**Technical Specification Document**

**Project Name:** NexPath

**Version:** 1.0 (Initial MVP)

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**1. Overview**

NexPath is a cross-platform software platform for large-format additive manufacturing (LFAM). It provides automatic slicing, intelligent toolpath generation, AI-based print parameter optimization, thermal simulation, and support for hybrid printing (AM + CNC). The system is designed for industrial users, machine manufacturers, and research institutions.

**2. Functional Requirements**

**2.1 Input and Pre-processing**

* Load 3D models in STL or OBJ format
* Validate model integrity (watertight, non-manifold)
* Adjust orientation, scale, and position

**2.2 Slicing & Toolpath Generation**

* Layer slicing with adjustable resolution
* Support for planar and non-planar slicing (multi-axis)
* Custom infill strategies (adaptive, gyroid, honeycomb, etc.)
* Geodesic path generation for curved surfaces

**2.3 AI Copilot (Suggested)**

* Recommend print parameters (speed, cooling, infill density) based on material and geometry
* Predict risk zones for overheating or weak adhesion
* Feedback loop for learning from print outcomes

**2.4 Thermal Simulation**

* Finite Element Model for layer-by-layer heat accumulation
* User-configurable material properties
* Visual output of thermal maps

**2.5 Hybrid Manufacturing Support**

* Enable toolpath switching between AM (additive) and CNC (subtractive)
* Define milling regions manually or automatically
* Export unified G-code for hybrid machines

**2.6 User Interface (UI/UX)**

* Visual programming editor (node-based workflow)
* 3D viewer for models, layers, toolpaths, and heatmaps
* Settings panel for parameters and simulation
* Light/Dark mode, multi-language support (EN, VI initially)

**2.7 Export & Device Integration**

* Export G-code compatible with Marlin, Duet3D, Siemens, KUKA
* Custom post-processing scripts per machine
* Live preview of print simulation and time estimates

**3. Non-functional Requirements**

* Cross-platform support (Windows, Linux, macOS)
* Desktop (offline) and Web (cloud) deployments
* Modular architecture for plugins and extensions
* High performance on systems with ≥8GB RAM, ≥2GB VRAM
* Security for enterprise customers (data isolation, file encryption)

**4. Technology Stack**

**Frontend:**

* PyQt6 (for desktop) or React + Three.js (for web)

**Backend:**

* Python 3.11+
* NumPy, Open3D, trimesh (geometry processing)
* FEniCS or scikit-fem (thermal simulation)
* scikit-learn, PyTorch, Tensorflow (AI modules)

**Visualization:**

* matplotlib, PyVista, vtk.js, Plotly

**Communication:**

* REST API (FastAPI)
* WebSocket for live simulation feedback
* TCP/IP integration for hardware

**Data Formats:**

* STL, OBJ (input)
* JSON, XML (workflow & config)
* G-code (output)

**5. Development Plan (Phase-wise)**

**Phase 1 (Months 1-2): Core Infrastructure**

* Load/display STL, generate simple slices
* Toolpath preview, G-code export

**Phase 2 (Months 3-4): AI Copilot and UI**

* Basic ML model for print parameter recommendation
* Node-based visual programming editor

**Phase 3 (Months 5-6): Simulation and Hybrid**

* Integrate thermal simulation engine
* Add subtractive toolpath & export for hybrid machines

**Phase 4 (Month 7+): Beta Launch and Testing**

* Partner with pilot users (hardware companies or labs)
* Bug fixing, performance tuning, feedback integration

**6. Risk Assessment**

* Complexity of FEM integration: High
* Hardware compatibility: Medium
* Data collection for AI training: Medium to High
* UI usability at scale: Medium

**7. Future Extensions**

* Cloud collaboration features
* AI-driven defect prediction from camera feedback
* Mobile app companion for monitoring
* Marketplace for plugins/workflows

**8. Appendix**

* G-code sample
* STL test models
* Material properties reference

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