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Projetando narrativas multimídia inclusivas para pessoas cegas: primeiros passos de uma abordagem perceptiva com impressão 3D

Diseño de narrativas multimedia inclusivas para personas ciegas: primeros pasos de un enfoque perceptivo con impresión 3D

Designing Inclusive Multimedia Narratives for the Blind: Initial Steps for a Perceptual Approach Using 3D Printing

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Resumo: Este artigo apresenta etapas iniciais de uma abordagem perceptiva para narrativas multimídia inclusivas a pessoas cegas, combinando modelos táteis impressos em 3D e mediação sonora. Descrevemos o fluxo narrativo e a produção de modelos exploratórios em PLA para avaliar legibilidade tátil e potencial narrativo.

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Palavras-chave: Acessibilidade; Mídia tátil; Impressão 3D; Design narrativo.

Resumen: Este artículo presenta pasos iniciales de un enfoque perceptivo para narrativas multimedia inclusivas para personas ciegas, combinando modelos táctiles impresos en 3D y mediación sonora. Se describe el flujo narrativo y la producción de modelos exploratorios en PLA para evaluar legibilidad táctil y potencial narrativo.

Palabras clave: Accesibilidad; Medios táctiles; Impresión 3D; Diseño narrativo

Abstract: This paper presents initial steps of a perceptual approach to inclusive multimedia narratives for blind users, combining 3D-printed tactile models and audio guidance. We describe the narrative workflow and the production of exploratory PLA models to evaluate tactile readability and narrative potential.

Key-words: Accessibility; Tactile media; 3D printing; Narrative design.

Introduction

Accessing news has long posed significant challenges for blind individuals, primarily due to the limited availability of content in accessible formats. Although technological advancements, such as screen readers, braille publications, and audio news services, have improved this scenario, they remain insufficient in ensuring equal access to current events. Many of these tools are unable to convey the full scope of information, especially as contemporary news media increasingly integrates visual elements such as charts, images, and videos.

One of the key barriers is that most of the news content is still predominantly visual in nature. Whether in online articles, television broadcasts, or social media, critical information is often communicated through visual media that cannot be interpreted by screen readers. While text can be rendered in audio format, important contextual and interpretive elements embedded in visuals, such as infographics or photographs, are often lost, limiting a blind person’s ability to fully grasp or critically engage with the material.

Also, many news platforms still do not treat accessibility as a priority. Although some offer audio versions or braille translations, these resources are frequently inconsistent or incomplete. In many cases, only selected articles are adapted, and significant delays may occur in the production of accessible versions, especially during unfolding or breaking news events. This compromises not only the immediacy but also the inclusivity of news dissemination.

As a result, blind individuals may experience a form of information exclusion, limiting their participation in civic life and public discourse. When access to crucial information, on politics, health, culture, or social issues, is restricted, so too is the opportunity to make informed decisions and engage meaningfully within one's community.

These limitations intersect with broader social and psychological consequences: vision impairment severely impacts quality of life among adult populations. Adults with vision impairment can experience lower rates of employment and higher rates of depression and anxiety (WORLD HEALTH ORGANIZATION, 2023). Thus, the inaccessibility of information is not merely a technical issue, but one that deepens social marginalization and reduces individual well-being.

Accessibility, in this context, should be understood as a communicational condition that shapes who can participate in mediated public life and how collective meanings are formed. When journalistic narratives remain tied to visual formats, blind and low-vision audiences are positioned at the margins of shared interpretation, particularly in stories whose relevance depends on images, spatial relations, and visual evidence.

By articulating tactile fabrication and audio mediation as a workflow, this research frames inclusive production as a practical route to social transformation, understood here as expanding access, interpretation, and participation in media narratives. In practical terms, this means translating media narratives that are historically anchored in images into multimodal experiences in which material form and guided listening help reconfigure meaning-making and reduce exclusion from shared public memories.

Despite these persistent barriers, recent developments in assistive technology offer promising possibilities. Tools such as voice-activated smart devices, AI-driven image description systems, and news applications designed with accessibility in mind represent steps toward more equitable information access. Nonetheless, the continued predominance of inaccessible content underscores the urgent need for further innovation and commitment to inclusive design.

Even with these advances, the field still lacks practical guidance that connects the constraints of desktop 3D printing to the communicational goal of tactile legibility. In applied contexts, the bottleneck is often not the idea of tactile media itself, but the slow and error-prone path from a narrative reference to a printable artifact that preserves meaningful structure. By making fabrication decisions explicit and relating them to perceived tactile outcomes, the present study contributes a replicable pathway that helps align production choices with narrative and accessibility requirements.

This study responds to that need by proposing a novel approach: the creation of an immersive narrative experience tailored to blind users. The project utilizes 3D-printed objects that work together with auditory information to present a subject through a multisensory framework. The narrative is constructed to offer rich tactile exploration, supported by synchronized audio cues, enabling blind participants to engage with content through an integrated sensory experience.

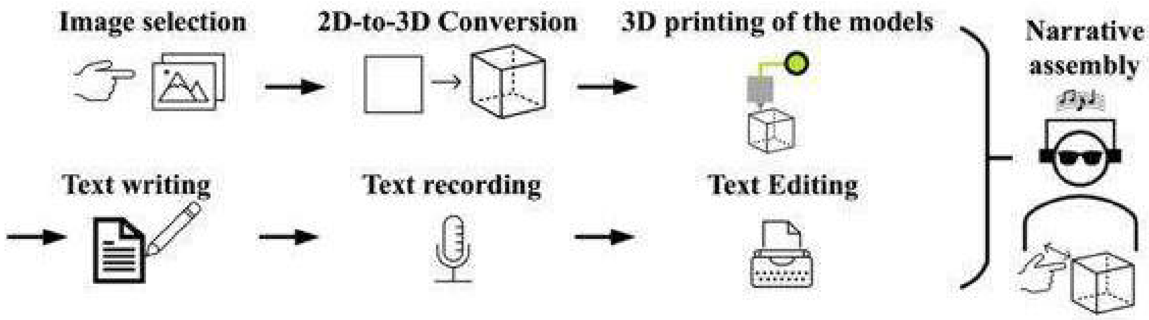
As an initial phase, a series of 3D-printed samples were developed and evaluated through tactile testing. These individuals assessed the physical characteristics of the objects to determine which designs most effectively conveyed the intended narrative. Insights from this process will guide future iterations of the project, helping to refine the design of tactile materials and ensure that the resulting narratives are both accessible and meaningful.

Narrative Design

The development of the narrative experience is organized into two complementary components that are designed in parallel: the tactile (three-dimensional) component and the auditory component. The tactile aspect involves the design and production of physical models intended for hands-on exploration, while the auditory component provides a synchronized sound narrative to guide the user during their interaction with the printed models.

The technical workflow for producing this multimodal narrative has been previously outlined by Empinotti et al. (2020a), and includes a series of structured steps, as summarized in Fig. 1. In this system, multiple tactile models may be produced to represent different stages, scenes, or viewpoints of a given news event.

Fig. 1. Narrative workflow



Source: Authors

The models are manufactured using Fused Filament Fabrication (FFF), a widely adopted technique in additive manufacturing due to its cost-effectiveness and accessibility. In this process, thermoplastic filaments, such as Poly (acid lactic) (PLA), are heated until they transition from a solid to a semi-liquid (pasty) state and are then extruded through a calibrated nozzle. The extruder head moves, in synchrony with the build platform, typically moves along cartesian coordinates (x, y, and z) depositing material layer by layer according to the geometries and profiles defined by the digital design. After completing each layer, either the nozzle or the build platform (depending on the kinematic configuration of the printer) moves along the Z axis by a distance equal to the layer thickness, initiating the next layer and progressively forming the complete 3D object (ALHNAN et al., 2016).

While the tactile models serve as the foundation of the narrative experience, the audio component plays a crucial role in orienting the user and enhancing comprehension. The audio is digitally recorded and edited, and may include elements such as narration, interviews, testimonies, ambient sounds, or other formats typically found in audio journalism. The audio also provides interaction cues: instructions on how to manipulate the models, and when to engage with each object. These cues aim to reduce the need for third-party guidance during testing and to support independent exploration. Each audio segment is designed to be concise, typically around one minute, allowing sufficient time for tactile engagement while including natural pauses to accommodate the user's pace or transitions between models.

Importantly, the auditory narrative will be developed only after the tactile structure is fully defined, to ensure that it responds precisely to the physical experience and user flow. This dual-channel approach (combining touch and sound) is grounded in inclusive design principles and has been reported as effective in enhancing non-visual access to complex information (EMPINOTTI et al., 2020a).

Format Definition

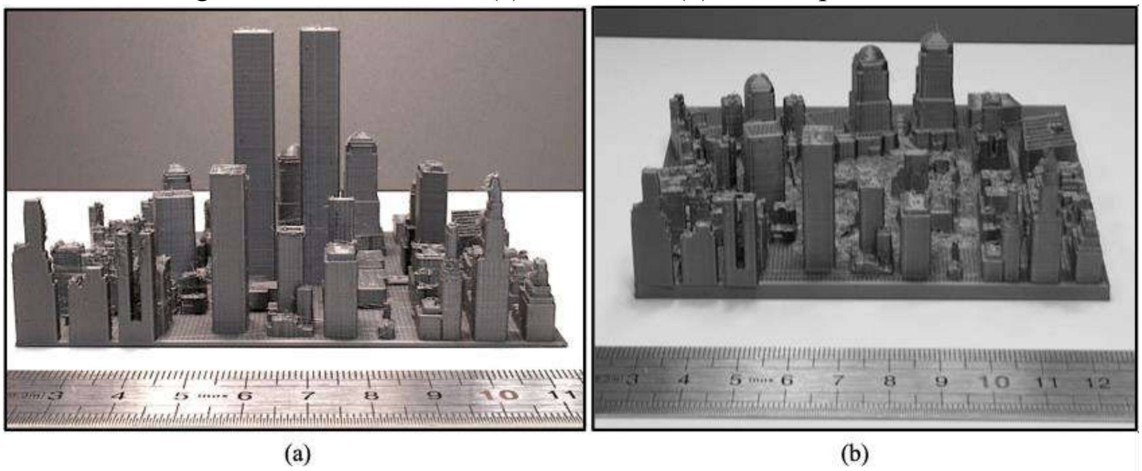
There are two primary methods for reproducing images through 3D printing that can serve as narrative components for blind and visually impaired individuals. The first is the lithophane system (Fig.2), which converts 2D images into thin, translucent reliefs that reveal detailed visuals when illuminated from behind. The second method involves modeling in full 3D format, which we refer to as scale models or maquettes (Fig. 3). Both formats were tested during the initial phase of this research to evaluate their narrative and tactile potential.

To guide the exploratory stage, we produced tactile representations of the World Trade Center site in New York City, both before and after the September 11, 2001 attacks. The models included the twin towers and the surrounding area, enabling a spatial and historical contrast between the two states. This research step has been previously described by Empinotti et al. (2020a).

Fig. 2. Litophane models: (a) before and (b) after September 11

Source: Authors

Fig. 3. 3D scale models: (a) before and (b) after September 11.



Source: Authors

The decision to begin with this subject matter was guided by two main criteria. First, we selected a globally recognized event to ensure that participants engaging with the models could draw from preexisting mental representations of the scene. Research in cognitive psychology and spatial memory suggests that familiarity with a subject enhances one's ability to process and interpret information through alternative sensory channels (MILLAR, 1994; UNGAR; BLADES; SPENCER, 1996). In this context, using a well-known historical event reduces cognitive load and facilitates the comprehension of the model's narrative.

At the same time, the World Trade Center event is a landmark of global mediatization, repeatedly narrated through images, testimonies, and competing framings over time. This makes it a meaningful test case for translating a highly visual, media-saturated narrative into a tactile and audio-mediated experience, allowing us to examine whether core spatial relations and narrative structure can be preserved when visual primacy is removed.

Second, to validate the fidelity and interpretability of the tactile representations, this phase of the study was conducted with sighted individuals. This approach is consistent with standard practices in tactile and inclusive design, in which preliminary validation often.

Involves users who possess visual experience, enabling them to compare tactile inputs with their vitsual memories (ROWELL; UNGAR, 2005). This methodological choice helps assess whether the models accurately convey the intended information and whether their form aligns with users' expectations based on prior visual exposure.

At this exploratory stage, using blindfolded sighted participants serves a calibration purpose. It allows the study to generate an initial benchmark under comparable conditions, while participants can still relate tactile input to prior visual memory and therefore help identify whether the printed forms convey the intended content. This step is not positioned as a substitute for studies with blind participants, but as a way to reduce technical uncertainty before target-audience evaluations focused on autonomy, exploration strategies, and narrative comprehension.

The insights gained during this stage are essential for refining the narrative structure and preparing the models for further testing with blind participants. By establishing a foundational understanding of the model's interpretability, we aim to ensure that subsequent tactile narratives are meaningful and accessible to individuals with no visual reference. All models were printed with Polylactic acid (PLA) filament, following the printing settings presented in Table 1. PLA is one of the most used materials in 3D printing, particularly within Fused Filament Fabrication (FFF) processes, due to its biodegradability, ease of printing, low warping tendencies, and favorable tactile finish.

Table 1. Models` Printing Parameters

Parameter	**3D Model Setting**	**Litophane Setting**
Layer Thickness	0.1 mm	0.1 mm
Print Speed	60 mm/s	60 mm/s
Infill Density	20%	100%
Raster Angle	90º/0º	90º/0º
Extrusion Temperature	215ºC	215ºC
Bed Temperature	50ºC	50ºC

Source: Authors

According to Santana et al. (2019), PLA is especially suitable for applications involving physical interaction, as it offers sufficient rigidity and surface detail without the emission of harmful fumes, making it appropriate for educational and sensory-based tools. Lithophane was initially considered due to its streamlined fabrication process. This method allows the user to input a 2D image into dedicated software, which automatically generates a printable model with minimal manual intervention. Moreover, lithophane prints are relatively simple to produce, requiring minimal structural supports and lower risk of printer failure, making it a practical option for rapid prototyping. Table 2 shows how lithophane models require less printing time and less material to be made, even when using a higher infill density percentage.

In contrast, the three-dimensional model format (maquette), while offering greater narrative and spatial depth, generally demands more manual preparation from the user prior to printing. Complex structures may require support materials, careful orientation, and additional slicing configurations. This introduces greater technical challenges, particularly when printing hollow or detailed models that demand precision and stable adhesion during extrusion.

Table 2. Models` Settings

Model	Printing Time	Mass of Final Model
(1) 3D model - WTC before	9h32m	45.95 g
(2) 3D model - WTC after	13h01m	45.95 g
(3) Lithophane - WTC before	7h00m	33.71 g
(4) Lithophane - WTC after	5h38m	24.71 g

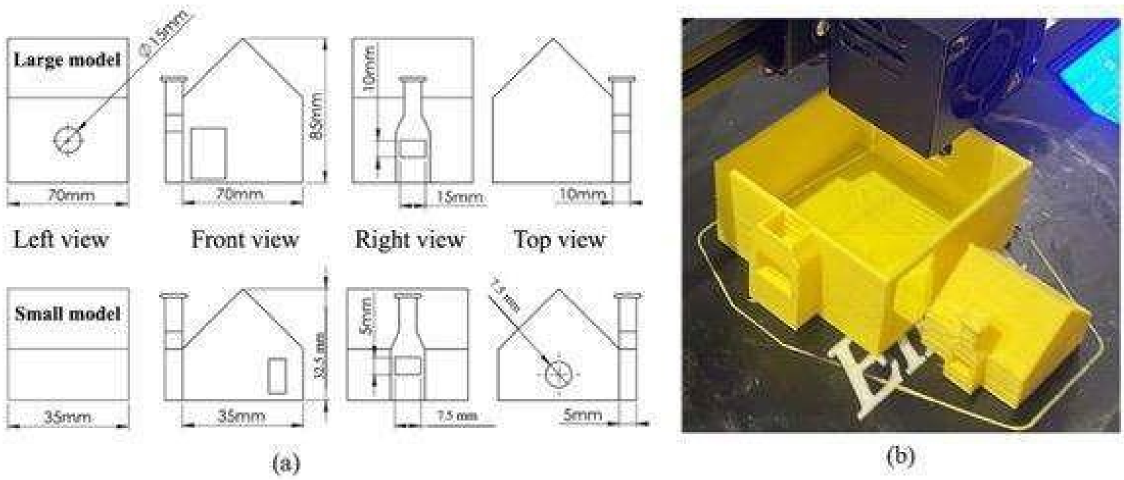
Source: Authors

Taking these factors into account, we conducted a set of basic intra-laboratory tests with members of the research group. The models were presented side by side, and participants were asked a single question: Which model best represents the scene depicted? The results were unanimous: the maquette was consistently identified as the most accurate and meaningful representation of the narrative space. This result guided our decision to proceed with the 3D model format for the next stages of the study.

Size Definition

Having completed the study focused on evaluating different strategies for modeling and presenting 3D tactiles elements — the next phase of our work adopted a more technical perspective, examining the variables involved in the interaction between the human factor, the 3D-printed component. This research step was partially described by Empinotti et al. (2020b). The first aspect investigated was the influence of model size on the tactile perception of details. To assess this, two samples representing houses were produced at different scales, as shown in Fig.4.

Fig. 4. Size and geometry details of models



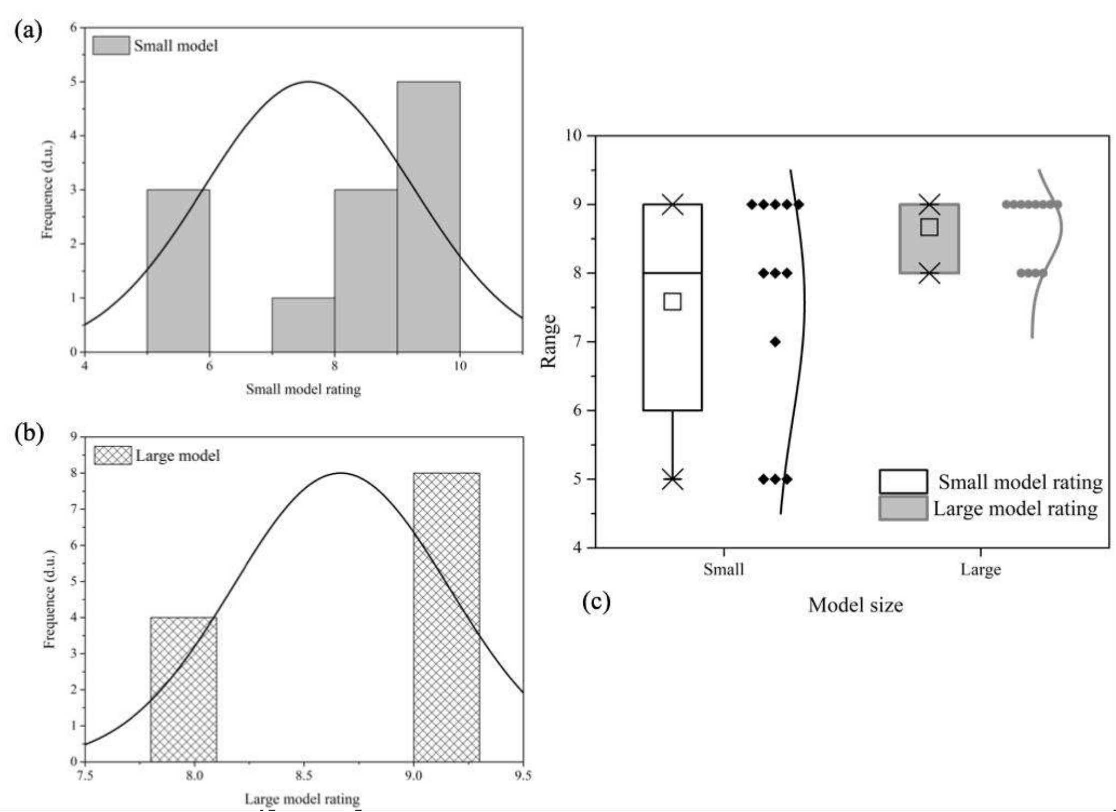
Source: Authors

Participants interacted first with the smaller house model, during which the researcher asked questions such as whether the house had windows, doors, a roof, and other architectural elements. The same protocol was then applied to the larger model. The purpose of this test was to determine whether model size (small vs. large) significantly affected the user's ability to identify tactile details.

Performance scores were assigned based on the number of correct answers given by participants during interaction. For example, correctly identifying the number of doors or windows earned one point each. The score distribution analysis indicated that the larger model (L) tended to yield a higher concentration of correct responses (Fig. 5a and 5b), suggesting improved perceptual clarity with increased scale.

However, a t-test for independent means (Student's t-test, 95% confidence level) revealed that the difference in mean scores between the two model sizes was not statistically significant ($t_{13} = -2.15$; t_critical = 2.16; P = 0.053) (Fig. 5c). Although the trend favored better performance with the larger model, the test results indicate that increasing the size alone did not significantly enhance tactile detail recognition in this initial sample.

Fig. 5. Histograms of subjects' scores - small model (a) and large model (b) and boxplot of general data (c).



Source: Authors

Even so, the upward trend in performance scores suggests that larger models may facilitate better user interaction, and so we will proceed with models with features based on this finding. Nevertheless, in future research we may aim to balance the trade-offs between model size, print time, material cost, and tactile effectiveness, identifying an optimal scale that maximizes perceptual clarity without compromising production efficiency.

Printing Settings

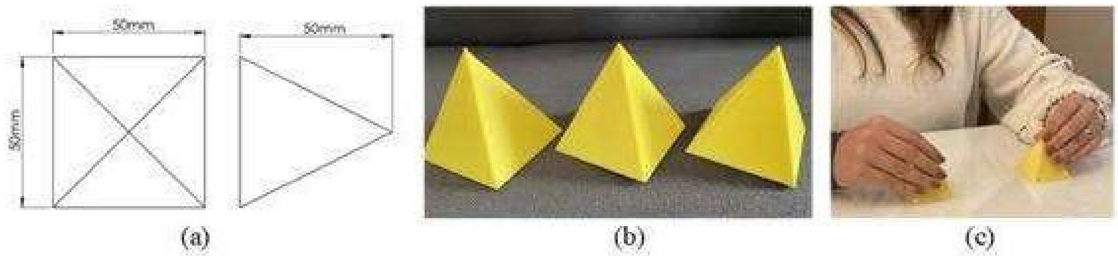
Design of tests

The next goal was to identify the most effective structural characteristics for the 3D-printed models. The test focused on analyzing the influence of four 3D printing parameters on the tactile quality of the models' surfaces: printing speed (20 mm/s, 60 mm/s), extrusion temperature (185°C, 215°C), layer thickness (0.1 mm, 0.3 mm), and extrusion multiplier (1.0, 1.5). Using Taguchi experimental design (4 factors at 2 levels, resulting in an L8 orthogonal array), we defined eight printing conditions with different parameter combinations, aiming to reduce the number of tests required while ensuring interpretability of results.

While twelve participants took part in the model size evaluation, nine were involved in the test assessing the influence of process parameters. Pyramidal samples (Fig.6) were fabricated according to the parameters defined in the Taguchi orthogonal array and submitted to sensory evaluation tests, involving both individual analysis and comparative assessment. In this initial stage, participants were blindfolded to eliminate visual input, but individuals with visual impairments were not yet included.

The individual analysis involved tactile exploration using one hand, while the other hand stabilized the model on a flat surface such as a table. During the interaction, participants answered a series of questions posed by the researcher.

Fig. 6. Pyramidal 3D scale models during test



Source: Authors

To characterize the surfaces of the printed parts, three perceptual attributes were defined and qualitatively assessed based on the individual perceptions of each participant: (i) smooth (positive polarity) versus rough (negative polarity); (ii) rigid (positive polarity) versus flexible (negative polarity); and (iii) pleasant (positive polarity) versus unpleasant (negative polarity). Each response was rated using a categorical–numerical scale ranging from –2 to +2, where the polarity indicates the direction of the perception, or opposition of concepts (positive or negative). The degrees of intensity were classified as follows: +2 or –2 for "very," +1 or –1 for "slightly," and 0 for "neutral" or "irrelevant." For example, a participant who perceived a surface as "very smooth" would assign a score of +2, while a "very rough" surface would receive a –2. This structured scale allowed for the quantification of subjective tactile responses in a standardized manner.

This sensory evaluation was first conducted using the participant's dominant hand (right or left) and subsequently repeated with the non-dominant hand, to assess possible differences in tactile perception. The second test consisted of a comparative evaluation between samples. Participants were asked to interact with two samples simultaneously, holding one in each hand. The samples were presented in random order, ensuring that all possible pairwise comparisons were assessed. Each sample pair was evaluated twice: once using the dominant hand and once using the non-dominant hand.

During the comparison, participants responded to the researcher's questions by indicating which sample they perceived as smoother and which one they found more pleasant to the touch. If no perceptible difference was detected, the participant could respond with “neutral.”

Discussion of results

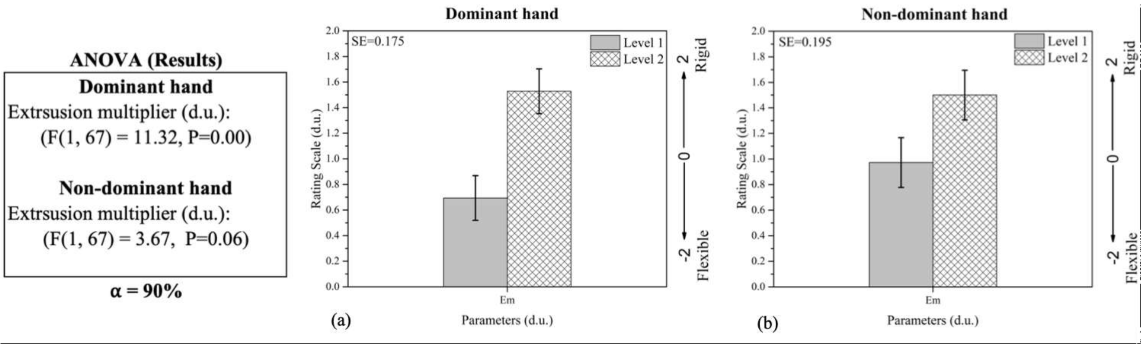
Our goal was to assess whether the evaluated process parameters influenced participants’ perception of the printed samples’ tactile characteristics, using ANOVA analysis at a 90% confidence level. The perception of pleasantness showed no statistically significant differences, while rigidity and roughness demonstrated significant effects.

In the case of rigidity, the extrusion multiplier was the only parameter found to have a significant impact, both for the dominant hand ($F(1,67) = 11.32$, $P = 0.00$) and, to a lesser extent, for the non-dominant hand ($F(1,67) = 3.67$, $P = 0.06$), with a directly proportional relationship (Fig. 7). This may be explained by the fact that increasing the extrusion multiplier results in more material being deposited, which can lead to thicker internal walls in the pyramidal model and improved bonding between filaments and layers, thereby increasing the sample’s structural rigidity.

Regarding surface roughness, both layer thickness in the dominant hand condition ($F(1,67) = 16.90$, $P = 0.00$) and non-dominant hand condition ($F(1,67) = 14.23$, $P = 0.00$), as well as extrusion temperature in the dominant hand ($F(1,67) = 3.10$, $P = 0.08$) and non-dominant hand ($F(1,67) = 3.56$, $P = 0.06$), were significant factors influencing the perceived roughness of the samples. In the case of layer thickness, lower values led to a smoother perception of the surface (Fig. 8). This is likely related to the increased build resolution and the reduced amplitude between peaks and valleys formed by deposited filaments.

> As for extrusion temperature, the effect may be associated with the material’s rheological behavior. As shown in Fig.8, higher extrusion temperatures resulted in samples perceived as smoother. This can be attributed to the enhanced fluidity of the material at elevated temperatures, which reduces its viscosity and allows for greater lateral flow and better accommodation during deposition. This effect can contribute to diminishing the topographical variation both within and between layers, thereby smoothing the surface. These findings are consistent with those reported by Chaidas et al. (2016).

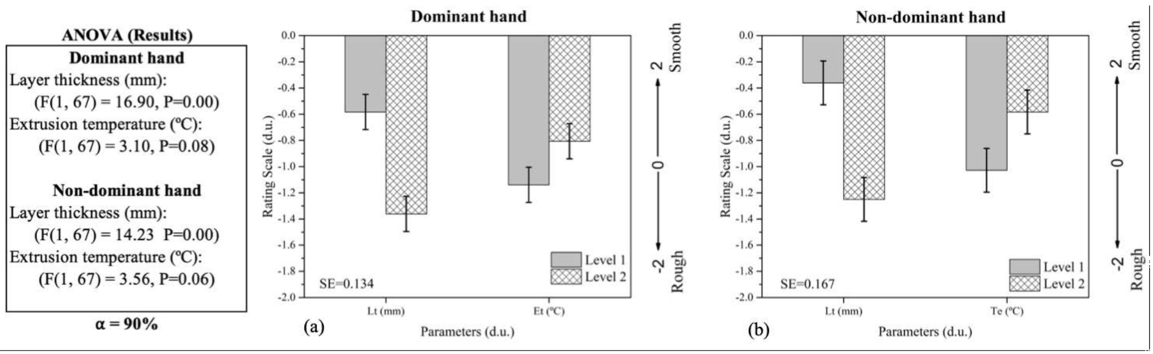
Fig. 7. Surface rigidity: means of significant factors according to ANOVA.



Source: Authors

Such technical effects matter for the narrative experience because tactile texture and stiffness function as carriers of legibility. Excessively rough surfaces can mask fine features that convey meaning and make exploration more cognitively demanding in dense areas, while overly smooth surfaces may reduce tactile contrast depending on the geometry. Likewise, rigidity shapes how confidently users can trace edges and reconstruct spatial relations, which directly affects the ability to follow the narrative logic embedded in the object. This reinforces that parameters such as layer thickness and temperature should be treated not only as manufacturing settings, but as design choices that modulate the readability of tactile narratives.

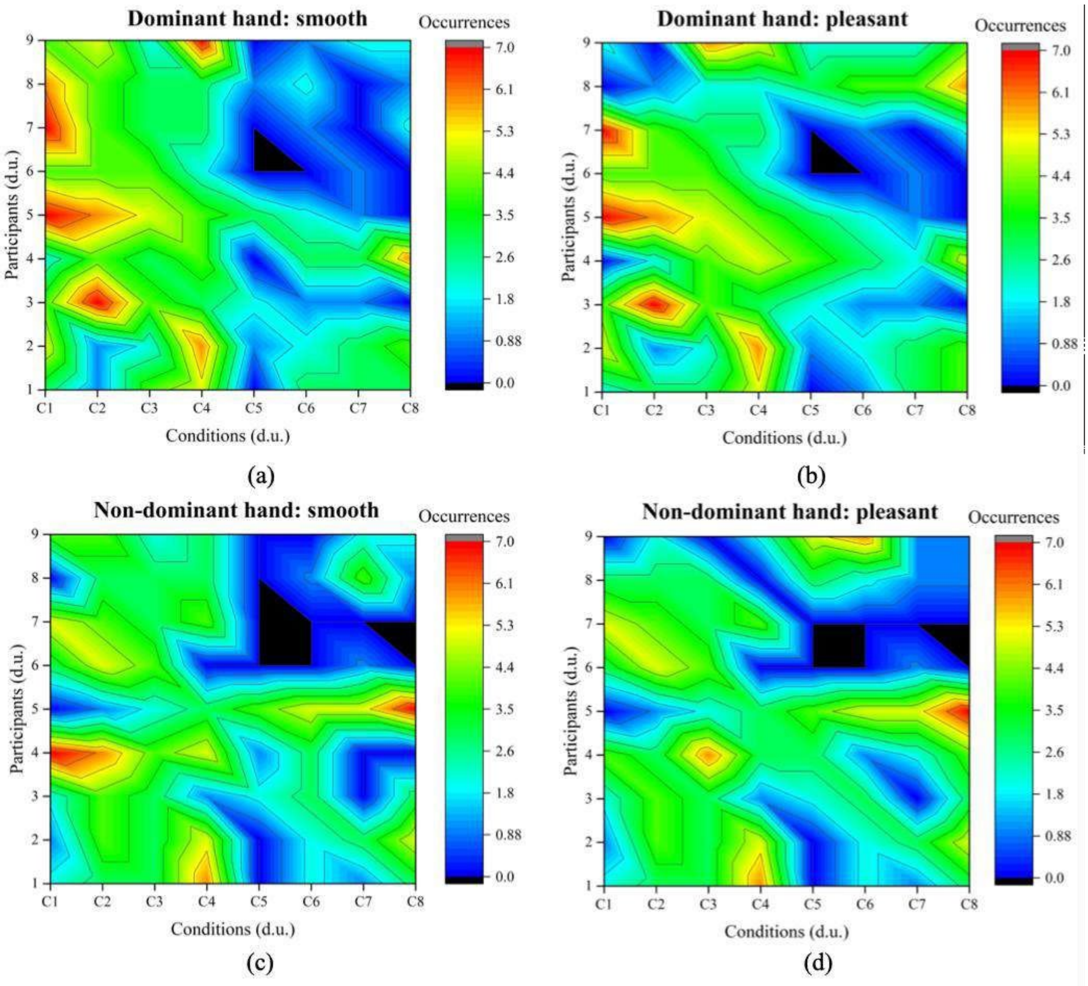
Fig. 8. Surface roughness: means of significant factors according to ANOVA.



Source: Authors

In the comparative tests, a relationship was identified between the “smooth” and “pleasant” characteristics, which are often associated with one another. The color maps in Fig. 9 provide visual evidence supporting this observation. It is also noteworthy that the highest concentration of occurrences (i.e., cases in which a given sample was perceived as smoother and/or more pleasant) was found under conditions 1 and 4, both of which employed a lower layer thickness (0.1 mm).

Fig. 9. Color maps for “smooth” and “pleasant” using both hands.



Source: Authors

The analysis of the influence of printing parameters on the tactile quality of the parts revealed that three out of the four tested parameters significantly affected the perception of the printed surfaces: extrusion multiplier, layer thickness, and extrusion temperature. Future studies will aim to technically characterize these surfaces through surface roughness measurements and mechanical testing.

Ongoing and Future Work

At this stage of the research, the work is concentrated on two main components. The first involves the development of 3D models through interactive AI-based tools. A survey of five available software is currently underway, with a focus on identifying and refining those that are user-friendly and do not require advanced technical skills, thereby making them accessible to a broader audience. This approach aims to democratize the creation of tactile content, supporting inclusive design practices and facilitating rapid prototyping without relying on high-level expertise.

In addition, AI has strong potential to accelerate the end-to-end 3D printing workflow, which is often slowed by technical bottlenecks and time-consuming iterations. In practical terms, AI can reduce the effort spent on repetitive and specialized tasks such as converting visual references into printable geometry, detecting non-manifold surfaces and fragile features, suggesting minimum wall thickness and tolerance adjustments for FFF, and anticipating print failures linked to overhangs, supports, or part orientation.

By shortening the design–repair–slice–print cycle and lowering the number of trial prints, AI can help users reach a reliable tactile prototype faster, even when facing typical constraints of desktop fabrication (material behavior, calibration, adhesion, warping, and post-processing). Ultimately, integrating AI into these stages supports a more efficient and scalable pipeline for producing tactile models, making inclusive fabrication more feasible in real-world settings with limited time, resources, and technical expertise.

Next, the workflow will be validated with blind participants to assess whether the proposed multimodal narrative structure supports comprehension and autonomy during exploration. This stage will combine quantitative indicators, such as task completion time, identification accuracy, and error patterns, with qualitative feedback on comfort, perceived coherence of the narrative, and the effectiveness of audio mediation in guiding transitions and reinforcing spatial information.

The second component of the ongoing work is a technical investigation into surface properties, including roughness, texture, hardness, and friction, factors that play a critical role in the tactile perception of printed components. Although the initial studies were conducted using PLA, due to its availability, printability, and stability, there is a growing interest in exploring material combinations that offer more suitable haptic characteristics for specific applications. For example, flexible materials such as thermoplastic elastomers can be used to represent soft objects, enhancing the realism and perceptual fidelity of the printed model.

The use of multimaterial strategies is particularly relevant in the context of inclusive and educational technologies, where conveying different material sensations may help users form more accurate mental models of real-world objects. These two parallel research directions, AI-assisted model generation and surface characterization, are expected to converge in near future stages, supporting the creation of adaptive, perceptually rich, and easily reproducible tactile models.

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