Factors influencing the creation of Braille 3d models in additive manufacturing

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Abstract

The article examines the processes of additive manufacturing of systems for creating three-dimensional Braille models. The main problem is that additive manufacturing is not one of the simple processes. Such production requires some research and understanding of how each process can affect the reproduction quality of any model. Since the scope of 3D printing is limitless, this article focuses on the creation of Braille models that are used by people with visual impairments. The purpose of this study is to analyze and determine how processes affect additive manufacturing processes for the creation of 3D models, especially models with relief Braille dots, and which factors have the greatest impact on the quality of creation of such models and considering the relationships between each manufacturing process and factor , which affects Taking these factors into account, this article builds a semantic network of influence factors as an initial graph of relationships of each production process of model creation in additive manufacturing and their impact on each process that affects the quality of Braille model creation. A comparative table with materials used in 3D printing, as well as a table for each production process, their impact on the 3D model and a description of the processes, was also built. Based on these data, a final hierarchical semantic model is built, taking into account the importance of each production process and their impact on the quality of creating a 3D Braille model in additive manufacturing. The obtained results of this study can be used to create three-dimensional Braille models, which will provide an understanding of the relationships between each additive manufacturing process and their impact on model quality and improve the quality of model creation. This will improve the processes of creating Braille models in additive technology and improve the quality of the models. It will also make it possible to create certain optimized standards for the development of 3D models with Braille, which will avoid financial costs and time, and also accelerate the development of inclusion for people with visual impairments through the rapid creation of 3D models with Braille in additive manufacturing, including the improvement of manufacturing processes and the quality of such models.

Keywords

Influencing factors, 3D-printer, 3D-models, additive manufacturing (AM), Braille, CAD, artificial intelligence

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1. Introduction

The visually impaired community faces various challenges related to the access to information and learning. One of the solutions to these problems is the use of Braille 3D models. These models provide a tactile display of information that is easily perceived by visually impaired people. However, the effectiveness of these models depends on various design factors. In this scientific work, an analysis of influencing factors on the creation of three-dimensional models with the formation of the Braille font in additive manufacturing is carried out. A semantic network of influencing factors is created. In order to create Braille 3D models, it is necessary to understand what factors affect the process of creating 3D models using information systems, such as CAD systems for printing on 3D printers and post-press processing. Specifically, the study will research how these reproduction factors affect the effectiveness of the models in improving the use of 3D Braille models among people with visual impairments. By understanding the influence of these reproduction factors, the study aims to contribute to the development of more efficient and accessible Braille 3D models. This research will identify gaps and weaknesses in 3D modelling processes and will allow further research to improve additive manufacturing processes to create models for people with visual impairments. The results of the study will be useful for creating more effective Braille 3D models for tactile learning among the visually impaired. The research reveals every process and factor that can affect the processes of creating 3D models. When designing these models, it is necessary to take into account such factors as software, materials, modelling, 3D printers, post-press processing, environment, complexity of the 3D model, resolution, etc. This will allow one to get complete information about the influencing factors in additive manufacturing for creating Braille models for people with visual impairments.

In addition, technological advancement in 3D modelling and printing has made producing a 3D model easier and more affordable than traditional manufacturing methods. The development of 3D CAD software and the ability to convert virtual 3D models into physical 3D models via 3D printing has made creating 3D models a real offer for many applications, whereas previously 3D models may only be created for computer simulations. In many cases, 3D models can be created by simply converting the virtual model into a physical model and may not require any manual construction. This is ideal for producing multiple copies of a 3D model for educational purposes or for creating a 3D model that needs to be reproduced later.

Despite the fact that additive manufacturing has achieved great success and is actively developing and researching, there is still a need for further study, research and improvement of production processes. Additive manufacturing has been explored by scholars such as Chua, C. K., Leong, K. F., & Lim, C. S. (2010). "Rapid Prototyping: Principles and Applications", this work is one of the main ones that describes the basic principles and technologies of 3D printing. Also Lipson, H., & Kurman, M. (2013). "Fabricated: The New World of 3D Printing", where laser fusion technology and its effects are developed and researched. Among them, there are many other scientists who also took part in the research of production processes, discovered new technologies, materials, etc. Therefore, additive manufacturing is used in many industries, including inclusion, to improve accessibility to services for people with disabilities. In this study, the main attention will be paid to the studied factors that affect the quality of reproduction of Braille 3D models used by people with visual impairments. This line of research was chosen because there is a need for the development of inclusion, and in this case for people with visual impairments. Therefore, it is necessary to improve the quality of inclusion, thereby applying additive manufacturing technologies to create tactile models, and for this it is necessary to determine how each process affects the creation of a 3D model, as a result, it will allow to improve production processes.

2. Literature review and problem statement

There are a vast number of factors that may influence the creation of 3D models, particularly those that are aimed at simplifying and enhancing the learning experience for visually impaired people. Some of the most common factors that might influence the creation of Braille 3D models include technological advancements, the availability of resources, expertise and training, and the user requirements and preferences. These factors are interlinked in many ways and may all have a significant influence on the end product, particularly when the products are intended to simplify and enhance the learning experiences of others. The main objective of this study is to identify and analyse the key factors that influence the creation of 3D Braille models for the visually impaired in additive manufacturing. Performing an analysis of influencing factors and constructing a semantic network will allow analysing which factors have the greatest influence on the process of creating models and will make it possible to avoid shortcomings that may appear during the creation of models. This will allow further scientific research and improvement of additive manufacturing processes or the search and creation of new materials, or a combination of materials for the high-quality formation of Braille on 3D models. It will also allow manufacturers and scientists to understand at which stages of Braille model creation problems arise. The analysis of recent research and publications in factors influencing the creation of Braille 3D models reveals a growing interest in utilizing 3D-printed models to enhance spatial awareness and improve the overall experience for visually impaired people. One such study aimed to answer the research question – how 3D printed models influence spatial awareness [1] The study focused on the integration of Braille and other tactile solutions, which has been a significant area of interest for researchers and inventors in recent years. In order to research the perception of the produced elements, the study was conducted through experiments with manufacturing materials and visually impaired individuals [2]. The findings from these experiments provided valuable insights into the potential benefits of using 3D printed models integrated with Braille. It is important to note that the success of these models hinges on numerous factors, such as the selection of materials, design optimization, and Braille integration with the 3D model structure. Recent research and publications in factors influencing the creation of Braille 3D models demonstrate the potential of 3D printed models to improve the lives of visually impaired people. By considering key factors such as material selection, design optimization, and the integration of Braille with the model's structure, researchers and inventors are paving the way for innovative solutions that can be integrated into society and benefit the disabled community as a whole [3]. The expansive reach of additive manufacturing technology, commonly referred to as 3D printing, extends far beyond the traditional confines of industry, redefining the very essence of manufacturing and assembly methods [4]. At the core of this transformative process is the ability to use computer-aided design (CAD) software, which directs machines to meticulously craft complex three-dimensional objects from an array of base materials, a technique that is as innovative as it is precise [5]. This technology is not constrained to creating simple prototypes or small components; it is increasingly being employed to construct a diverse range of items, from the framework of houses to the delicate intricacies of foodstuffs, illustrating its versatility and potential to touch on virtually every aspect of human life. As the costs associated with additive manufacturing continue to decrease and the efficiency of the manufacturing process itself escalates, the technology becomes more accessible not only to large-scale commercial manufacturers but also to individual enthusiasts and entrepreneurs. The combination of affordability and the ability to rapidly iterate designs propels additive manufacturing to the forefront of innovation, particularly in fields where customization and low-volume manufacturing are paramount, such as in aerospace, race cars, and the medical industry [6].

Within the 3D modelling realm, additive manufacturing presents several general advantages that substantially benefit both design and manufacturing stages [5, 7]. Primarily, it heralds a significant reduction in material waste, as it allows for the precise creation of complex geometries that perfectly conform to the digital model, eliminating excess material use typical of subtractive methods. This precision not only conserves materials but also reduces the manufacturing time by streamlining the manufacturing process, which can be particularly advantageous when rapid prototyping or manufacturing is required. Moreover, the elimination of expensive tooling is another economic boon, ensuring that the transition from design to manufacturing is both cost-effective and efficient. This is especially pertinent when creating customized and personalized products, as additive manufacturing can adapt to individual specifications without the need for new tools or molds, thus offering long-term economic benefits due to its flexibility and adaptability [8]. Therefore, additive manufacturing for 3D modelling not only enhances the efficiency of manufacturing but also supports economic sustainability and customization, catering to the needs of modern manufacturing practices.

One significant hurdle in Braille integration into 3D models is the necessity of modifying the models to accommodate Braille tactile features. While Braille can be added to simple models relatively easily, the challenge escalates when dealing with more intricate designs. For complex 3D models that require Braille integration, the model must first be deconstructed into a flat sketch that aligns with the ground plane rather than being directly applied to the model's face. This process ensures that the Braille is uniformly accessible and legible for touch-readers. Adapting the model in such a manner requires careful consideration of the spatial arrangement and dimensions of Braille dots to maintain their tactile functionality and ensure that the sizing aligns with standardized requirements for Braille legibility. This transition from a 3D surface to a 2D sketch can be time-consuming and demands precision, as any errors in the placement or sizing could render the Braille ineffective for users [9]. Consequently, the integration of Braille into complex 3D models not only involves technical design challenges but also necessitates a deep understanding of Braille standards to create an accessible and practical result.

Incorporating Braille enhancement into 3D printing significantly influences the design process, as it requires designers to consider tactile features that are accessible to visually impaired users. This consideration is crucial as it alters the standard approach to the object creation by placing emphasis on textural details and the user interaction. For example, the integration of Braille labels into 3D printed graphics is a transformative step that not only makes these items accessible but also adds a new dimension to tactile learning and environmental customization [10]. The flexibility of 3D printing technology is exemplified by the different information systems and software, which can merges full-colour graphics in Braille, allowing for a rich multisensory experience [10]. Moreover, this enhancement circumvents the traditional barriers faced by visually impaired individuals, such as the lengthy waiting periods for shipped Braille items and the high costs associated with specialized Braille embossers [10]. The design process must now accommodate the variability of 3D printers, as each printer may produce different Braille sizes and qualities, necessitating a calibration print to determine the optimal settings for each device [9]. Therefore, Braille enhancement not only broadens the scope of 3D printing applications but also demands a more thoughtful, inclusive approach to design that addresses the needs of a diverse user base.

The main seven categories of additive manufacturing, including material extrusion, sheet lamination, binder jetting, material jetting, directional energy deposition, powder layer fusion and photopolymerization, where each of these technologies require different materials, layering, etc. [11] which are also factors affecting the quality of Braille font formation. The choice of the appropriate additive manufacturing technology affects the accuracy and legibility of 3D-printed Braille models [12].

3. Determining the importance of factors influencing the processes of creating Braille three-dimensional models in additive manufacturing

The direction of our research on additive manufacturing processes is focused on the factors and processes that affect the quality of creating three-dimensional models and the formation of Braille on them. In this research, a number of key factors and processes are identified that can affect the quality of creating three-dimensional models with Braille relief-dot font and the ability to tactilely read information from them by visually impaired people. Another area of research studies is the role of additive manufacturing processes. The study of processes and influencing factors refers to complex processes in additive manufacturing that cannot be characterized by certain values that could be used in calculations. From a review of the literature, it is known that such calculations can be performed by a number of methods, including the analytic hierarchy process method and the ranking method, which have proven themselves well in practice. This study will use the Analytical Process Hierarchy method because it uses dimensionless factor values, thereby neglecting to reduce the studied values to the same dimensions. This method was proposed by the American mathematician T. Saati, which is based on a pairwise comparison of factors that are selected with the help of respondents and are recognized as important when considering this process. This method uses a pairwise comparison scale, which has proven its feasibility in practice and has shown good research results.

3.1. Determining the priority of factors influencing the quality of creating Braille models in additive manufacturing

Determining the priority of factors that influence the process of Braille formation in additive manufacturing involves a multifaceted approach. The key factors to consider are presented here. Let one look at the formulas for calculating each additive manufacturing process that affect the quality of 3D models:

$$f(ab) = \begin{cases} 0, if\ factor\ ii\ does\ not\ drpend\ on\ factor\ ab \\ 1, if\ factor\ ii\ depends\ on\ factor\ ab \end{cases}, \quad (1)$$

Material Properties: The type of material used in additive manufacturing can significantly affect the quality of Braille dots. Properties such as hardness, elasticity, and melting temperature need to be considered.

Material suitability index could be calculated as:

$$RP = \frac{Hardness + Elasticity}{Melting\ Temperature}, \quad (2)$$

A comparison table listing materials and their corresponding MSI values (Table 1):

Table 1
Table of materials and their values MSI

Material	Hardness (H)	Elasticity (E)	Melting Temperature (MT)	MSI (H+E/MT)
ABS Plastic	103	2.1	200 C	0.525
PLA Plastic	83	3.3	180 C	0.480
PETG	104	2.8	260 C	0.411
Nylon	110	1.2	250	0.444

Printing Resolution: The resolution of the printer determines the clarity and readability of the Braille dots.

$$RP = \frac{Nozzle\ Diamentr}{Layer\ Hight}. \quad (3)$$

Dot Height and Spacing: The height and spacing of Braille dots are crucial for tactile readability.

$$DHS = Dot\ Height \times \frac{Dot\ Spacing}{Dot\ Diametr}. \quad (4)$$

Printing Speed: Faster printing can lead to imperfections in the dot formation.

$$PS = \frac{Optimal\ Speed}{Actual\ Speed}. \quad (5)$$

Environment Factors: Temperature and humidity can affect the printing process.

$$EF = \frac{1}{Variability\ in\ Temperature + Variability\ in\ Humidity}. \quad (6)$$

User's Sensory Testing: The end-user's ability to perceive tactile information can vary, affecting the design parameters for Braille.

$$UST = \frac{Tactile\ Sensitivity}{Age\ Factor}. \quad (7)$$

As described in our studies, in general the results show that for optimal settings for Braille generation, thin layers and high printing speeds can reduce the percentage error, and for maximum accuracy, a layer thickness of 0.11 mm is preferred. In addition, dense infill and high printing temperature can optimize dimensional accuracy in the Z direction [12]. The study proposes a set of optimized parameters for 3D Braille printing, including 47% infill, 95.8 mm/s printing speed, and 226 °C printing temperature. which is assumed to result in a percentage error of 0.06% [12]. However, it is important to note that the optimal parameters may vary depending on the specific printer and 3D printing technology used [12].

These factors can be prioritized based on the specific requirements of the Braille readers and the capabilities of the additive manufacturing setup. It is also important to conduct empirical studies to validate the influence of these factors on the Braille formation process.

3.2. Selection of factors influencing the quality of creating Braille models in additive manufacturing

In the process of conducting scientific research and analysis of factors influencing the creation of 3D models with Braille formation in additive manufacturing, factors influencing the result and the quality of the resulting Braille three-dimensional model using the additive method are identified. The key factors and processes that can influence are identified here.

Factors that affect the creation of models with a relief dot font:

Level 0 - software for creating Braille 3D models on the model.

Level 1 - the difficulty of creating a model and text. It includes the size, orientation of the model (whether there is a need for temporary stands and materials that are removed after printing), indents, text size, texture, etc.

Level 2 - software slicers (pre-press preparation). print settings, model location, 3D printer settings.

Level 3 - type of 3D printing, SLS, SLA, FDM, DLP, etc.

Level 4 - the type of 3D printer and its ability to print complex models.

Level 5 - selection of materials for printing. also depends on the type of 3D printer and printing.

Level 6 - manufacturing environment. the influence of temperature on the creation of the model and other external factors.

Level 7 - post-press processing. the effect of chemical treatment on Braille quality on models.

A comparative diagram of factors affecting the quality of a Braille 3D model in additive manufacturing is created (Table 2).

A scientific analysis and study of each factor (Figure 1) that affects the creation and quality of 3D models of Braille formation in additive manufacturing, each factor, and the interrelationships between other influencing factors are carried out.

Analysis of each factor and its influence on other factors:

Level 0 - software for creating 3D models. The software used to create the models has an influence on the creation and quality of Braille 3D models. It also depends on the complexity of the software, its capabilities, and professional skills of using the software and its tools of the user himself. This requires an understanding of the software that can meet the needs for creating quality models with dot embossing. Also an important factor is the ability and knowledge of the user to use programs, so it is not enough to know only software such as CAD systems, for example, Autodesk Fusion 360, SolidWorks, AutoCAD, Autodesk 3DS Max, Blender, OpenSCAD, etc., but also to improve skills working with them and understanding the principles of operation of these programs and understanding in which situations and for which models they should be used.

Table 2
Influencing factors and their processes

Factors	Influence on 3D Model	Details
Level 0	software for 3D-Models with Braille font	AutoCAD, Fusion 360, Solidworks, etc.
Level 1	hard of 3D-Model creation and text Braille	Orientation, size, temporary stands, indents, texture, text, contrast
Level 2	software slicers and include print settings	Location, model, support Brim, Raft, etc.
Level 3	types of 3D-Printing	SLA, SLS, FDM, DLP, MJF, DMLS, PolyJet, EBM
Level 4	types and brands of 3D printers and complexity	Ultimaker, Prusa, Elegoo, Formlabs, CraftBot, Creality, etc.
Level 5	types of materials	ABS, PLA, PETG, Nylon, TPU, PVA, HIPS, Composites, combination of materials
Level 6	environment	Temperature, room, light, etc.

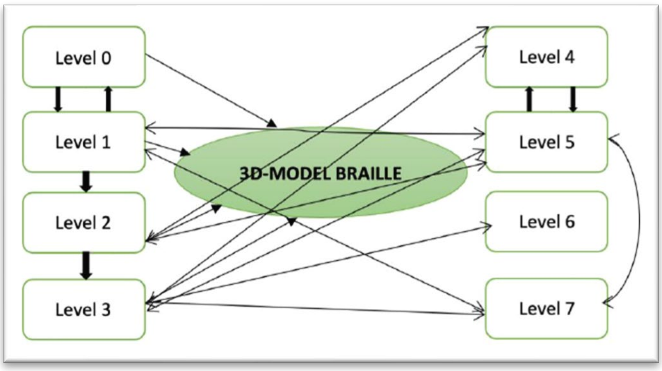

Figure 1: The initial graph of the relationship among the factors.

0 ⟶ 1 ⟶ 3D model – this factor affects the complexity of creating a three-dimensional model (Braille application, model formation, dimensions, scaling, etc.), software capabilities and its functionality, the possibility of Braille integration, as well as quality final finished three-dimensional model and the ability to read information by people with visual impairments.

Level 1 - the difficulty of creating the three-dimensional model itself. There are many different 3D models and texts of varying complexity. For example, if the 3D model is quite complex, where there may be uneven surfaces (cylinders, circles, models with folds), complex and voluminous text with various symbols. This factor also includes factors such as size, orientation, indents, text size, texture, and the need for temporary stands and materials. The complexity of the model and text affects the overall quality and file size of the 3D model, leading to different results in the 3D printing process [1].

1 ⟶ 5 ⟶ 3D model – the complexity of the 3D model and the complexity of the text to be translated into Braille affect the selection of 3D printing materials to be used. There are many materials, from plastic to metal, etc. This can affect the result and the quality of the created model and the quality of the Braille font. Therefore, the selection of materials for 3D printing must begin at the stage of creating models, as this can affect the result and quality.

Level 2 - software slicers (pre-print preparation): the pre-print preparation stage involves the use of software slicers to convert the 3D model into a format suitable for printing. Printing settings, model placement, and 3D printer settings play a critical role in determining the quality of the final product and its compatibility with the chosen printing method [2].

2 ⟶ 3 ⟶ 4 ⟶ 5 ⟶ 3D model – slicer software is specialized software that forms 3D models into a set of instructions for 3D printers (G-CODE). They affect the result and quality of the models the most. Slicers influence selection. Materials and vice versa, since different software slicers support different materials, and not all slicers can support all materials for 3D printing. Slicers have the ability to adjust the temperature, flow, speed depending on the choice of material. This factor also affects the type of additive technology, 3D printing. Since there are quite a few slicer programs, each slicer may support one or another type of additive manufacturing, while other programs may not. Among these, the selection of slicer affects the selection of 3D printer brand. There are many brands of 3D printers, and they have their own specifics and capabilities, so when choosing a brand of a 3D printer, it will depend on the slicer program, and vice versa. In summary, slicers affect almost the entire process of creating Braille models and the final result and quality of those models. Therefore, if the result of the model is not of high quality, it is worth analysing the programs and choosing a slicer that is able to meet the needs.

Level 3 - type of 3D printing: the choice of 3D printing technology, such as SLS, SLA, FDM DLP, etc., affects the quality of 3D models. Since there are many types of 3D printing, each printing method has its advantages and disadvantages, and affects the selection of materials [3].

3 ⟶ 4 ⟶ 5 ⟶ 6 ⟶ 7 ⟶ 3D model. The selection of the type of 3D printing affects the selection of materials. Because different types of 3D printing require certain materials, such as plastic, metal, powder, resin materials. In addition, materials have their own properties that are suitable for certain types of 3D printing.

Moreover, the selection of the type of 3D printing affects the selection of 3D printer of different brands. Because each 3D printer offers its own capabilities and manufacturing technologies. For example, Ultimaker, Prusa, Creality, Anycubic, etc. - these are popular brands of FDM/FFF printers, Formlabs, Anycubic, Elegoo, etc. also popular brands of SLA/DLP printers. HP, EOS, 3D are brands of SLS/SLM/MJF printers, etc.

Regarding the external environment, or premises, also affects the selection of 3D printing technology. Some 3D printers, such as FDM/FFF can work in home or office environments but can be sensitive to air and temperature changes in the room. While SLA, DLP printers are light sensitive. SLS/SLM/MJF printers may require special rooms with temperature control and ventilation because they work with high temperatures and powders that can be harmful to health.

Also, depending on the type of 3D printing, it affects post-press processing, since it is necessary to determine which chemicals can negatively affect the quality of the three-dimensional model. Therefore, depending on the type of 3D printing, it is necessary to carefully approach the processes of post-press processing.

Level 4 - type of 3D printer and its ability to print complex models and high-precision details, such as Braille: The capabilities of the 3D printer you choose directly affect the quality and level of detail of the finished model. 3D printers with high accuracy and the ability to create complex models will give the best results, especially for the needs of creating fairly complex models and Braille.

4 ⟶ 2 ⟶ 3 ⟶ 5 ⟶ 3D model. The type or brand of 3D printer affects the choice of slicer software because each 3D printer brand has its own specifics, and not every slicer supports certain brands of 3D printers. Also, the brand of the 3D printer affects the type of 3D printing because each 3D printer supports one or another type of 3D printing. The main factor influencing the selection of a brand of 3D printers is the type of materials. Since there are many types of materials, such as ABS plastic, rubber, ASA, PLA, Nylon, etc. Therefore, before choosing a 3D printer brand, it is necessary to take into account what materials will be used, what type of 3D printing and slicer programs, since such factors affect the quality of the final result of the 3D model.

Level 5 - the selection of materials is a particularly important component in the creation of models in additive manufacturing, which affects the quality of the model, durability, reliability, accuracy, and the ability to qualitatively read information by people with visual impairments.

5 ⟶ 1 ⟶ 2 ⟶ 3 ⟶ 4 ⟶ 5 ⟶ 7 ⟶ 3D model. This factor, the selection of materials is interconnected with the selection of slicer software, the complexity of creating a 3D model, the choice of type of 3D printing and the selection of post-press chemicals. Since chemicals affect the material in one way or another, some materials can be sensitive to certain chemical elements, which can negatively affect the quality of the models. The selection of materials for 3D printing is the main factor affecting the final result of the finished 3D model.

Level 6 - – the manufacturing environment and external influences such as temperature, humidity and other environmental conditions can affect the 3D printing process and the quality of the 3D model.

6 ⟶ 3 ⟶ 3D model. Since some types of 3D printing and materials can be sensitive to light, temperature, etc.

Level 7 – Post-Print Processing: Chemical processing and additional processing of the printed 3D model effect the quality of the finished model, the ability to read information qualitatively, and its further longevity and reliability.

7 ⟶ 1 ⟶ 3 ⟶ 5⟶ 3D model. A thorough approach to post-press processing, which includes chemicals and elements that affect one or another material of the model, and additional tools for processing. This will ensure the quality, reliability and durability of the model.

4. Results — construction of a multi-level structured model of priority of factors

With the help of the obtained results of calculations of iteration levels, a multilevel structured model of the priority of influencing factors affecting the quality of Braille font formation in additive manufacturing is constructed Figure 2.

Here a hierarchical model of factors is obtained whose priority influences the quality of creating 3D models with embossed dotted Braille.

The highest priority or factor is Level 5 is the selection of materials. The material is a key factor in what the final 3D model will be, and the ability to read text by blind people. Level 3 received the type of 3D printing as an equally important factor. Level 7 post-processing, despite the choice of materials and type of 3D printing, post-processing can affect the quality of the 3D model, such as chemicals, removal of suspensions, etc. Level 2 and level 4, the choice of 3D printer and slicer is also an equally important factor. The least important factors were the complexity of the 3D model, the selection of software and the environment, although these factors should also be considered when creating 3D models.

Based on these factors, experimental research and calculations were carried out, with the creation of a Braille 3D model, as a result of which it was confirmed that the choice of material for 3D printing has the greatest impact, since each material has certain properties. Also, the type or technology of 3D printing is a key influencing factor. Other factors are no less important and affect the quality of creating models.

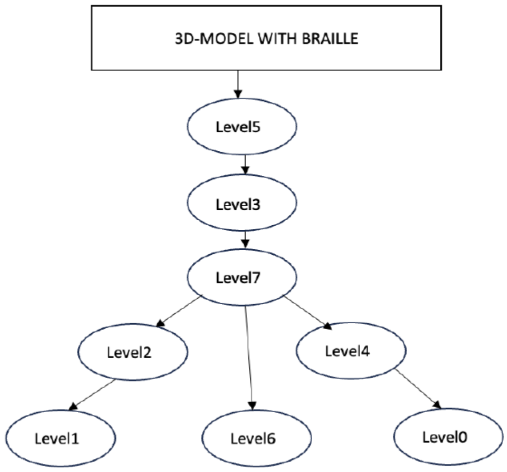

Figure 2: Hierarchical model of factors that influence the quality of creating Braille 3D models.

5. Discussion

Creating a three-dimensional model in additive manufacturing is a rather complex technology with many different processes, and with many different factors that affect the quality of creating models, including the Braille formation. Considering these influencing factors at each stage of the manufacturing process will prevent defects and improve the final result, while ensuring high quality and reliability of three-dimensional models, including Braille models. These manufacturing processes or factors are interrelated one by one, selecting this or that technology, model, a brand of 3D printers, materials are dependent on each other. Since the wrong selection of this or that technology can reach a lot of financial costs on the part of manufacturers. Therefore, understanding the principles and factors that influence and are related to each other will help to more carefully approach the creation of models in additive manufacturing. This gives the result of approaching with an analysis of the selection of certain technologies, satisfying the needs, and will speed up manufacturing processes and improve the quality of creating models. Further research into materials, types of 3D printing, brands of 3D printers, and software will facilitate the process of creating models for people with visual impairments. By analysing these technologies, it will make it possible to improve manufacturing processes and initiate integration in inclusion.

But on the other hand, further research is needed, but later, we can come to the conclusion that in future research, attention will be focused on the application of information systems, such as artificial intelligence, computer vision, neural networks, which will allow avoiding flaws and factors at the production stage, from creating a digital model to carrying out post-printing processes. Also, one of the methods of using artificial intelligence is to combine generative models of artificial intelligence based on API into a unified system, which is a significant step in the direction of process automation, not only for creating digital content, but also for additive manufacturing processes, to satisfy modern market requirements. By simplifying content creation workflows, such integration promises increased efficiency and scalability while fostering creativity and innovation. In addition, the integration of generative models of artificial intelligence into a single system opens up opportunities for the development of personalized and innovative solutions adapted to the needs and preferences of end users [12]. Therefore, the use of artificial intelligence will make it possible to speed up production processes even more, improve the quality of creating three-dimensional models, and allow to automate processes, thereby obtaining financial and economic benefits.

6. Conclusion

Overall, the research and study of additive manufacturing processes for creating haptic models have helped to shed light on how each manufacturing process can affect the quality of Braille models and provided valuable information on how each process, such as type selection, 3D printing, 3D- printer, materials, software, post-press processing, the complexity of creating a 3D model have the greatest impact on the quality of creating tactile models. The special role of using a careful approach to the use of this or that technology at the stages of processes in additive manufacturing is also noted.

As a result of the conducted research, we will receive the following perspectives and novelty: for the first time, the factors that influence the quality of the creation of Braille 3D models at each stage of the additive manufacturing process have been identified, on the basis of which a semantic model and a hierarchical model with influencing factors from the highest to the lowest have been built. This makes it possible to: 1) improve the quality of additive manufacturing processes from the creation of a digital prototype to model reproduction and post-printing processing, 2) improve the quality and expand accessibility to various spheres of life for people with visual impairments, 3) speed up the reproduction processes of Braille models and financial and economic benefit, without the need to conduct experiments to identify factors that affect the quality of reproduction of models. But the other side of this study has certain limitations, since this work investigated general factors that affect the processes of reproduction of Braille models. For in-depth research, it is necessary to decompose each factor into sub-factors, for example, materials for 3D printing, because there are many types of materials with different chemical and physical properties, and each material has its own advantages and disadvantages. Likewise, in relation to other factors, such as 3D printing technologies, 3D printers, etc. Future research will focus on the identified factors, such as the temperature for applying a layer to the model, the working mechanisms of 3D printers, etc. As well as the creation of new information systems that will be integrated at every stage of the additive manufacturing process, from the creation of a digital prototype to the elimination of defects after printing.

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References

[1] How can you improve 3D model performance, quality, and file size? URL: http://www.linkedin.com/advice/0/how-can-you-improve-3d-model-performance.

[2] M. Teplá, P. Teplý, P. Šmejkal, Influence of 3D models and animations on students in natural subjects. IJ STEM Ed 9, 65 (2022). https://doi.org/10.1186/s40594-022-00382-8.

[3] J. Bashyal. 3D Printing: Working Principle, Application, Advantages, Disadvantages. URL: https://scienceinfo.com/3d-printing-working-principle-application-advantages/.

[4] What is 3D Printing. URL: http://www.createeducation.com/about-us/introduction/.

[5] Additive Manufacturing Overview. URL: https://monroeengineering.com/guide-3d-printing.php.

[6] R. Linke, Additive manufacturing, explained. URL: https://mitsloan.mit.edu/ideas-made-to-matter/additive-manufacturing-explained.

[7] What is 3D Printing? URL: https://3dprinting.com/what-is-3d-printing/.

[8] I. Guicciardini, Introduction to Additive Manufacturing: definition, how it works, applications. URL: https://www.roboze.com/en/resources/introduction-to-additive-manufacturing-definition-how-it-works-applications.html.

[9] Easy 3D Printed Braille to Add to Everything! URL: https://www.instructables.com/Easy-3D-Printed-Braille-to-Add-to-Everything/.

[10] 3D Braille Printing (Amazing Use-Cases). URL: https://www.elegoo.com/blogs/3d-printing-projects/braille.

[11] N. Tarasov, O. Khamula, Influence of additive technologies and selection of materials on the quality of 3d printed Braille models. 2(86) (2023). URL:http://pvs.uad.lviv.ua/static/media/2-86/14.pdf.

[12] O. Pavlova, A. Kuzmin, Analysis of artificial intelligence based systems for automated generation of digital content URL: https://elar.khmnu.edu.ua/server/api/core/bitstreams/453b5330-f71a-432e-bbbb-b74b391ad216/content