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An approach towards the development of an inclusive subject environment using additive manufacturing technologies

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Article Info

ABSTRACT

This research aims to identify the principles of designing the objects of the inclusive environment with the employment of additive manufacturing technologies, and to discover methods and techniques for creating an inclusive objective environment using the example of our own development. The results of the survey, which has been directed to investigate the topicality of the problem of inclusiveness in Ukraine and the means of its solution, are presented in the article. In the course of work, the principal peculiarities of three-dimensional (3D) modelling and printing technologies have been established, and promising areas of their application have been proposed. The principles of designing an inclusive objective environment have been detected with the use of photogrammetry and 3D printing, due to which the model can be constructed by considering a person's individual physical characteristics. Moreover, due to the wide range of materials for 3D printing, various types of objects can be realized. It gives great potential for the employment of 3D printing when designing an inclusive environment and considerably simplifies the manufacturing process while taking the individual characteristics of every person into consideration.

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1. INTRODUCTION

The number of disabled people is considerable in the world as well as in Ukraine [1]. According to the State Statistics Service of Ukraine, as of January 1, 2019, there were 2 million 659,7 thousand people with disabilities [2]. It amounts to 6.3% of the total population and in the wartime and postwar period, their share will increase significantly. Providing disabled people with an accessible environment, which is the component of creating an inclusive environment, is a highly topical problem nowadays. Three-dimensional (3D) technologies, namely photogrammetry [3] and 3D printing [4], may play an essential role in creating an inclusive environment [5].

The options of employment of 3D printing for designing an inclusive environment have been discussed at the Global Technology Governance Summit which was held online on the 6th-8th of April in 2021 [6]. Currently, many organizations around the world are experimenting with the solution to the problem of accessibility with the help of innovative technologies. For instance, the Venus Arm project, developed by

young scientists with the support of the United Nations Children's Fund (UNICEF), employs 3D printing technology to create bionic prostheses while reducing the price of an artificial arm to 1/30 of the average price [7], [8]. Such international organizations as the International Committee of the Red Cross also use prostheses created with the help of 3D printing in developing countries. Hence, 3D printing technology has enormous potential.

One of the cases of employing 3D technologies for designing inclusive environments is discussed by Auricchio et al. [9]. In the course of this research, the peculiarities of creating a 3D model of the tactile map for the Museum of Electrical Technology in Pavia, Italy, are examined. Additive manufacturing technology has been chosen for developing the above-mentioned maps. The author determined the following number of its virtues: i) Flexibility and ability to customize (inasmuch as developers can make the necessary adjustments such as the size of the objects, the presence of certain details, and so on with the help of 3D editors); ii) Reduction of manufacturing waste; and iii) The vast choice of materials, most of which are durable and ecologically safe.

Based on the advantages described above, the author acknowledges that 3D development and 3D printing technologies are the most suitable for the declared aim. Besides the above-mentioned virtues of 3D printing, it is important to mention that 3D printing is economically effective [10]. The employment of 3D printing reduces the electricity consumption, the need for human resources, and CO_2 emission associated with it throughout the life cycle of a product. Also, 3D printing [11] causes changes in labor structure and generates improvement in the digital sphere.

The ability to use the photogrammetry method [12], [13] to design an inclusive environment was observed at the conference called "International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)" that was held in 2019 in Jakarta, Indonesia. The ability to employ the photogrammetry method to produce the prosthesis for the amputated limb was described in research [13]. In this case, the 3D model is designed by photographing the rest of the amputated limb, and, after that, it is reproduced in photogrammetry software and is used as a reference for designing prostheses for the limb with the help of other modeling technologies. 3D printing is employed to produce the prosthesis.

Though there are not many examples of the use of 3D printing for designing an inclusive environment [14], this area is rather promising and can fairly simplify the production process [15]. Since there is still a large field for research on this topic, it has been decided to explore the principles of designing inclusive environments with the employment of 3D technologies and to develop the algorithm for designing inclusive environments with the help of photogrammetry and 3D printing by creating our own original development.

The main contribution of this article can be summarized as follows: i) We have used an expert assessment method to determine the topicality of the problem and to outline possible ways of solving it; ii) We have studied and described the principles of designing elements of an inclusive environment using photogrammetry and 3D printing technologies; iii) We have shown methods and techniques to create objects of an inclusive environment based on the example of our own application; and iv) We have developed a new original design of a graphic pen nozzle using photogrammetry with 3D printing reproduction.

2. METHOD
2.1. Problem determination using the expert assessment method

This paper aims to explore the principles of designing objects in an inclusive environment and to offer a new and original design of the graphic pen nozzle and how to create it using photogrammetry with 3D printing reproduction. It is necessary to determine if the problem is topical and to outline its possible solution to achieve the declared aim. One of the methods of expert assessment [16] is used for it. This method consists of surveying a certain group of people. The questionnaire should include questions related to the research problem and can be sent online [17], [18]. In this case, the questionnaire has been created with the use of the Google Forms website [19]. The link to the form has been sent to the potential respondents via messengers such as Viber and telegram as well as via Instagram social media.

The survey is divided into two parts [20]. The first part is aimed at exploring the topicality of the problem of inclusion in Ukraine as well as possible ways of its solution. The second part of the questions is designed to analyze the respondents' experience in using the graphics pen to be able to outline general requirements for future development.

A total of 73 people has been surveyed. According to age, the respondents can be divided as follows: adolescents (between the ages of 0 and 17): 8 people; the youth (between the ages of 18 and 35): 53 people; the middle-aged (between the ages of 36 and 60): 7 people; the elderly (above 61 years old): 5 people. Of these, 59.3% (43 people) are women and 41.1% (30 people) are men. Residents of several Ukrainian cities participated in the survey. The number of respondents according to the cities: L'viv: 25 people, L'viv region (Stryi): 1 person; Kyiv: 21 people, Mykolaiv (the center of the region): 25 people.

Also, one person from Kamianske (Dnipropetrovsk region) took part in the survey. 6,8% of respondents (5 people) have a certain form of disability. 4 out of 5 people belong to the category of elderly people, one person – to the middle-aged category of people. The respondents were asked if they considered the city in which they live to be sufficiently provided with elements of an inclusive environment. Only 11% of respondents (8 people) believe that their city is sufficiently equipped with elements of an accessible environment. All 8 respondents that answered 'Yes' are residents of Kyiv and do not belong to the category of people with disabilities. Instead, disabled people living in Kyiv have chosen the "no" option. Only 8.2% of respondents (6 people) answered 'Yes' to the question "Are you satisfied with the quality of existing elements of an inclusive environment in your city?". All of them are also residents of Kyiv and do not have any disabilities.

The next question allowed respondents to choose several options. The question was as follows: 'If you have answered "No" to the previous question, then, what exactly does not suit you? Among the answers, there were: the objects of an inclusive environment are decrepit and it is frightening to use them; the elements of an inclusive environment start to develop and are imperfect; the elements of an inclusive environment are not suitable (convenient) for everyone; poor quality of the materials (fragility and unreliability). Besides these, respondents had an opportunity to add their options. The options of answers and the percentage ratio between them can be observed in Figure 1.
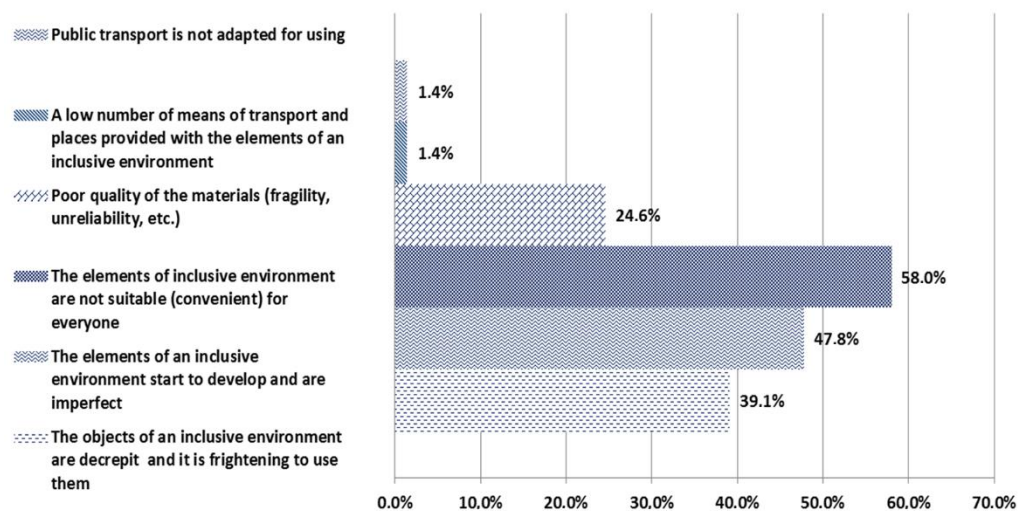

Figure 1. Factors that do not suit the respondents regarding the elements of an inclusive environment in their cities

Thus, based on Figure 1, people consider unsuitable (inconvenient) elements of an inclusive environment to be the biggest problem, as 40 people (58% of respondents) have chosen this option. This option has been chosen by the representatives of each of the cities listed in the survey. According to the number of answers, the next option is "elements of inclusive environment start to develop and are imperfect". It has been chosen by 33 people (47.8% of all respondents).

In order to finally determine the character of our development, the second part of the questionnaire has been created. The questions in this part are intended for the people who use (or have used) a graphics pen. The answers to this part will help analyze the respondents' experience in using the pen and draw conclusions regarding the need to develop a 3D model of a graphics pen attachment as well as the main aspects of developing a model.

The analysis of respondents' answers to the second part of the questionnaire revealed that 26 out of 73 people use a graphics pen, so the percentage ratio in diagrams henceforth will be calculated relative to the number 26. Most respondents who have a graphics pen use it for 2-4 hours per day. A more detailed distribution of answers can be observed in Figure 2.

As a result of the study, it was found that most people (65.4%) sometimes feel discomfort while using a graphic pen. Nevertheless, a small number of respondents (19.2%) never feel such discomfort, while 15.4% note that this discomfort occurs to them often, as shown in Figure 3. These results highlight the importance of research into the ergonomics of graphic pens for improving user comfort.
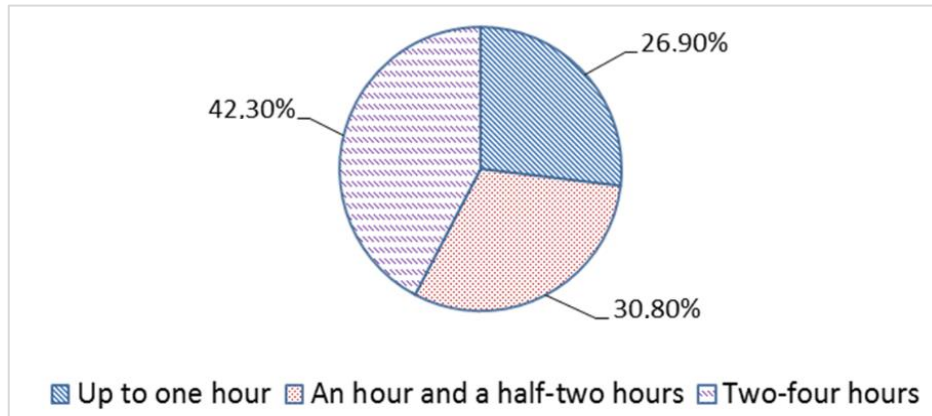
Figure 2. The number of hours that the respondents use a graphics tablet per day
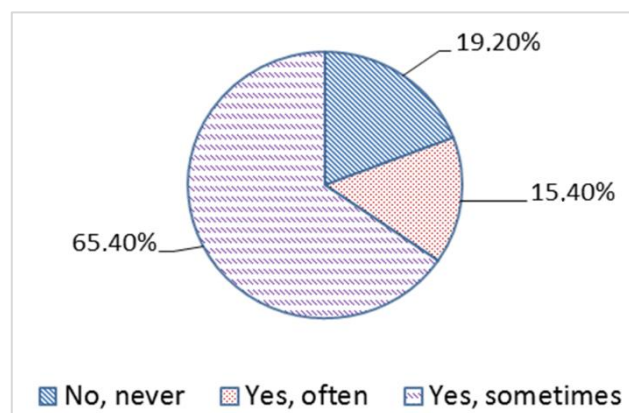

Figure 3. The number of respondents feeling discomfort while using a graphics pen

The next question allowed choosing several options of answers. Respondents have been asked to choose which of the factors cause discomfort. The option "the hand becomes tired when using the pen for a long time" has received the biggest number of answers. It has been chosen by 19 people (79.2% of respondents). The second most popular answer was the option "a pen sometimes slips out of the hand". It has been chosen by 33.3% of respondents (8 people). In addition, 6 people (25% of respondents) have chosen the option "the material of which the pen is made is too hard and not elastic" while three more people have chosen the option "the material of which the pen is made is tactilely unpleasant". The processed results in the form of a diagram can be seen in Figure 4.

In the course of the survey, it has appeared that 88.5% of respondents wanted the graphics pen to be improved and 96.2% of people would like to have an elastic and tactilely pleasant attachment to the graphics pen. The next question also had several possible answers and was aimed at identifying the reasons why respondents did not buy an attachment to the graphics pen. It appeared that the main reasons why the users of graphics tablets did not buy a graphics pen attachment were the following: attachments to the particular model of pen do not exist (this option has been chosen by 42.3% of people or 11 respondents); an attachment to the particular model of a pen is difficult to find in the respondent's city/country (this has also been chosen by 42.3% or 11 respondents). Also, 8 people have marked that none of the existing attachments is convenient for them. Three more people have noted that the purchase of the attachment costs too much. The distribution of the answers in the form of a diagram can be seen in Figure 5.

According to the results of the study, 96.7% of respondents answered "yes" to the question of wanting to learn the process of developing and using a 3D printer to create an application that perfectly fits their graphics pen and hand. This shows the great interest in using 3D technologies to create an inclusive environment. The research shows that learning about the design process of such an application can be useful to a wide range of people.

The last question of this part had the following meaning "In the course of the research, the algorithm for creating an inclusive environment with the help of 3D technologies will be developed. Based on this algorithm, a graphics pen attachment that is developed for the individual characteristics of each person will be designed. This attachment will support a thumb since it will help hold a pen in hand without fatigue. Who do you think needs this development the most?". The answer to this question was compulsory, and that is why all 73 respondents answered it. This question also allows choosing several options. Most of the respondents (78.1% or 57 people) have chosen the option "everyone". Also, 43 people believe that disabled people need this product, 36 people think that the elderly need it, 35 people – children, and only 1 person claims that it is suitable for indigent people.

When analyzing the respondent's answers to the second part, it can be concluded that most respondents sometimes feel discomfort while using a graphics pen and would like to purchase a comfortable attachment to a graphics pen but are unable to do so for a number of reasons, as shown in Figure 5. Hence, the research on the process of creating an inclusive environment with the help of 3D technologies using the example of designing an attachment to a graphics pen is strictly necessary. Almost any object can be designed with the help of 3D technologies while taking the characteristics of each person into consideration. Therefore, it is important to develop a clear and effective algorithm for designing elements of an inclusive environment.
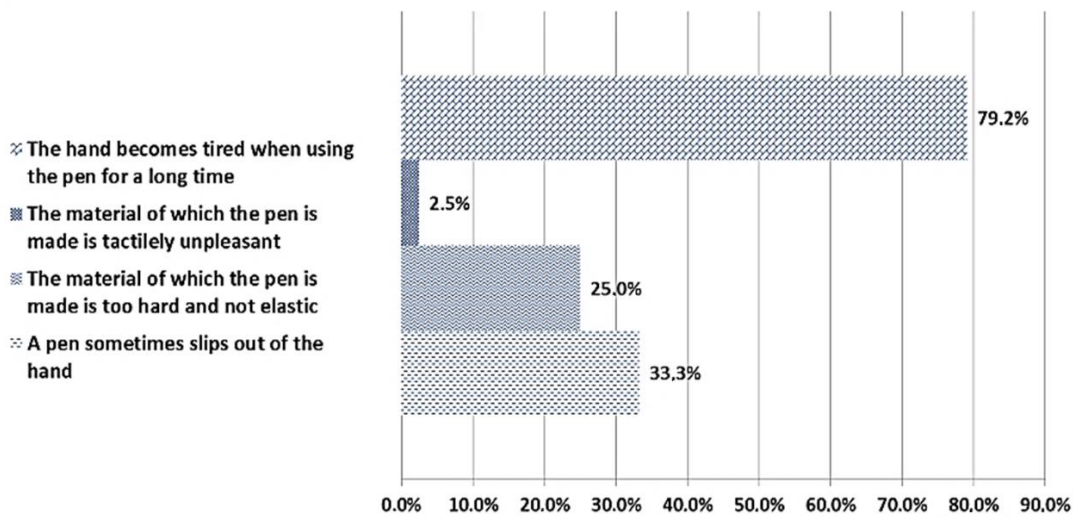

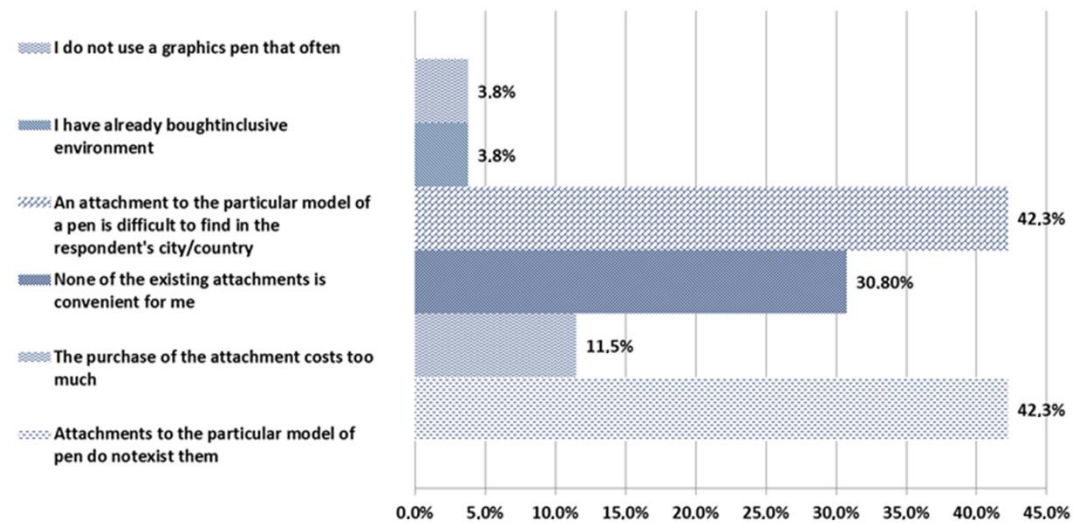Figure 4. Factors that cause discomfort to respondents when using a graphics pen

Figure 5. Reasons why respondents did not buy a graphics pen attachment

2.2. The choice of materials and printing method

As it was mentioned before, the process of each type of additive 3D printing is based on the layer-by-layer application of material to the product based on the corresponding digital data [18]. To choose the most optimal printing method, the most popular of them were examined: fused deposition modeling (FDM) and stereolithography (SLA) [21]. In the course of the research, it was discovered that the FDM method is faster and cheaper; however, it is inferior to the SLA method in accuracy as well as in smoothness of the material. Inasmuch as an attachment is designed for particular characteristics of a person's hand and the probability of using it for a long time should be tactilely pleasant, the accuracy and smoothness of the material are extremely important factors.

That is why it has been decided to use the SLA printing method. Besides it, SLA printing has got a bigger number of materials available, including rubber plastics. Flexible 80A Resin and Elastic 50A Resin have been considered as the possible printing materials. The assessment has been done with the help of three main parameters: hardness of a material, rupture strength and stretching strength. All three parameters are essential. If the material is too hard and not elastic, it will be uncomfortable for the person to attach it to the graphics pen as well as to place a finger into the attachment [22], [23]. In addition, based on the conducted survey, the excessive hardness of a pen's material has been considered a significant disadvantage by respondents. If the material is not strong enough not to rupture or not to stretch, there is a probability that the material will deform or tear under active use. That is why it is important to have high strength indices.

The hardness of the material has been assessed using the shore scale [24]. The bigger the index, the harder the material. Both materials are placed in the A-class and thus they are soft types of plastics. Elastic 50A material has a hardness of 50A, a Flexible 80A Resin – 80A, which means that Elastic 50A is softer. Rupture strength is the measure of the minimum force required for a material to tear when being stretched [25]. This characteristic is measured with the help of a special testing rig for stretching as well as samples of individual materials. The higher the number, the higher the strength.

The threshold of variable mechanical pressure's value is called the dynamic limit of stretching strength [26]. If this value exceeds, the mechanical pressure will lead to the deformation of the object, which is made of the corresponding material. The higher the number, the more pressure the material can resist. Numerical indices of the properties of both materials can be seen in Table 1.

Table 1. Comparative characteristics of materials

Characteristics	Elastic 50A	Flexible 80A Resin
Shore hardness	50A	80A
Stretching strength (MPa)	3.2	8.9
Rupture strength (kN/m)	19.1	24

In the course of comparison, flexible 80A resin has been chosen [27]. This material is among the soft materials according to the shore scale and, although it is harder than Elastic 50A, it is stronger regarding rupture and stretching, thus it is more durable and more suitable for long use. Flexible 80A is one of the strongest materials among the series of flexible resins with the Shore hardness of 80A. This material imitates the flexible properties of rubber. Due to the successful combination of softness and strength, this resin can resist many cycles of compression and bending. Flexible 80A Resin has the following virtues: the ability to resist repeated use without deformation and cracking; the ability to resist bending and compression; the simplicity when using due to the fewer number of points of contact with supporting structures as well as a short hardening time; perfectly transparent. Flexible 80A Resin is often used for printing medical devices, prostheses, consumer goods, elements of mechanical engineering and robotics, theatrical scenery. So, this material is rather suitable for printing an attachment to a graphics pen.

2.3. The process of designing the model
2.3.1. Making a sketch of the model

Making a sketch is the first stage of designing a 3D model [28], [29] of an attachment to the graphics pen. Based on the results of the conducted survey, most of the respondents feel that their hand is tired when using a graphics pen for a long time. The second problem is that the pen slips out of hand while the third problem is the hardness of the material. Having summarized these aspects, the following requirements for a graphics pen attachment have been formed:
- Providing comfort when using an attachment for a long time. That is why it has been decided to develop an attachment that supports the user's thumb. The part, which supports the thumb, will immensely simplify the process of using a pen as the user will not have to strain the hand for the pen to stay in hand and not slip out.

- The choice of elastic and tactilely pleasant materials. This requirement is necessary to increase the user's level of satisfaction when using a graphics pen.
- Versatility of the attachment. This aspect means for each person to be able to adjust the attachment to themselves. For this reason, it has been decided to use a photogrammetric method of model development since this method can help take the individual characteristics of each separate person and peculiarities of any graphics pen (diameter and presence or absence of buttons) into account.

After having formed the main requirements, the basic measurements of a pen and a finger were taken, and a sketch [30] was made in the Adobe Illustrator environment. An attachment will be developed considering its peculiarities. The model of the graphic tablet for which the attachment will be modelled is Wacom Intuos Pro M. The created sketch can be seen in Figure 6.
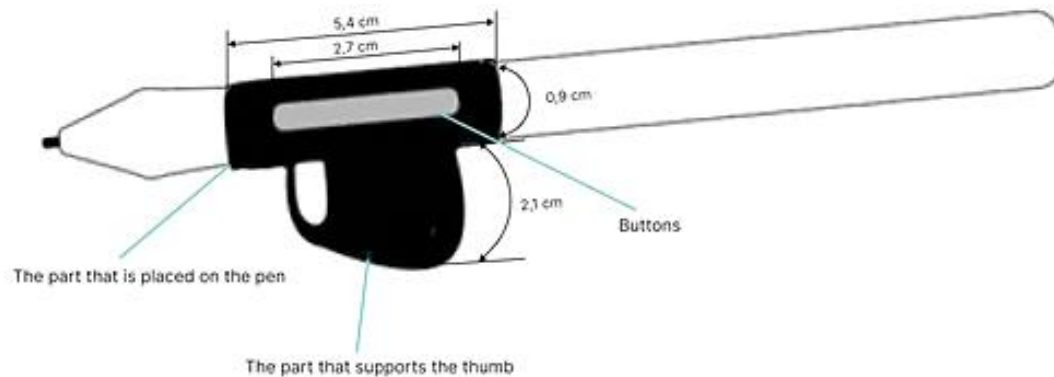

Figure 6. A sketch of a graphics pen attachment

The basic measurements that have been taken for further verification when creating a 3D model are: L1 is the length of attachment; L2 is the length of the first button; D1 is the diameter of a graphics pen; D2 is the diameter of a thumb's widest part. After receiving the finished sketch, it was analyzed for conformity with the above-stated requirements. After verifying that the designed attachment meets the requirements, developing a model proceeded to the second stage, namely prototype development.

2.3.2. Prototype development

The stage of prototype development [31], [32] is necessary in order to subsequently create 3D models with the help of photogrammetry while maintaining basic proportions and peculiarities of hand build. In addition to it, this stage is necessary to make sure that the initial idea and sketch are effective and convenient. The prototype development has been carried out with the use of sculptural plasticine. After all elements of an attachment had been made, they were combined with the graphics pen and tested for comfort. In the course of testing, it has been detected that the attachment suits the hand well and it is comfortable to use. The created prototype of an attachment can be seen in Figure 7.

Figure 7. Prototype of an attachment

2.3.3. Making a 3D model

Photogrammetry is used for model making, which involves the creation of a model based on photographs. Before starting the process of creating a model in the software environment, it is necessary to first take photos of the pre-molded prototype. Photographs of this prototype are used for further analysis and creation of a three-dimensional model.

a. Photographing the object

To make a 3D model, it is very important to get clear images without motion blur and depth blur [33]. For this, tripods or a fast shutter speed should be used to avoid motion blur. Besides this, it is necessary to avoid transparent, shiny or too dark materials of photographed objects. To ensure photographs are of good quality, it is necessary to dispose of the strong shadows that the object casts. Also, it is important for the lighting to be constant during the photo shoot, and the camera, photographer, and other moving objects not to cast their shadow on the photographed object. If the lighting changes or unknown shadows appear in the photos, it will be more difficult for the model making program to detect the object's position in the photos.

Material, which the object is put on, should not have a very marked texture, otherwise, it will have to be removed manually in the 3D model manipulation software. It should be photographed from all possible angles without moving the object. Also, detailed photographs of certain parts of the object can be done. The more photographs there are, the better the 3D model the program will make. In this case, 131 photographs have been taken initially. It is not recommended to edit photographs. However, before uploading photographs to the software environment, it is necessary to make sure that the object is in focus in all photographs, and that photographs do not have noise and blur. Unsuitable photographs should be deleted. After checking all the photographs and deleting abortive ones, making a model in a software environment can proceed to the new stage.

b. Making a 3D model in a software environment

The photos have been transferred to Meshroom and 3DF Zephyr Lite environments to make 3D models [34]. The following criteria have been determined to compare the two mentioned programs: user-friendliness of an interface, the amount of time needed to make a model, the presence of additional program features as well as the accuracy of a model reproduction. In the course of analysis, it was detected that 3DF Zephyr Lite makes a 3D model much more quickly and has additional useful functionality. Despite this, Meshroom depicts the features of the object more accurately. Inasmuch as accuracy is a vital index for designing an inclusive environment, Meshroom is better to use for making inclusive objects.

In the course of the research, two options for using the model created with the help of photogrammetry have been marked. The first option is to further edit the object in 3D editors; the second one is to use the object as a reference based on which the exact object will be reproduced with the help of 3D tools. The proportions and other individual characteristics will be preserved at the same time. As it was previously mentioned, Meshroom has been chosen as one of the programs to make a 3D model. It is a free 3D model making software that employs a photogrammetric method. This software can be downloaded from the official website Alice Vision – a framework for photogrammetry.

Model making is done with the help of nodes that are automatically created by the program. For each node, there is a separate folder in the cache folder in which data is saved during the operation. So, if the work has been accidentally interrupted, the program will resume the process of designing a model from the same place where it has ended. After the program had finished the model making, it was detected that Meshroom had not used some of the photographs. The reasons for it may be an insufficient quality of the photo (blurring, grain) or excessive glare/shadows on the object. This way, only 55 photographs have been chosen out of 120 by the program. All of them were related to only one side of the model. Photographs that have not been used by the program are marked with a red camera as shown in Figure 8.

Meshroom provides the ability to add additional photographs to refine the results. For this, the model has been photographed again from the necessary angles and transmitted to the environment in the same way as the first time, but the augment reconstruction parameter has been chosen this time. This way, a group of thirty-four photographs has been added. In order not to see the object in the form of spots, but textured, it is necessary to double-click on the texturing node, after which a new layer will appear in the scene window, which, if desired, can be turned off later.

In Figure 9 the state of the made model after having added new photographs is shown. As can be seen, a new group of nodes, which is made to process the added photographs, is automatically created for each new group of photos. Also, in this figure, the textured model can be seen, and the cameras are only placed on the front and the sides. The latter means that there are still not enough pictures of the rear part to create a complete model. Therefore, the photographs were taken again from the non-visualized side and the same steps were repeated to upload them to Meshroom.
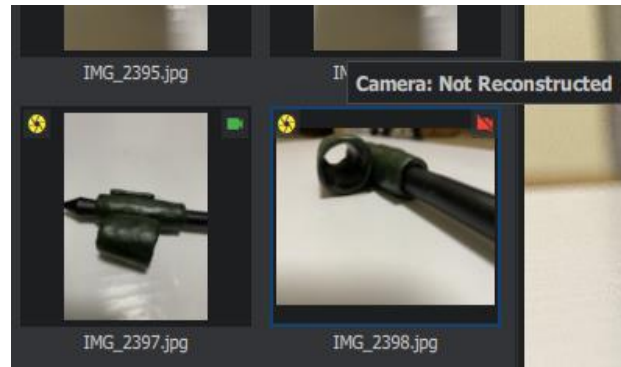
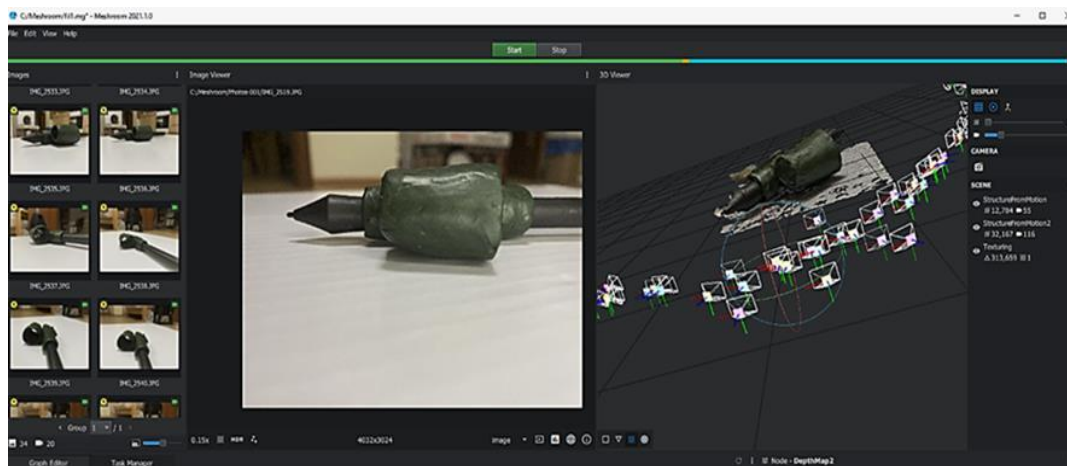Figure 8. The icon view of used and unused photos

Figure 9. The model after having added other photographs

2.3.4. Making the final look of the model

It has been decided to use the model made in the Meshroom environment, since this program reproduced it more accurately, as a basis for making the final look of the model. The created model has been imported into the 3Ds Max environment. Then, the model was rotated for convenience, and simple polygonal tube forms were laid and scaled on top of the model. Afterward, the tube object was edited with the help of Edit Poly to reproduce the shape of the scanned object. Now, the part for supporting the finger has been made beveled with the help of the slice modifier as shown in Figure 10. The next stage was to select and delete unnecessary polygons. Then, buttons have been made with the help of the Box primitive form according to the data obtained from the photogrammetric model.
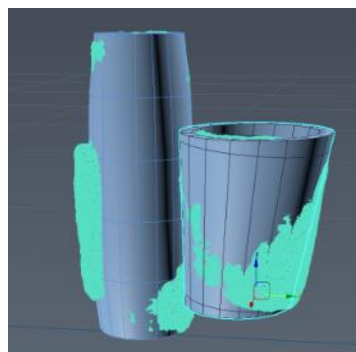

Figure 10. Making the part beveled with the help of slice modifier

After this stage, the forms made based on a photogrammetric model with the help of primitives are ready. Now it is necessary to edit the forms in order to connect them to make a fully-fledged object. First, all parts are connected with the help of attach in order to make a whole model. Buttons were edited using cut, connect and extrude tools. As a result, a low-poly model was received with a correct mesh. Now it is necessary to smooth the object. The turbo smooth modifier was employed for this. For smoothing to work correctly, edge loops were added using the swift loop tool.

In order to make sure that the model has been made properly, a standard rubber texture has been laid on the object. This made it possible to evaluate the model without a polygonal mesh and to ensure that it is properly displayed. According to the results of the analysis, as shown in Figure 11, the model is displayed correctly, which means proceeding to the next stage - preparing a graphics pen attachment for printing.
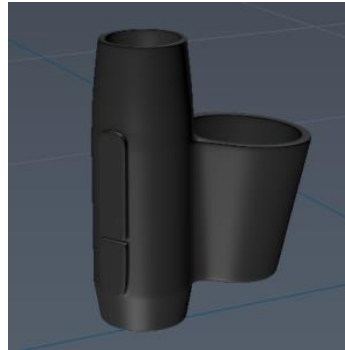

Figure 11. The final look of the model

2.3.5. The preparation of the model for printing

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn. The Cura 3D printing program has been used to verify that the model is ready for printing. In order to make sure that the model will be divided into layers correctly, which will be then printed one by one, it is necessary to assess the model by pressing the Slice button. After making sure that the model will be printed correctly, the model file can be given to printing. In Figure 12 the printed model of a graphics pen attachment is shown.

Figure 12. The completed 3D model of a graphics pen attachment

3.   RESULTS AND DISCUSSION

Therefore, in the course of the research, the main principles of designing an inclusive objective environment [35] using photogrammetry and 3D printing technologies were determined, and the following action algorithm was formed for designing objects of an inclusive environment with the help of 3D technologies:
a. Idea generation.
b. Making a sketch of the future development.
c. Making and testing a prototype. It is important that the material used to make a prototype is transparent and not shiny.

d. Photographing an object. It is better to photograph an object by moving the camera around the object, from all the possible angles. This way, it will be easier for the program to detect the object's position in a space. It is not recommended to turn over the object to photograph the lower part. The more photos are taken, the higher the chance of getting an accurately reproduced 3D model as a result. In addition, it is important to avoid blurred photos or images in which the main object is not in focus. The lighting should be adjusted so that the object does not cast hard shadows. It is not recommended to manipulate photographs in graphics software before making a model.

e. Making a 3D model. At this stage, the photos of an object are uploaded to photogrammetry software and a 3D model is formed based on the received data. Meshroom is a recommended software for photogrammetry as it is free and shows fairly accurate results for reproducing the model. In addition, additional photos can be uploaded to the Meshroom environment to make results that are more precise.

f. There are two possible ways of using the completed model. The first way is the further processing of the object in 3D editors to ensure the ability to print the model with the help of additive technologies. In this case, it will be necessary to spend much time clearing the model of useless spots, reconstructing the lower part of the model that was not visualized, smoothing the model and reducing the number of polygons as well as adjusting the polygonal mesh. It is a long-term and rather difficult process during which it is very important not to lose primary information about an object that is being modelled: its dimensions, proportions and physical characteristics of a person for whom the object has been designed. The second way is using the object which has been made with the help of photogrammetry as a reference, based on which the exact object will be reproduced with the help of 3D tools, keeping the same proportions and other individual peculiarities, but with the necessary number of polygons and without holes. It eliminates the necessity for a 3D model editing stage before printing. It is appropriate to use this way if the object that is to be reproduced is relatively simple, and its reproduction, based on the obtained data in the designing software, will take less time than editing the object received with the help of the photogrammetry method.

g. After having reproduced the final look of a model, it needs to be verified whether it is suitable for printing. For this, it should be opened in the Slice software and made sure that the model is divided into layers correctly. After this, the model can be given for printing.

4. CONCLUSION

In the course of the research, the main peculiarities of 3D modelling and printing technologies have been determined, and promising ways of its application have been proposed. The principles of designing an inclusive objective environment with the help of photogrammetry and 3D printing technologies have been detected. A new original design of a graphic pen nozzle made of photopolymer material and a method of its creation using photogrammetry with 3D printing reproduction are proposed. The attachment provides comfort during prolonged use due to the developed design, which supports the user's thumb and greatly simplifies the process of using the pen. The use of durable, elastic and tactilely pleasant materials, which are necessary to withstand many compression and bending cycles and increase the level of user satisfaction when using the graphics pen. The attachment is universal. This aspect implies the ability of any person to customize the nozzle for himself. The photogrammetric method of model development was used for this purpose, since this method will help take into account the individual characteristics of each individual person, as well as the characteristics of any graphic pen (diameter and presence or absence of buttons). In addition, the use of 3D printing can simplify the manufacturing process and reduce manufacturing waste.

According to the conclusions, it is reasonable to mention that the practice of designing an inclusive space should use more and more objects that are created using 3D printing technologies. Because of this, objects created with the use of 3D printing technologies will become dominant components of object-spatial space solutions. Based on this, research in the aspect of employment of 3D printing technologies for designing an objective inclusive environment is quite promising and requires expansion in both theoretical and practical terms.

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