digital model. Intricate facial features are reproduced effectively, indicating the reliability of the adopted workflow. Minor surface irregularities inherent to the FDM process were observed and were reduced through post-processing.

Step1: Image Acquisition

Initially, six high-resolution images of a human face were captured from different viewpoints, namely the front view, left profile, right profile, top view, bottom view, and three-quarter angle. Capturing multiple perspectives ensured accurate representation of facial geometry, surface contours, and depth information, which are essential for reliable three-dimensional reconstruction. All images were stored in JPEG format to facilitate compatibility with the modelling software and subsequent processing steps. The acquired facial images from various viewpoints are illustrated in **Figure 2**.

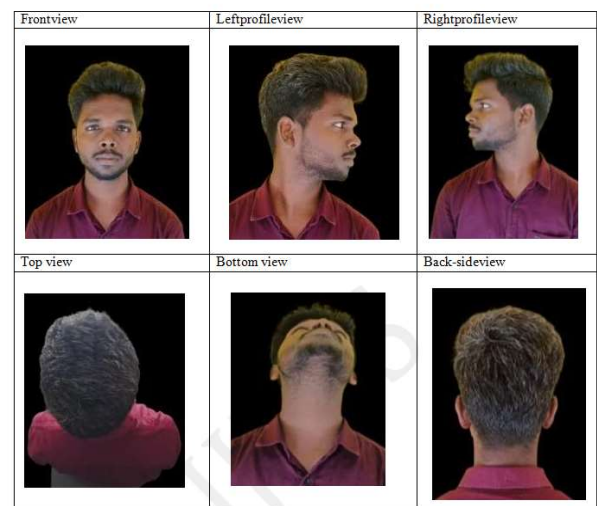


Fig.2. Multiview images in JPEG

Step2: Importing Images into Blender

The captured facial images were imported into Blender software and positioned as reference planes in the front, side, and top views to guide the three-dimensional modelling process. This alignment ensured accurate preservation of facial proportions and spatial relationships among key features. Blender was selected for its robust mesh modelling and sculpting capabilities, which allow precise reconstruction of complex facial

geometries. The setup of the reference images within Blender is illustrated in **Figure 3**.

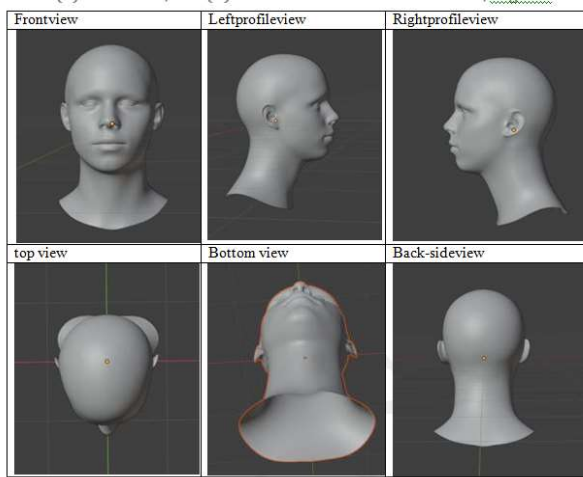


Fig.3.Reference images in blender

Step3:3DFaceModelling

Using polygonal modelling and sculpting tools within Blender, a base mesh of the face was generated and iteratively refined to conform to the features visible in the reference images. Particular attention was given to critical facial regions, including the eyes, nose, lips, jawline, and cheekbones, to ensure accurate anatomical representation. Subdivision surface modifiers were applied to enhance the smoothness of the mesh while maintaining geometric fidelity. The progression of the 3D facial model from the base mesh to the refined structure is shown in **Figure 4**.



Fig.4.Refinement of the 3D facial model from base mesh to detailed geometry

Step4:ParameterModificationandModelOptimization

Following the creation of the initial 3D facial

geometry, the model underwent extensive parameter modification and optimization to improve surface quality, structural integrity, and suitability for additive manufacturing. Key modelling parameters such as smoothing intensity, mesh density, vertex distribution, and edge flow were carefully adjusted to enhance the overall smoothness of the surface while preserving the fidelity of critical facial features. Internal faces, non-manifold edges, and other mesh errors were systematically identified and removed to ensure the model was watertight and free from defects that could cause printing failures. Additionally, the model was scaled accurately to correspond to real human facial dimensions, and its orientation was adjusted within the digital workspace to optimize fit within the printer's build volume and to minimize the need for supports during fabrication. These optimization steps were crucial for achieving high dimensional accuracy, reducing surface irregularities, and ensuring reliable Fused Deposition Modelling (FDM) print outcomes.

Step5:ConversiontoSTLFile

After completing the final 3D facial model, the mesh was exported in STL (Stereolithography) format, a standard file format extensively used in additive manufacturing due to its broad compatibility with slicing and 3D printing software. Prior to exporting, the model underwent a thorough validation process to ensure it was free from common geometric issues, such as non-manifold edges, inverted normals, overlapping faces, and holes, which could compromise printability or cause failures during the FDM process. The STL file preserves the surface geometry of the model through a tessellated representation of triangles, allowing accurate layer-by-layer reconstruction by the slicing software. This step is critical in bridging the digital model and physical fabrication, ensuring that the printer receives a clean, error-free representation of the optimized facial

geometry. Proper STL generation thus forms the foundation for achieving high-quality prints with precise dimensional fidelity and surface smoothness.

Step6:ImportintoBambuStudioSoftware

The STL file was imported into Bambu Studio slicing software for print preparation. The model orientation was carefully adjusted to minimize the need for supports while preserving the accuracy of critical facial features. Tree (Auto) support structures were generated to provide adequate backing for complex overhang regions, including the nose, lips, and chin, ensuring structural stability during printing. The setup of the model with optimized orientation and support generation is illustrated in **Figure 5**.

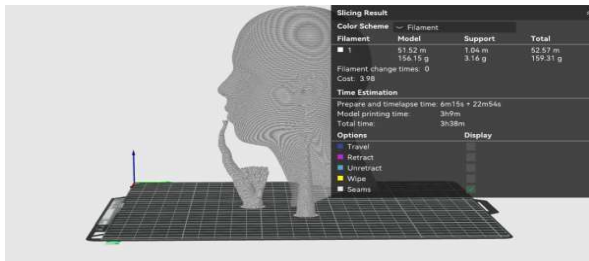


Fig.5.Model orientation and tree support generation in Bambu Studio for FDM printing Step 7:

Slicing and G-Code Generation

Printing parameters such as layer height, infill density, print speed, nozzle temperature, and support density were selected. The slicing software converted the 3D model into G-code instructions, which control the printer movements and material deposition.

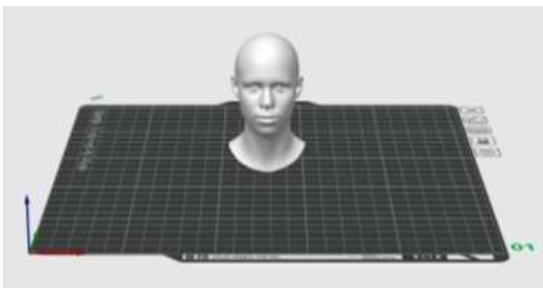


Fig.6.Selection of printing parameters and G-code generation for FDM fabrication Step 8:

FDM Printing

The generated G-code file was transferred to the Bambu Lab A1 FDM 3D printer. PLA filament was used as the printing material. The printer fabricated the facial model layer by layer following the programmed tool path.

Step9:Post-Processing

After printing, support structures were removed carefully. The surface was refined using sanding and minor finishing operations to improve smoothness and visual appearance. The post-processed facial model is shown in **Figure 7**.



Fig.7Physical model fabricated in FDM

CONCLUSION

This study presents a systematic digital-to-physical workflow for fabricating a three-dimensional human facial model using FDM technology. The integration of image-based modelling, software optimization, and controlled printing parameters enables accurate reproduction of complex facial geometries. The proposed approach demonstrates the potential of FDM for applications in medical visualization, customized prosthetics, and educational models.

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