Integration of Additive Manufacturing and New Technologies into The Modern Needs of Visually Impaired People

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Abstract: - This article examines the potential of 3D printing to overcome the deficit of specialized educational materials for children with visual impairments. The main focus is on the methodology for designing and manufacturing tactile cards (tiles) with the Bulgarian alphabet (from A to Я), combining a relief letter, a Braille sign and an associative 3D image. The study analyzes the advantages of additive technologies over traditional methods (thermoforming) in terms of personalization, durability and cost-effectiveness.

Key-Words: - additive manufacturing, 3D printing, 3D modelling, 3D print materials, 3D print methods, Braille, visually impaired, blind, tactile tiles, tactile cards.

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1 Introduction

The World Health Organization (WHO) reports that the number of people with visual impairments is steadily increasing, currently estimated at approximately 2.2 billion globally, which underscores the urgent need for developing more effective navigation and learning aids [1]. Early literacy represents a critical stage in the cognitive development of children, yet for students with visual impairments, access to adequate educational resources remains severely limited [2].

Traditional methods for teaching visually impaired children rely predominantly on Braille paper and thermoformed sheets (Braillon), which demonstrate significant disadvantages: low mechanical wear resistance, risk of deformation of the embossed dots during repeated use, and insufficient height along the Z-axis, which is crucial for forming a spatial perception of volume [3]. Furthermore, these conventional approaches lack a meaningful connection with the real shapes of objects, limiting the development of associative thinking in young learners.

In the context of the Bulgarian educational system, there is a notable absence of a standardized set of interactive tactile aids adapted for the Cyrillic alphabet. While educational materials for Latin-based alphabets have seen considerable advancement through modern manufacturing technologies, resources for Bulgarian-speaking visually impaired children remain scarce and outdated [4].

The emergence of additive manufacturing (3D printing) technologies provides an unprecedented opportunity to create "hybrid" educational tools that stimulate both tactile receptors and associative thinking [5]. Unlike two-dimensional tactile graphics generated through specialized thermal paper (Swell paper), 3D printed models allow full control over geometry, texture, and dimensional accuracy [6].

The aim of the present publication is to create alphabetic tactile cards of the Bulgarian alphabet for blind children through additive manufacturing, employing three types of 3D printing technologies – FDM (Fused Deposition Modeling), MSLA (Masked Stereolithography Apparatus), and PolyJet. The primary objective is to define a methodology for the design and fabrication of tactile tiles that overcome the limitations of conventional methods. The designed modules follow the principles of "Universal Design" and incorporate four functional zones: a graphic zone with an embossed Cyrillic letter, a Braille zone for rapid identification, a semantic zone with an associative 3D object, and an orientation marker indicating the correct position of the tile.

2 Role of Additive Manufacturing in Education

Additive manufacturing enables the rapid transformation of digital models into physical

objects, offering significant advantages for creating educational materials for visually impaired learners [7]. Unlike tactile graphics created using swell paper or thermoformed sheets, 3D printed objects provide a third dimension along the Z-axis, which is essential for fully perceiving the shape, volume, and texture of the depicted object [8].

Research has demonstrated that 3D printed models significantly improve the spatial understanding of blind students by providing higher resolution and greater structural strength compared to conventional relief maps and traditional tactile materials [6]. The ability to produce complex geometries with precise dimensional control makes additive manufacturing particularly suitable for creating educational aids that accurately represent real-world objects [9].

Furthermore, 3D printing technologies allow for customization and rapid prototyping, enabling educators to create personalized learning materials tailored to individual student needs [5]. The durability of 3D printed objects ensures repeated use without degradation of tactile features, addressing one of the primary limitations of traditional Braille paper and thermoformed materials [10].

3 Methodology for Creating Tactile Models of Braille Alphabet Cards

The goal of the development is to create a standardized set of 30 tactile tiles representing the letters of the Bulgarian alphabet.

1) Creating the base

The base is created from a Plane in Blender. The dimensions of the base (width and length) are set in the Item panel. Two variants of the base were created: one with dimensions of 100x100 mm and the other 150x150 mm. Subsequently, in Edit Mode, a depth of 1 mm is set by using Extrude.

To avoid sharp corners, a Bevel modifier is added to the base. Two such modifiers were added. The first one applies the "Bevel Weight" method. In Edit Mode, Edge Select mode is chosen. The edges located at each corner of the plate are selected, and from the Sidebar, under the Item tab in the Mean Bevel Weight field, a weight is set (values range from 0 to 1). In this case, the weight is set to 1, corresponding to the maximum influence of the modifier in the selected areas. Then, for the Bevel modifier, the Limit Method is set to Weight. The Amount and Segments parameters determine the area covered by the bevel and the smoothness of the surface.

The second Bevel modifier is applied with its default settings to the entire model for an overall softening of the plate's edges. This ensures that the edges will not be sharp to the touch, improving the tactile experience. Only the Amount and Segments values were adjusted for this modifier to achieve a visually pleasing result.

2) Positioning of the Orientation Platforms

The platforms serve an orientation purpose, indicating the top of the plate and marking zones containing specific content. They are created in a manner analogous to the base. The first platform, which contains two parallel horizontal lines and a letter written in Bulgarian Braille, has dimensions of 40x0.4x13 mm. The second platform, containing the corresponding word written in the Braille alphabet, has dimensions of 70x0.4x13 mm.

The depth is 0.4 mm, but only 0.2 mm is visible above the plate. The remaining 0.2 mm tolerance is allowed for technological overlap, ensuring a stable connection between the platform and the base. The dimensions were selected to ensure sufficient space regardless of the length of the word or letter to be inscribed. A Bevel modifier was added to each platform using the "Bevel Weight" method described above.

3) Braille Inscription

Standard dots are used to inscribe a character from the Braille alphabet. The dot is created by adding a UV Sphere. Then, switching to Edit Mode, half of the sphere is deleted to form a hemisphere. Next, the dimensions of the hemisphere are set in Object Mode, where the depth (Z-axis) must be 0.6 mm. To ensure overlap with the platforms, an additional tolerance of 0.2 mm is added, bringing the total depth to 0.8 mm. The dot has dimensions of 1.5 mm along the other axes.

To obtain each letter of the alphabet, a template of two columns and three rows (totaling 6 dots), called a Braille cell, is used. To create a Braille cell, an Array modifier is utilized. Before using the modifier, it is necessary to Apply the Rotation and Scale transformations to the dot. Two Array modifiers are used. Through the first modifier, the Count along the specific axis is set to 2 (equivalent to 2 columns), and the distance between the outer edges of the spheres is set to 3 mm. Through the second added Array modifier, the Count along the Y-axis is set to 3, and the distance between the outer edges of the spheres is set to 8 mm. The modifiers are then Applied.

To form a word, sequentially arranged Braille cells are required. The distance between two Braille

cells must be 3 mm. For this purpose, a Duplicate of the finished Braille cell is made, placed along the desired axis, and positioned at 8 mm (or -8 mm, depending on the axis along which the letters are arranged). Since one cell has a width of 5 mm, adding the necessary spacing between cells (3 mm) results in 8 mm.

Subsequently, to write a specific word using the Braille alphabet, each cell is selected individually, and Edit Mode is entered. There, using Wireframe shading, the unnecessary hemispheres are deleted depending on the letter to be inscribed. Wireframe mode visualizes both the internal and external geometry of the object simultaneously, allowing for the precise selection and deletion of the entire hemisphere.

4) Adding a Cyrillic Letter

The Cyrillic letter is added using a Text object. Then, in Edit Mode, the specific letter in Bulgarian is typed, and its dimensions are set using the Extrude and Depth parameters. The font used is Arial Regular because the letters have the most distinct contours. Subsequently, in Object Mode, the letter is converted to a Mesh. Finally, it is positioned onto the plate, and the Transformations (Rotation and Scale) are Applied.

5) Modeling the Tactile Contour

I. Contour (bus, etc.)

Bezier Curves are used to create the contour. Initially, a contour depth (height) of 0.6 mm and a width of 1 mm are set for each curve. A total depth of 0.8 mm is reserved for the contours, similar to the Braille cells. Thus, after the contour is placed on the base, 0.2 mm of the contour sinks into it to ensure they become a single solid part during 3D printing.

Setting the dimensions is done via the Geometry section in the Extrude and Depth fields of the curve properties. The entered values are: Extrude = 0.1 mm, Depth = 0.4 mm. These values are automatically doubled, resulting in a contour depth of 0.8 mm and a width of 0.8 mm + 0.2 mm = 1 mm.

Once the dimensions are set for the curve, the creation of the contour begins. A reference image of the specific object (e.g., a bus) can be used, or a 3D model of a bus can be used to trace the contours. These two approaches ensure correct proportions of the 3D object represented by the contour. To close the contour, the two ends of a curve can be merged into one using the J key.

After drawing the contour, in Edit Mode, all vertices (control points) are aligned along the vertical axis using the command S->Z->0. This ensures that the contour lies on a perfectly flat plane. This geometric uniformity is critical so that the entire element sinks uniformly into the base with the intended tolerance of 0.2 mm. Afterward, when the contour is ready, it is still a curve. Therefore, it is necessary to convert it to a Mesh. The Transformations (Rotation and Scale) are also Applied.

II. Orientation Lines

The lines on one of the orientation platforms are intended to orient the user as to where the top of the plate is located. They are created in a manner analogous to the contours. Bezier Curves are used once again.

6) Placement on the Base

Once all parts of the plate are ready, they are checked to ensure Rotation and Scale have been Applied, and any modifiers not yet applied to individual parts are Applied. If a change in rotation or scaling is required, Rotation and Scale must be Applied again afterwards. All created elements are placed onto the base. As mentioned above, a tolerance of 0.2 mm is left for each element to sink into the base.

7) Merging

After all individual elements are positioned on the base, they are selected, and using Join (Ctrl + J), they are combined into a single model (single mesh). In this case, the base is selected last, making it the Active Object; therefore, after the Join operation, its name is preserved for the entire plate.

The Join operation results in overlapping geometry, but modern slicers successfully interpret overlapping geometry, turning it into a monolithic 3D print without artifacts. Alternatively, a Boolean modifier with a Union operation can be used.

8) Final Model Check for 3D Printing

Every single model must have Rotation and Scale Applied; otherwise, errors will occur in modifier calculations and final printing dimensions. All modifiers must be Applied, and curves must be converted to Mesh.

Before exporting to a suitable printing format (e.g., .stl), it is critical to check if the model is non-manifold, which indicates whether the model is watertight. In Blender, this check is performed using the built-in add-on "3D Print Toolbox". The "Check All" function performs an analysis of the model, with the most important indicator being "Non

Manifold Edges". If its value is 0, this means the model is ready for 3D printing.

Another important step is checking the Normals orientation. Correctly oriented faces are visualized in blue, while flipped normals are visualized in red. Correct orientation is crucial so that the slicer can correctly distinguish the inside and outside of the model.

4 Experimental Implementation through Additive Technologies

In order to determine the optimal method for physically reproducing the tactile cards, experiments were conducted with three different 3D printing technologies, and the resulting prototypes will be subject to practical testing by students with visual impairments under the methodological guidance of special educators.

4.1 Fused Deposition Modeling (FDM)

The Bambu Lab P1S 3D printer used is a high-performance fused deposition modeling (FDM) 3D printer (Figure 1) designed for use in both home and professional production environments [11]. Its design includes automated calibration systems, including sensors for automatic leveling of the bed, which significantly facilitates preparation for printing and improves accuracy [12]. The printing technology is based on FDM, supporting a variety of thermoplastic materials. The device is equipped with quiet stepper motors and soundproof components, which contributes to a low level of operating noise. Management is carried out via an intuitive web interface or mobile application, providing remote control and monitoring of the process. Additional technical features include an air filtration system, automatic filament feeding and integrated cooling functions, which improves print quality and reliability [13], [14], [15], [16], [17], [18].



Fig. 1: 3D printer Bambu Lab P1S
Source: [11]

The final digital models generated in the Blender environment are exported and imported into the specialized slicer software Bambu Studio. Polylactide (PLA) was chosen as the working material for the physical fabrication. To achieve maximum haptic resolution and smoothness, the 0.08mm Extra Fine base profile was applied, the parameters of which were additionally optimized. The extrusion process is carried out at a working layer height of 0.08 mm and an initial layer height of 0.2 mm to ensure optimal adhesion to the work plate. Maximum structural strength of the tiles is guaranteed by 100% rectilinear infill and two outer perimeters (Wall loops: 2). To eliminate tactile noise on the contact surfaces, a Monotonic lines pattern has been set for the upper and lower base, with 9 top shell layers (Top shell layers with a total thickness of 0.8 mm) and 7 bottom shell layers (Bottom shell layers). The 3D printed tactile alphabet card is shown in Figure 2.



Fig. 2: Braille alphabet card produced with FDM printing technology
Source: created by the authors

4.2 Masked Stereolithography Apparatus (MSLA)

The Anycubic Photon M3 Max 3D printer, presented in Figure 3, operates based on MSLA (Masked Stereolithography Apparatus) technology, also known as LCD-masked stereolithography. This technology is a variant of photopolymer stereolithography, in which each layer of the printed object is built through ultraviolet curing of a liquid photopolymer resin. Unlike classical SLA technology, which employs a laser beam, MSLA printers utilize an LCD screen as a mask, allowing ultraviolet light to pass only through the zones corresponding to the geometry of the current layer [19], [20], [21], [22], [23]. MSLA technology is particularly well-suited for producing parts with high precision and smooth surfaces, using photopolymer (UV) resins. The Anycubic Photon M3 Max model is equipped with a 13.6-inch monochrome 7K LCD display and an advanced UV light matrix (Light Matrix 3.0), which ensure uniform illumination and high detail accuracy [19]. Owing to this method, an exceptionally high surface resolution is achieved, where individual layers are virtually imperceptible to the touch.

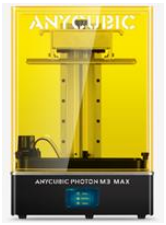


Fig. 3: 3D printer Anycubic Photon M3 Max
Source: [19]

The tactile alphabet cards, previously modeled in the Blender environment, are prepared for printing through the printer's software – Anycubic Photon Workshop (Figure 4). The selected software enables the creation of precise three-dimensional models optimized for photopolymer 3D printing, allowing control over the geometric parameters and orientation of the objects during the printing process.

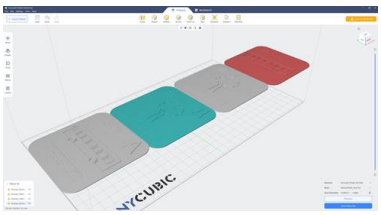


Fig. 4: Anycubic Photon Workshop
Source: created by the authors

Using MSLA technology, three versions of tactile alphabet cards have been produced – with a printed letter, without a printed letter, and in two sizes: 100/100 mm and 150/150 mm (Figure 5).

Upon completion of the printing process, the models undergo mandatory UV curing for a duration of 15 minutes [25]. This step is essential for removing residual surface tackiness, achieving full polymerization of the material and consequently greater structural strength, and ensuring safety for use by children.

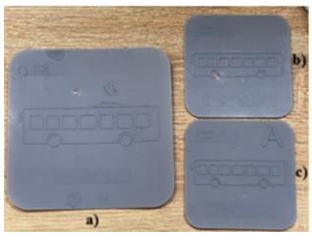


Fig. 5: 3D printed tactile alphabet cards: a) with dimension 150/150mm without printed letter; b) with dimension 100/100mm without printed letter; c) with dimension 100/100mm with printed letter
Source: created by the authors

The surface blemishes observed on the prototypes in Figure 5 (a) and (b) are purely visual artifacts that occurred during the initial testing phase. They were caused by hardware degradation of the MSLA printer specifically, a worn FEP (Fluorinated Ethylene Propylene) film and a partially burnt-out LCD masking screen, which resulted in uneven light exposure on the flat base layers. Following the replacement of these hardware components, subsequent batches were produced with flawless visual surfaces. However, it is crucial to emphasize that these hardware-induced artifacts are strictly cosmetic. They occurred exclusively on the flat base of the cards and did not compromise or deform the geometric integrity of the raised semantic contours or the Braille dots. Because the primary sensory channel for the end-user is tactile rather than visual, these blemishes have absolutely zero negative impact on tactile perception or readability. Such prototypes remain fully functional for educational purposes and can be effectively utilized by visually impaired learners under the guidance of a sighted teacher.

4.3 PolyJet technology

The Stratasys Objet260 Connex3 3D printer uses PolyJet technology, which is characterized by extremely high accuracy and the ability to combine different materials and colors in a single printing process [25]. Unlike FDM technology, which extrudes thermoplastic filament, PolyJet works by injecting microscopic droplets of photopolymer material onto the platform, which are then instantly cured by UV light. The process is repeated layer by layer, achieving extremely high resolution - most of the layers are 16–30 μm, as well as smooth surfaces and fine geometric details.

Preparation for printing is carried out using GrabCAD Print and Objet Studio software, where 3D models (in STL or VRML format) are imported, oriented and configured in terms of materials, quality level and support type. After sending the job, the printer automatically performs the entire printing process, ensuring high accuracy and repeatability.

After completion of the production, the samples are separated from the platform and the support material is removed by water jetting or alkaline cleaning (depending on the type of support). The resulting parts have high dimensional accuracy (up to ±0.1 mm), smooth surfaces and are suitable for both visualization and functional testing.

The printed tactile alphabet cards with polyjet technology were produced with Vero White material. Figure 6 shows the final result of the 150/150mm version with printed letters, braille inscription and embossed image.



Fig. 6: Tactile alphabet card with PolyJet technology
Source: created by the authors

Table 1 (Appendix) presents a quantitative and comparative analysis of the dimensional accuracy achieved using FDM, MSLA, and PolyJet printing technologies. To evaluate scaling behavior at a macroscopic scale, prototypes with two different nominal sizes (100×100 mm and 150×150 mm) were measured.

The FDM and PolyJet technologies demonstrated exceptional precision, with deviations remaining below 0.05 mm for both the 100 mm and 150 mm long profiles. In contrast, the MSLA process exhibited noticeable shrinkage of the photopolymer during UV curing. This shrinkage was uniform across the XY plane (reducing the overall length and width by approximately 0.40 to 0.50 mm, regardless of the card's total size). However, with MSLA, significant shrinkage was observed along the Z-axis, resulting in a base thickness of only 0.64 to 0.72 mm, compared to a nominal value of 1.00 mm. This Z-axis deviation is a well-known phenomenon in resin 3D printing, often caused by the overexposure of the bottom layers, a step necessary to ensure proper adhesion to the build platform.

At the micro-level which is critical for tactile recognition the total height of the Braille elements (base plus dot) and the spacing between the cells were evaluated. PolyJet technology provided the most pronounced vertical tactile feedback, with a measured total height of 1.69 mm (against a nominal value of 1.60 mm). With FDM, the total height was highly accurate (1.57 mm), but the spacing between the cells proved to be slightly smaller (2.60 mm, compared to the nominal 3.00 mm). For the dots printed via MSLA, a significant reduction in the base diameter was observed (measured at 1.08 mm, compared to the nominal 1.50 mm). Combined with a reduced base thickness, this results in a sharper, yet physically smaller, tactile profile. Interestingly, across all three technologies, the spacing between the cells narrowed to a range of 2.60–2.67 mm, which aligns more closely with the "Marburg Medium" standard for Braille spacing. Furthermore, all three technologies reproduce semantic contours with high accuracy, demonstrating their capability to produce both continuous raised lines and individual Braille dots.

In addition to dimensional accuracy, quality and economic factors play a key role in the scalable production of technologies to assist the visually impaired. PolyJet produces the highest detail and perfectly smooth surfaces with zero tactile noise, but is associated with high production costs (approximately 412 euros per 1 kg) [26].

Furthermore, material safety and cost-efficiency are of critical importance. Although MSLA technology enables the creation of smooth surfaces with imperceptible layers at a relatively low material cost (~ €24 per 1 kg), standard resins tend to fail in a brittle manner upon impact [27]. From a health perspective, the photopolymer resins used in MSLA and PolyJet are toxic in their liquid state; consequently, MSLA prints require post-processing via UV exposure [28]. If they are not fully cured or not properly cleaned (for example there is still remaining liquid on the detail), they can pose a risk of causing contact dermatitis, a highly undesirable outcome for educational aids that are handled daily [29]. In contrast, while FDM technology results in a certain "tactile unevenness" due to visible layers, the material used PLA is inexpensive (~ €20 per 1 kg) [30], impact-resistant, and biologically inert (non-toxic). It requires no chemicals for post-processing, making it the most practical, scalable, and safe choice for producing durable tactile maps.

5 Conclusion

The integration of additive manufacturing in special pedagogy unlocks the possibility of decentralized and personalized creation of teaching aids. The methodology developed and described in this study proves that by using open digital modeling software and modern 3D printers, high-quality tactile maps for the Bulgarian alphabet can be created. Sharing the optimized STL files in open repositories would allow resource centers to locally reproduce these materials, eliminating logistical and financial barriers to inclusive education.

The comparative analysis conducted in this study demonstrates that selecting the optimal 3D printing technology for tactile educational tools requires a careful balance between dimensional accuracy, economic feasibility, and user safety. While photopolymer-based methods (PolyJet and MSLA) offer superior surface smoothness and high-fidelity micro-details, they are limited by either prohibitive material costs or strict post-processing requirements. Although resin prints are safe for end-users once

completely UV-cured, the necessity for rigorous chemical washing introduces additional labor and a margin for processing errors.

Ultimately, the findings establish Fused Deposition Modeling (FDM) using PLA as the most pragmatic and scalable solution. Despite introducing minor tactile noise due to layer resolution, FDM delivers sufficient dimensional accuracy for Braille legibility and contour recognition. More importantly, it provides unmatched advantages in cost-efficiency, mechanical durability, and immediate biological safety without the need for post-processing chemicals. Therefore, FDM is highly recommended as the most suitable manufacturing method for the mass production of robust, accessible, and safe tactile learning aids for the visually impaired.

Future research will focus on extensive empirical testing with visually impaired students to further optimize CAD geometries and completely eliminate tactile confusion across various FDM materials.

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Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the accuracy, integrity, and final content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Gabriela Kotseva, Nikolay Stoimenov, Stanislav Gyoshev performed the 3D printing optimization.
Salzica Martinska, Elena Paunova-Hubenova designed the tactile cards (tiles) with the Bulgarian alphabet.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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APPENDIX

Table 1. Comparative evaluation matrix of FDM, MSLA, and PolyJet technologies for tactile cards production

Evaluation Criteria	**FDM (PLA)**	**MSLA (Standard Resin)**	**PolyJet (Vero White)**
A. Dimensional Accuracy (Measured vs. CAD)			
Card length (Nominal: 150 mm)	149.98 mm	149.49 mm	149.95 mm
Card width (Nominal: 150 mm)	149.97 mm	149.60 mm	149.99 mm
Base thickness (Nominal: 1 mm)	0.99 mm	0.72 mm	1.02 mm
Card length (Nominal: 100 mm)	99.97 mm	99.47 mm	99.93 mm
Card width (Nominal: 100 mm)	99.96 mm	99.57 mm	99.99 mm
Base thickness (Nominal: 1 mm)	0.98 mm	0.64 mm	1 mm
Braille dot height (Nominal: 0.60 mm)	1.57 mm	1.50 mm	1.69 mm
Dot base Diameter (Nominal: 1.50 mm)	1.46 mm	1.08 mm	1.26 mm
Cell spacing (Nominal: 3.00 mm)	2.60 mm	2.67 mm	2.66 mm
Contour thickness	1.02 mm	1 mm	0.99 mm
Contour height	1.49 mm	1.47 mm	1.50 mm
B. Economics & Fabrication			
Material Cost	Low (~€20/kg)	Low (~€24/kg)	Extremely High (~€412/kg)
Fabrication Time scaling	Depends on part quantity	Depends only on Z-axis height	High speed, scalable
Post-processing burden	Low (bed removal only)	High (IPA washing & UV curing)	Medium (support removal)
C. Surface & Tactile Quality			
Layer Lines / Surface	Visible layer lines	Smooth, unnoticeable layers	Ultra-smooth, high detail
Tactile Noise	Moderate (due to layers)	Low to None	None
D. Safety & Durability			
Mechanical Durability	High (impact-resistant)	Low (prone to brittle fracture)	Moderate
Toxicity / Biocompatibility	Non-toxic, generally inert	Toxic in liquid state; risk of contact dermatitis if uncured	Safe when fully cured, but uncured residue poses risks

Source: [11, 15, 19, 25, 26, 27, 30]