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Trends in 3D Nail Modeling

Kits Nataliia *

Vancouver, WA, USA.

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Abstract

The study presents an analysis of the contemporary ecosystem of three-dimensional (3D) nail modeling, focused on the contradictory unity of artistic innovations, technological breakthroughs, and procedures of professional standardization. The purpose of the article is a comprehensive analysis of the defining trends in the development of advanced 3D nail modeling. The methodological basis is a mixed approach that combines a systematized review of academic and industry sources, content analysis of the regulations of leading international championships, and in-depth case studies of proprietary techniques of creative modeling. The results obtained record a dual dynamic: on the one hand, a rapid expansion of additive technologies that enable mass customization and the generation of complex base forms; on the other, the consolidation of elite, highly skilled manual execution legitimized through the system of professional competitions. The conclusion confirms the hypothesis of market bifurcation and affirms the resilience of the value of expert manual competencies in the premium segment of the industry. The information presented in the article will be of interest to practicing technicians, instructors and curriculum developers in the beauty industry, the judging body of professional championships, as well as specialists in research and development of cosmetic technologies and materials.

Keywords: 3D Nail Modeling; Nail Art; Creative Modeling; International Championships; Digital Fabrication; Additive Manufacturing; Quilling Technique; Stained-Glass Technique; Professional Training Of Technicians; Innovations in the Beauty Industry

1. Introduction

The nail service industry remains one of the most dynamic segments of the global beauty economy. According to analytical reviews, in 2024 the aggregate size of the global market for nail care products is estimated in the range of 23,6–24,56 billion USD, with an expected compound annual growth rate of about 5% through 2032 [1, 2]. The artificial nails segment, constituting the technological core for 3D modeling, is growing even faster: in 2024 its size reached 1,52 billion USD with a projected CAGR of 5,86% [3]. These parameters indicate not only persistently strong consumer demand but also a well-established institutional and technological basis for the implementation of artistic and engineering innovations [4].

At the same time, despite the existing body of market metrics and the availability of patent descriptions of new solutions, an evident gap remains in the academic discourse. There is a lack of studies that consistently examine the complex synthesis of three key domains that define the current context of 3D nail modeling: 1) elite artistic practices requiring exceptional manual skill; 2) the institutionalized role of international championships as a mechanism for standardization and verification of professional competencies; 3) the transformational potential of digital technologies, primarily additive manufacturing. The existence of works that study these components in isolation does not compensate for the lack of understanding of their synergistic interaction. The present study addresses this gap.

* Corresponding author: Kits Nataliia

The objective is a comprehensive analysis of the defining trends in the development of advanced 3D nail modeling. For empirical illustration and verification of the theoretical propositions, a case study of author-developed methodologies is employed, focused on creative modeling and the training of practitioners for international competitions, which makes it possible to demonstrate the pinnacle of professional qualification and its influence on the future configuration of the industry.

The proposed hypothesis proceeds from the premise that the evolution of nail services is not reducible to a linear substitution of manual labor by automation. On the contrary, a bifurcation into two parallel yet interrelated streams is observed. The first — mass, relying on digital fabrication for hyper-personalization and accelerated production. The second — elite, where complex handmade art, validated by competitive achievements, constitutes a distinctive value and occupies a premium niche.

The scientific novelty lies in the systemic conceptualization of 3D nail modeling as a complex ecosystem in which artistic innovations, competitive standardization, and technological breakthroughs not merely coexist but operate in a mode of continuous mutual determination, setting the trajectory for the development of the entire industry.

2. Materials and methods

The body of sources on the studied topic breaks down into four complementary blocks: market and industry reviews as the context of demand and commercialization channels [1–4]; technological and materials science foundations of additive manufacturing for cosmetics and peri-onychial interfaces [5–6, 12, 15–16, 20]; engineering and applied solutions for the digitization of nail design and creation, including patents and IoT configurations [17–20]; the regulatory-ethical and competitive framework as an operationalized metrology of quality of the result [7–10], while the humanistic-aesthetic perspective and medical-dermatological constraints shape the requirements for design and materials [11–13].

Market reports demonstrate the sustained institutionalization of the segment, where 3D nail modeling is no longer only an artistic technique but also a product category/service with multiple consumer touchpoints: in-salon services, hybrid online–offline chains, and DIY solutions. In the reports of Fortune Business Insights [1; 3] and Global Market Insights [2; 4], segmentation is conducted by product (polish, base/top coats, acrylic/gel/dip systems, press-on and others), distribution channels, and demographic clusters; these same slices define the window of opportunity for introducing personalized 3D design as a mass customization service in salons and in e-commerce. In the logic of the innovation cycle, this sets requirements for technological stacks: printing/post-polymerization speeds under conditions of high turnover, compatibility of consumables with dermatological regulations, and the convenience of contactless service scenarios.

The technological foundation of the trends is delineated by reviews on 3D printing in cosmetics and adjacent biomedical domains. Jiao Y. et al. [6] identify pathways for transferring additive technologies from pharma/biotech to beauty: photopolymerization (SLA/DLP), inkjet and extrusion printing for shape formation, dosing, and decorative functionality; critically important are formulation rheological windows, photoinitiator systems, toxicological profiles, and post-processing to reduce unreacted monomers. Olowe M., Parupelli S. K., Desai S. [16], based on 3D-printed microneedles, systematize architectural and mechanical metrics (stiffness, brittleness, critical bending load, geometric reproducibility) that translate directly to standards for assessing the mechanics of 3D elements on the nail plate (fatigue adhesion, resistance to impact–abrasive loads, compatibility with cyclic deformations of the natural nail). The push toward green and safe photopolymers is reinforced by bio-derived synthesis: Jašek V. et al. [5] propose a castor-derived reactive crosslinking moiety for additive manufacturing, opening a path to bio-based resins with tunable modulus and lower toxicology, which is relevant to the nail context where contact with keratin and periungual tissues is prolonged. The clinically oriented review by Schoon D. [12] shows that for atypical/pathological nails the requirements for materials become stricter (nonocclusivity, hypoallergenicity, capability for atraumatic removal), which in turn constrains the acceptable classes of monomers, solvents, and adhesives for 3D modules. Kao H. L. C. [15] discusses inclusive approaches to on-skin interfaces; transferred to the nail substrate they establish a methodology for designing a hybrid body, where cognitive acceptability, cultural codability, and sensory comfort are as important as engineering functionality.

The engineering–applied line in the body of sources is represented by both scientific publications and patent applications. Kim N. P., Kim J., Han M. S. [20] describe the convergence of 3D printing and nail art, from parametric modeling of the tip/overlay form to integration of printers into salon infrastructure. Emphasis is placed on linking CAD profiling of individual nail-plate geometry with curing and adhesion control, that is, on a reproducible pipeline scanning → modeling → printing → finishing. Subsequently, Kim N. P. [19] proposes an IoT architecture for contactless printing on nails: remote delivery of designs, machine vision for centering/scaling the print, minimization of physical contact under conditions of epidemiological sensitivity. The patent group, WO2015132734A1 [18] and US20220047058A1 [17], specifies two key approaches. First, full customization of artificial nails based on mobile imaging/scanning followed by 3D printing of an individualized set; second, the introduction of soluble/washable intermediate layers and/or supports (soluable in the wording of the application) for gentle removal without aggressive solvents. These solutions typologically expand the spectrum from classic press-on to functional smart targets (microstructures, channeling of rhinestones/pigments, sensor fixation), while simultaneously increasing the demands on geometric registration accuracy and on the management of residual stresses in the multilayer keratin–adhesive–polymer system.

The normative and competitive framework represented by the Nailympia rules for different regions [7–9] and the Premiere Orlando competition regulations [10] effectively serves as an applied metrology of quality: it formalizes criteria of symmetry and architecture (balance of the apex and longitudinal/transverse parallels), thickness–surface parameters (uniformity, absence of pores, laminator/hairline defects), substrate cleanliness, and the safety of materials/processes. For research design, these documents set measurable outcome KPIs (geometric accuracy, finish), and for the market they provide quasi-standards of consumer expectation that influence the choice of technologies and formulations.

Humanities–aesthetic and media aspects determine how technological capabilities are packaged into trends. Kim J., Jeong S. [13] reconstruct the technical–expressive repertoire of nail art (color-block composition, applied 3D elements, relief textures), which—in terms of 3D printing—is equivalent to libraries of parameterized motifs and tactile profiles. Social-media dynamics turn this into an accelerated diffusion cycle: Shaikh Z. et al. [14] show a shift from connectedness to the influencer economy, which for the nail sector implies reliance on visually dense formats, UGC standards, and engagement metrics as selection factors for designs aimed at mass customization. Nanda S., Grover C., Bansal S. [11] remind that aesthetics must always be aligned with the biology of the nail plate and skin, and consequently with the photochemistry and extraction properties of resins, solvents, and pigments during prolonged wear.

Thus, one can say that market reports [1–4] use econometric and segmentation methodology (top-down/ bottom-up estimates, channel cohorts) to extrapolate demand for personalization. Technology reviews [6, 16] are bibliometrically rich state-of-the-art surveys with normalization of technological routes and material classes. Applied engineering works [19, 20] are system prototyping and service design (CAD pipeline, machine vision, IoT orchestration). Patent applications [17–18] record IP strategies for the individualization of geometry and gentle removal. The regulatory block [7–10] is a practical specification of quality and safety criteria to which technological solutions should be extended. Aesthetic-media and dermatological sources [11-15] formulate requirements for expressiveness, inclusivity, and biocompatibility.

However, there are contradictions as well: first, there is tension between the strength/durability of 3D elements and the atraumaticity of removal: the higher the modulus, the more difficult it is to ensure gentle removal without aggressive solvents — patent solutions involving soluble interlayers [17–18] are not yet clinically standardized. Second, sustainability/bio-based formulations come into conflict with the optical saturation and the photopolymerization rate required in a high-throughput salon; compromises on photoinitiators and monomer sorption have been described but not validated under real wear regimes. Third, IoT scenarios of contactless nail-design printing increase service scalability but amplify biosafety/privacy risks and require regulatory articulation that currently lies outside the scope of industry regulations [7–10]. Fourth, market reports [1–4] diverge in growth indicators and channel structure, which complicates quantification of the effect of implementing 3D personalization in specific salon business models. Finally, there is a methodological gap in the standardization of mechanical testing for nail additive parts: metrics from microneedle systems [16] are applicable but not adapted to the specifics of the keratin substrate and everyday loads (moisture, solvents, impact/shear).

3. Results and discussion

The development of 3D modeling of nails is directly conditioned by generational changes in the materials that serve as the vehicle for the artist's concept. In historical perspective, a key impetus was a dental observation that led to the application of acrylate polymers for forming artificial nails [14]. It was acrylic that for many years set the benchmark for mechanical strength and predictable extension of the nail plate. A radical technological shift occurred with the introduction of UV- and LED-curable gels: they provided higher plasticity, eliminated the pungent odor characteristic of the acrylic system, and, due to rapid photopolymerization, optimized the technician's workflow [14].

The current stage is defined by the market entry of compositions engineered for complex three-dimensional design tasks. Central to this are high-viscosity sculptural gels, often labeled as 5D [15]. In contrast to traditional self-leveling systems, their rheological profile makes it possible to literally create volumetric elements that retain the specified geometry until curing in the lamp. Increased viscosity prevents uncontrolled spreading, granting the technician full control over shape and enabling the refinement of micro-details and complex textures [16]. In essence, this solution has become a direct response to the growing artistic ambitions of specialists, resulting in a self-sustaining cycle in which creative demand initiates scientific and technological development, and new materials expand the horizons of authorial expression.

Based on these formulations, innovative authorial practices take shape, elevating nail art to the level of miniature sculpture. Within this study, three principal techniques will be considered:

3D Sculpting: the basic method of constructing relief, three-dimensional forms directly on the nail plate using acrylic or sculpting gel [17]. It simultaneously imposes technological requirements and demands of artistic vision on the practitioner: mastery of the material, compositional thinking, and the principles of light and shadow in miniature.

Quilling: an example of interdisciplinary transfer — an adaptation of the art of paper quilling to nail design [18]. Its essence consists in twisting, forming, and joining thin strips of polymer material to obtain lace-like, volumetric ornaments, which lends the composition visual lightness and elegance.

Vitral: a technique that reproduces the aesthetics of classical stained glass. Semi-transparent colored gels are introduced layer by layer into cells delineated by thin black or metallized lines [19]. The decisive factor is delicate work with color, the construction of depth through layering, and impeccable contouring precision.

A comparative analysis of the properties of the key materials used in the specified techniques is presented in Table 1.

Table 1 Comparative analysis of materials for creative 3D nail modeling (compiled by the author based on [7;16-19]).

Material (Material)	**Viscosity (Viscosity)**	**Curing Time (Curing Time)**	**Sculpting Capability (Sculpting Capability)**	**Durability (Durability)**	**Suitability for Competitions (Suitability for Competitions)**
Acrylic powder/monomer (Acrylic LandP)	Varies by technician	3–5 min (air)	High, requires speed	Very high	High, classical system
Hard Gel (Hard Gel)	Medium, self-leveling	60–120 s (UV/LED)	Limited	High	Medium, for basic constructions
High-Viscosity Sculpting Gel (High-Viscosity Sculpting Gel)	Very high, does not flow	60–120 s (UV/LED)	Very high, plastic	High	Very high, for complex 3D elements

As can be observed, it is precisely high-viscosity sculptural gels that provide the greatest potential for the realization of complex ideas; consequently, they are the preferred material for competition entries and high-level authorial nail art.

In the absence of formalized state standards for high-level nail artists, international championships—above all Nailympia and Nailpro—assume a quasi-institutional role as an industry analogue of a peer-review system [7]. These platforms do not limit themselves to showcasing talent; they effectively institutionalize the profession by setting and disseminating global benchmarks of quality, technical proficiency, and creative novelty.

An in-depth content analysis of the regulations and judging protocols of these competitions reveals the core of the professional values being cultivated. Foremost, the emphasis is placed on unique manual skills and originality. In most creative categories, the use of ready-made components—stickers, decals, pre-printed appliques, and elements produced by stamping—is strictly prohibited [7]. Thus, the focus of evaluation is deliberately shifted toward the artist's handwork—their ability to paint, sculpt, and construct complex elements from scratch.

Originality of design is among the central criteria as well: the regulations typically require that submitted works do not reproduce pre-existing solutions and do not duplicate projects that have participated in other competitions. This norm sustains ongoing creative inquiry and an innovative dynamic, preventing stagnation and the replication of uniform ideas. Technical execution is assessed according to strict parameters: impeccable nail architecture, uniformity of forms, absolute smoothness of the surface, and the cleanliness and precision of lines (especially the smile line in French manicure) [8]. Even in the most creative categories, creativity is guided by technical constraints—for example, a height limit for three-dimensional elements (no more than 1/4 inch in the Stiletto Nails category at Nailympia) or the requirement of an absolutely smooth surface in a number of Nailpro categories [11].

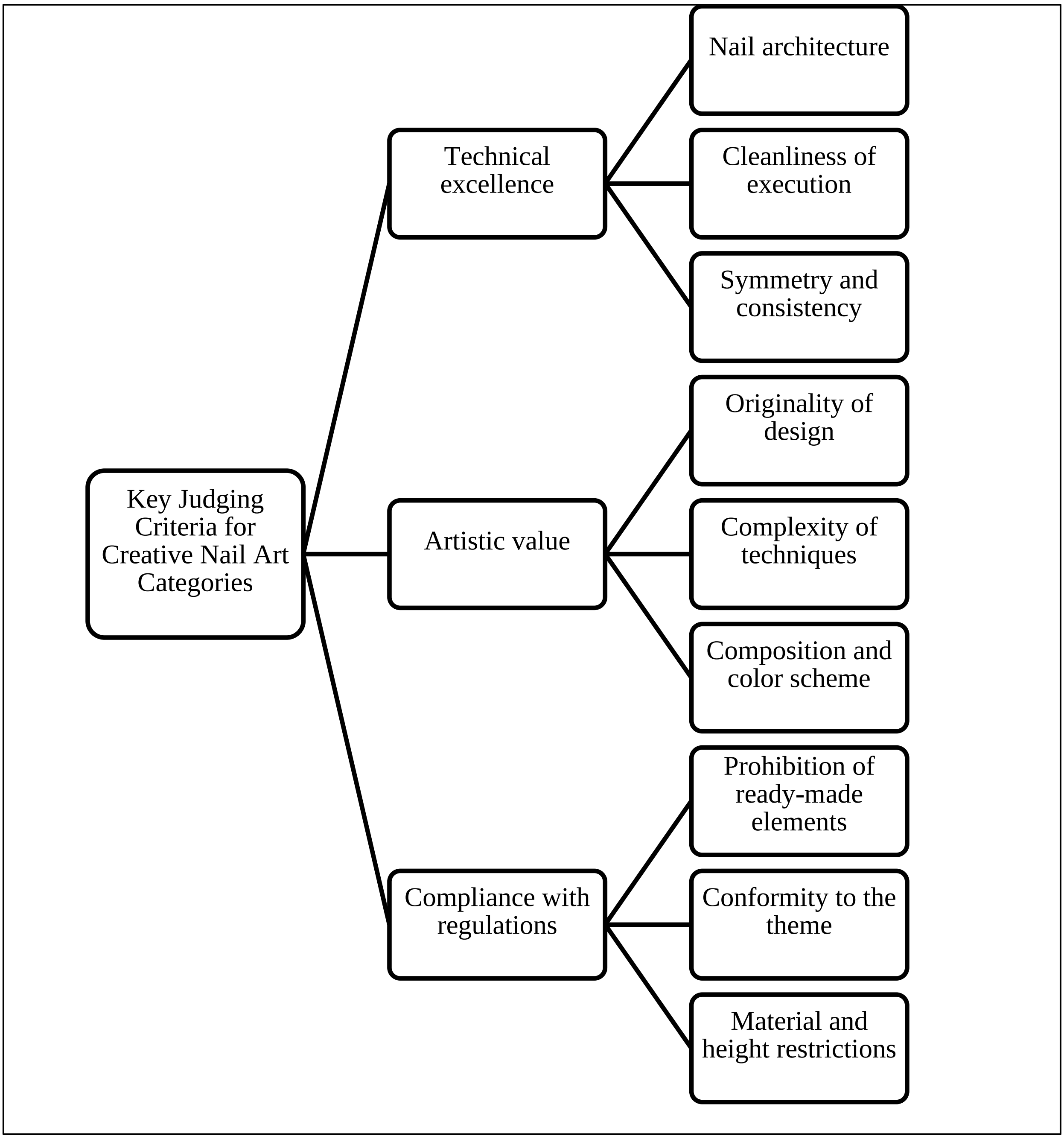

Figure 1 Key judging criteria in creative nail art categories (compiled by the author based on [7, 8, 11])

The case study under consideration demonstrates that preparing practitioners for competitions of such a high level is a multi-level, methodologically complex pedagogical process. It must be precisely oriented toward the development of those competencies that are subject to judging evaluation (Fig. 1). An effective instructional strategy encompasses not only bringing basic technical operations to stable automatism, but also cultivating creative thinking—the capacity to generate original solutions and implement them within strictly prescribed regulations. A logical extension of such a strategy is the development of specialized tools, including lines of brushes. These means are engineered for specific technological tasks of competition works—for example, ensuring maximal precision in rendering ultrafine lines or increasing convenience when working with high-viscosity sculptural gels.

Thus, international championships constitute a space of restrained innovation: while demanding novelty, they simultaneously establish strict technical and technological boundaries, thereby institutionally sustaining and amplifying the value of traditional manual craftsmanship. This mechanism serves as an effective counterweight to tendencies toward potential dequalification associated with automation and guarantees the preservation of the status of the master-artist as the central actor in the premium segment of the industry.

In parallel with the consolidation of manual practices, the industry is undergoing an intensive digital transformation driven by two key forces: social media and additive manufacturing.

Social media, primarily Instagram and TikTok, function as accelerators and relays of trends in nail art [3]. They shorten the fashion life cycle and generate mass demand for visually complex, photogenic, and virally disseminated designs. The effect is twofold: on the one hand, the Do It Yourself (DIY) segment expands, as influencers systematically publish educational materials and reviews of products for home use [12, 20]; on the other hand, expectations increase for professional technicians, from whom clients expect the reproduction of the most complex and topical exemplars seen online.

Against this backdrop, additive manufacturing technologies (3D printing) are penetrating the cosmetics domain, opening qualitatively new opportunities for customization and design engineering. Methods such as stereolithography (SLA), digital light processing (DLP), and fused deposition modeling (FDM) enable high-precision fabrication of objects with complex geometries. In the nail industry, this is reflected in the emergence of patents for systems for creating individualized artificial nails. A typical process includes 3D scanning of the client's nail plate, selecting or developing a design in a specialized application, and subsequent printing of press-on nails precisely matched in shape and size. A number of concepts provide for the integration of IoT technologies for remote control of printing [11, 13].

The economic logic of this trend is illustrated by the projected growth of the artificial nails market — the key target niche for the deployment of 3D printing (Fig. 2).

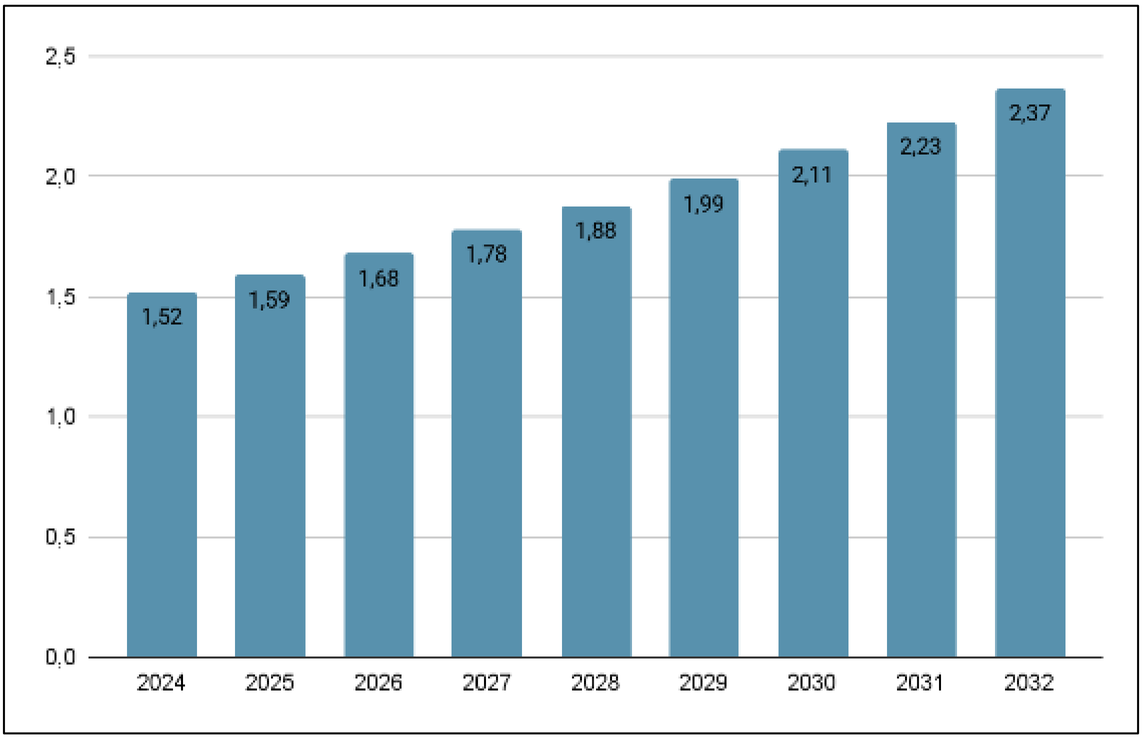

Figure 2 Projected growth of the global artificial nails market, 2024–2032 (compiled by the author based on [3]).

Despite the evident potential, the mass diffusion of additive manufacturing encounters a set of barriers, whose consideration is a necessary precondition for an impartial assessment of its prospects (Table 2).

Table 2 Opportunities and barriers for the adoption of additive manufacturing in the nail service industry (compiled by the author based on [5, 6, 10, 13, 19])

Opportunities	**Barriers**
Hyper-personalization: Creation of nails that perfectly match the client's anatomy.	Cost of equipment and materials: A high entry barrier for salons and independent technicians.
Reduction of service time: Rapid printing of complex base forms.	Material limitations: Issues of biocompatibility, mechanical strength, aesthetics, and the color palette of printed polymers.
Fabrication of complex geometries: Implementation of designs impossible to execute manually.	Need for post-processing: Printed items often require sanding and coating to achieve smoothness and gloss.
New business models (D2C): Direct sales of custom kits to consumers via online platforms.	Risk of deskilling of technicians: A threat of devaluation of modeling and construction skills.

A comparison of potentials and constraints shows that the trajectory of 3D modeling is unlikely to be reduced to a duel between the artisan and the machine. The most realistic scenario is a hybrid organization of the process, in which a 3D printer produces a high-precision and structurally complex foundation — a kind of canvas — whether a press-on nail or a skeletal element (for example, an openwork lattice), that is practically unattainable or excessively labor-intensive in hand fabrication. Then the master artist takes over, transforming this technological semi-finished product into a completed object by applying the final, representational layers: hand painting, fine sculpting, the Vitrage and Quilling techniques. This configuration synergistically combines the metrological precision and structural sophistication of digital fabrication with the irreplaceable creativity and sense of color and texture inherent in human craft. As a result, the value of the artisan's participation is preserved and, moreover, amplified: their role shifts from a technician-operator to the status of a finisher and decorator of high-technology artifacts.

4. Conclusion

The conducted study convincingly demonstrates that contemporary practice of 3D nail modeling constitutes a complex, multicomponent ecosystem at the intersection of artistic practice, materials science, professional norms, and digital technologies. The economic weight of the sector, as evidenced by the steady dynamics of the global market, creates a favorable environment for subsequent innovations.

The key results are concentrated in three theses. First, the industry's development trajectory is determined by materials-science innovations: high-viscosity sculptural gels have emerged as a technological response to the artistic demand of practitioners oriented toward creating increasingly complex and micro-detailed 3D compositions. Second, international championships institutionalize standards and validate the upper tier of qualification, purposefully cultivating the value of unique manual skills and an original authorial style through a tightly regulated system of rules. Third, digital transformation, fueled by social media and additive technologies, creates new market niches and consumption patterns.

Analytical data support the hypothesis of market bifurcation. On the one hand, the development of 3D printing and associated software leads to the automation and democratization of the segment of mass customization, providing rapid personalized solutions for consumers. On the other hand, rigid benchmarks entrenched by professional competitions will continue to consolidate and protect the premium segment, where elite, hand-crafted art, based on years of training and unique talent, preserves and increases its value.

Ultimately, the future of 3D nail modeling is delineated not as the displacement of the human by the machine, but as a productive, finely tuned symbiosis in which technologies take over routine and structural operations, freeing time and expanding the horizons of human creativity.

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