Technical Aspects of Museum Exposition for Visually Impaired Preparation Using Modern 3D Technologies

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Abstract—People with visual impairment are excluded from experiencing the cultural heritage presented by museums in a traditional manner. To enable them to touch the museum exhibits, a set of touchable copies needs to be made. The article presents the use of latest computer graphics technologies, such as 3D scanning, postprocessing and 3D printing, in improving such an enterprise. The current state of research is discussed both in the technical and organisational aspect of preparing "tactile expositions". This is followed by a step-by-step description of preparing touchable museum objects, with a discussion of the possible use of 3D technologies to aid this task. Attention is also paid to issues connected with engineering education of students. The authors think that the problem of creating objects accessible to the blind is socially useful and will encourage students to be active in this area. Finally, a genuine museum object is described as an illustration of preparing a touchable exhibit, clearly showing the advantages of using 3D technologies to this end.

Keywords—museums for the visually impaired; creating museum expositions; 3D digital technologies

I. Introduction

People with visual impairment, deprived of their most important sense, are excluded from experiencing the cultural heritage presented by museums in a traditional manner. They are one of the most challenging categories of the disabled to be taken into account in the process of visiting museum exhibitions [1]. Proper experience of an exposition for these people could only be available by approaching the exhibits literally in a hands-on fashion. In most cases, however, such direct contact with them is not possible due to the risk of damage. In paper [2] the authors deal with the issue of providing blind people with information about museum collections in the Internet. The knowledge thus acquired (only in descriptive form) is intended to assist the hard of seeing with a real visit to the museum and facilitate their being guided by museum staff. The research reveals that the contents of the museum pages is not well prepared for the visually impaired, as they are difficult to navigate and the descriptions of the objects on display are insufficient. The Smithsonian Museum, for instance, provides guidance on the design of suitable expositions [3]. The main postulate was formulated as follows: "Items essential to the exhibition's main theme must be accessible to people by tactile examination (e.g. touching artifacts, reproductions, models) and/or comprehensive audio description."

It is therefore sensible to prepare "touchable" models of exhibits. An exposition containing such exhibits would be a way to provide cognitive benefits for visually impaired people. Paper [4] describes important research (though not involving blind people) on the behaviour of visitors to the Burke Museum of Natural History and Culture in Seattle, interacting with objects that are copies of museum exhibits made by using 3D printing technology. Copies of 4 small archaeological objects were made: Alaskan snow goggles and a toggling harpoon point, a Thai bowland a Honduran metate, whose size did not exceed 15 cm. The results show that experiencing museum artifacts using the sense of touch is a very attractive form, and replicas created by 3D printing are fit for this purpose.

It has thus been proven that 3D technologies can greatly facilitate the creation of models that have so far been produced manually. Selected technical issues related to the scanning of museum objects can be found in studies [5], [6], [7]. Article [5] discusses aspects of selecting appropriate 3D scanning technologies for museum objects considering their budget, requirements and staff experience. The results of the research on objects such as the Hercules statue from the Antalya Museum (Turkey) and the Khmer head (the Rietberg Museum, Zurich) show that good results are obtained by applying a 3D scanner working with structural light. In paper [6] the authors investigate the usefulness of 3D laser scanners, stationary and mobile, based on digitisation of archaeological vessels. The disadvantage of the examined scanners was their inability to capture information about the objects' colour and texture. Moreover, in the case of a mobile laser scanner, markers had to be affixed, and the stationary scanner had high limitations regarding the size of the object. Study [7], in addition to the technical aspects of 3D digitization by using laser scanners and 3D printers, also raises practical issues in the reconstruction of the reliefs making up the earthenware frieze of the Ospedale del Ceppo (Pistoia, Italy). The authors' experience may be useful in the preparation of exhibitions made of copies of artifacts. In paper [8] the authors describe, among others, the method of creating a 3D copy of architectural objects through CAD design rather than 3D scanning. 3D-printed objects were intended for kinesthetic exploration within a historical board game.

Non-technical issues of blind people's access to museum collections are presented in [9]. On the example of the Victoria and Albert Museum in London the practical aspects are discussed of creating touch-screen exposures (using originals and replicas), placing descriptions in Braille, using soundtracks and touch books, organising meetings, museum events, workshops and training sessions.

Recently, several museums have taken practical steps to prepare pilot museum exhibitions [10], [11], [12], [13], [14]. Article [10] presents a prototype low-cost system increasing the availability of museum exhibits for visually impaired users. The solution includes navigation in showrooms and touch-screen exploration of exhibit replicas using touch-sensitive audio descriptions and touch gestures on a mobile device. The prototype exhibition included exhibits printed in 3D with touch sensors attached to the Arduino board. An essentially similar solution is presented in studies [11], [12]. A device called 'Tooteko' brings a work of art closer to blind people. The 'Tooteko' ring on the finger allows one to read from the surface signals from NFC sensors, which are then converted to audio tracks played through a suitable application from a smartphone or tablet device. Acquiring an active surface required obtaining its digital 3D recordings by scanning and then printing in 3D. The operation was tested on the façade model of the San Michele church (Isola, Italy). Study [13] describes the use of modern technology developed by the Spanish printing studio Estudios Durero, which turns a high-resolution photo into 3D prints. In this way, the corresponding parts of the image become convex, creating a tactile surface for the blind. A sample exhibition of six prints printed in 3D has been made in the Prado Museum (Madrid, Spain). Users can touch and feel the shape and the glyphs. In reference [14] practical solutions are presented in the so-called touch museum, which is primarily addressed to the blind, e.g. the Tactual Museum (Athens, Greece). However, existing exhibitions still require further research and implementation of innovative technologies that will combine 3D and interactive digital technologies.

The works discussed do not contain a technical description of the procedure for creating 3D models for exposure to the blind using existing 3D technologies. This procedure, which takes into account aspects specific to the work of museum objects, is presented later in this paper.

The study describes in detail the selection of 3D scanning technologies, the process parameters, the tools applied or issues to do with postprocessing the obtained point cloud being a rough reflection of the exhibit surface. Moreover, choosing the 3D printing technology is presented with a view of the safety of the person interacting with the copy, the produced object's durability and the cost of its production.

The article also presents applying the above 3D technologies in an attempt to build expositions for the visually impaired, realised by staff members and Computer Science students of the Institute of Computer Science of University of Technology (LUT) in collaboration with the Zamoyski Museum in Kozłówka, based on a set of sculptures from the mid 20th century. During this work staff and students have the opportunity to use modern IT technologies in practice.

II. The Process of Preparing an Exhibition

Introduction of 3D technology strongly modifies the procedures used to create copies of real objects. At the same time, it is not a typical 3D copy production procedure due to the specific requirements for handling the original and the acceptable shape of the copy.

From the museum's point of view, the exhibition preparation algorithm, which contains copies of exhibits adapted for the blind, can be presented as a diagram (Fig. 1). This version is a significant extension of work [10], taking into account more issues in the use of 3D technology and aspects of engineering education. Each stage is based on the skills of both museology and IT.

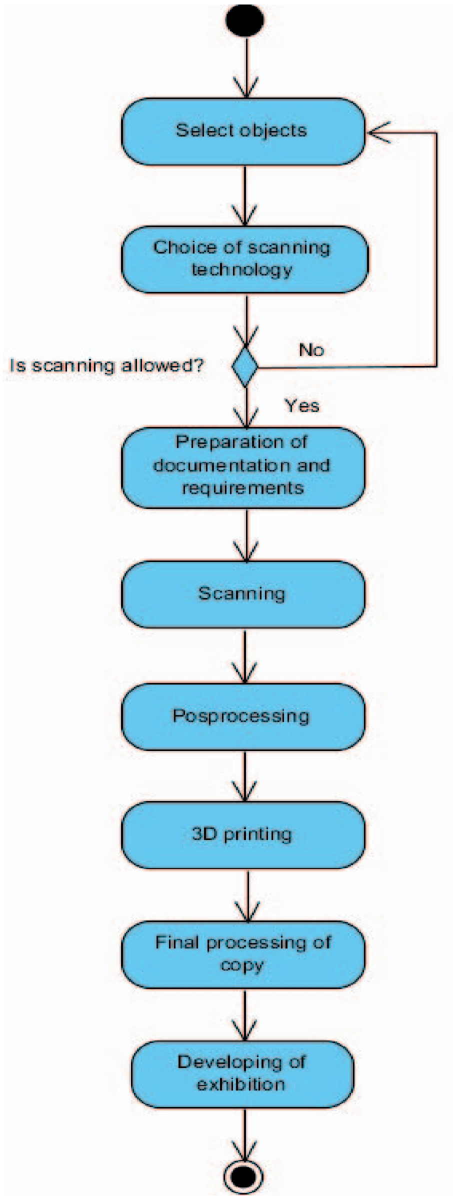

Fig. 1. Diagram of the process of preparing exhibitions for the blind.

A. Step 1: Selection of objects

At this stage, the knowledge and expertise of the staff of the cultural heritage institution is primarily used. Their decision is subject to the selection of a set of objects best reflecting the nature of the exhibition presented in the facility. One should choose exhibits whose geometric shapes will be significantly different from each other, and the artistic form – the composition and expression of the presented characters –will be rich in content and easy to create relevant descriptions. An important element is also the sculptures' finish: smoothness and surface texture. The knowledge of available 3D technologies is important in that it is possible both to select an object which would be too difficult to reconstruct by traditional techniques, and reject one that, for technological reasons, could not be reproduced with satisfactory accuracy.

B. Step 2: Selection of the 3D scanning technology

Selected exhibits are analysed in terms of the choice of scanning technology. The target copy scale is matched to the requirements of touching. The optimum technology is selected on the basis of object's dimensions and the required precision. Next, the protection of the exhibit is also analysed (e.g. avoiding strong lighting). Based on these limitations, the scanning device's parameters are selected. If the selected scanning method is able to meet the constraints, a decision is made to perform a scan. Otherwise, a more secure scanning method is selected, or the scanning of the object is cancelled.

C. Step 3: Preparation of the documentation

Museum documentation is created by the museum staff, detailing the important features to be displayed in the produced copy. Also, a decision on the possible exposition of only a part of the original is taken. However, one must remember the multidisciplinary approach, postulated in work [2], which requires the creation of a team consisting of many people with different competences (art historian, linguist, cultural animator, museum guide, computer graphic designer). This solution allows for the creation of effective and comprehensive descriptions of objects useful for the blind.

The scanner evaluates the features and develops the requirements for the process and the scanning parameters to achieve the required precision. It is taken into consideration that once acquired, a scan can be matched to the needs of different expositions.

D. Step 4: 3D scanning

The scanning process is in progress. The 3D scanner performs partial scans and pre-merges them to identify and complete unscanned areas (Fig. 2, Fig. 3a).

E. Step 5: Postprocessing

At the postprocessing stage, the defect in the scan surface is first identified and replenished due to technological constraints (e.g. surface inaccessible to the scanning head, Fig. 3b). The modifications indicated in step 3, which match the cognitive abilities of persons with visual impairment, are introduced. When analysing the degree of visibility of important details, it is necessary to consider the scale in which the object will be printed. The specific detail must be perceptible and easily recognisable. With reduced-scale printing, such details can be as small as the resolution of a 3D printer – so they need to be emphasised by modifying the grid. These modifications are also intended to provide a safe means of touching the copy's surface and the relative strength of all its fragments. Depending on the decision taken in step 3, a copy containing the specified fragment of the object may be created.

F. Step 6: 3D printing

The printing process is carried out. Depending on the scale of the copy and the working space of the 3D printer, the print may be completed in whole or in part. Depending on the printing technology selected, it may be necessary to select a model in the work area to minimise the number of necessary supports. It is also important to control the weight of the model by controlling the way it is filled. The 3D printing technology decides on the optimum setting and the potential division of the model.

G. Step 7: 3D print processing

At this stage, the technician performs the final surface treatment of the model. Supports are removed, surfaces and sharp edges smoothed over. Alternatively, the print's parts are joined together and the model is attached to the base.

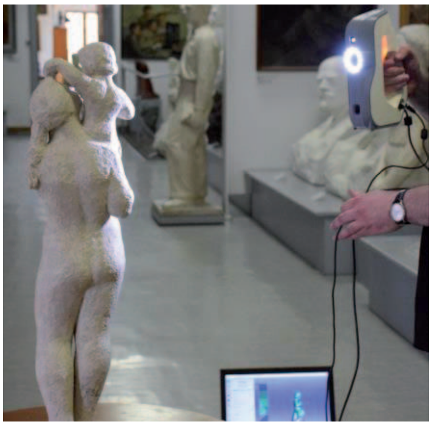

Fig. 2. The scanning process.

a)

b)

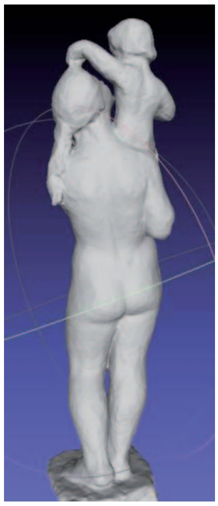

Fig. 3. Processing procedure: a) matching the obtained point clouds, b) analysis of the completeness of the obtained model.

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H. *Step 8:Preparation of the exposition*

This stage is largely based on the skills of building interesting exhibitions by museum staff: interior design, construction of appropriate communication lines, access to the various exhibits. 3D design (CAD) technology can help design an exposition by making available its virtual counterpart allowing to find the optimum layout for security and ergonomics.

The next part of the article presents the implementation of the above procedure for the construction of an exhibition for the visually impaired, which took place in cooperation with the Zamoyski Museum in Kozłówka, for the exposition of sculptures from the mid 20th century.

III. REALISATION

The exposition includes stone sculptures from the mid-twentieth century, depicting mainly human figures.

At the first stage, the museum's staff selected 10 sculptures from the exposition of 20th century sculpture. The selection was consulted with scanning technologists. At the second stage, the dimensions and shape of the sculptures were assessed in terms of the choice of scanning technology. Structural light technology was chosen as the most distinctive detail of stone sculptures. The use of mobile scanners was identified as facilitating the scanning process, reaching all surfaces of objects. As a result, the Artec Eva scanner was selected for scanning with white light. A scanner working on the same principle was used in study [4]. Continuous scanning takes up to 15 frames per second. It can take place at the distance of 0.4 to 1 m from the surface of the object. The scanning head is 262 × 158 × 63 mm and can be freely moved during scan recording. This is a useful feature that allows the printhead to be easily positioned, so that any object surface can be scanned during an individual registration process. The only condition is that no surface is overshadowed by another surface of the object. The precision of scanning at 0.5 mm is sufficient to scan the surface of sculptures of dimensions up to 1.5 m. Fig. 4 shows the process and effect of scanning an exemplary object.

a) b)

Fig. 4. Effect of scanning by a hand scanner: a) scanning process, b) 3D model obtained.

The operating mode of the scanner: illuminating the object with a beam of strong white light, was presented to the museum staff. Approval for use of this technology was obtained – sculptures were not covered by paintings or other surfaces sensitive to strong lighting. Preliminary scanning was performed (Fig. 4). The achieved results were of the required precision without the need to assist the scanning process with additional markers or surface dimming. The necessity to use the aforementioned aids could be met with refusal by the museum to continue the scanning process. As a result, a satisfactory scanning procedure was selected, acceptable by the museum staff.

At a later stage the museum staff pointed out the special features of the facilities, important for the preservation of the nature of the exhibition. For some sculptures, it was decided to display only their fragments. These features and the shape of the sculptures were assessed by the scanning and 3D printing technologist. No surfaces were found that were unsuitable for scanning or requiring significant post-processing interventions. The special features of individual objects were noted in order to ensure that they are properly displayed during 3D printing.

Preliminary scanning and assembly of selected objects was performed. Most models did not require additional follow-up of the partial scans. The models were postprocessed. Surface discontinuities unnoticed while scanning the model were completed. The alignment of the model grid was performed to optimise further processing. Fused Filament Fabrication (FFF) technology was selected due to its accuracy (0.1 mm) and the availability of a printer with adequate work space.

No significant offsets or unduly weak connections to the rest of the model were found in the example model. There was no need for modifications to increase the print strength. However, the specific features of the object were modified to match the resolution of the selected 3D printing technology. Otherwise, such details could have been partially or completely lost during the conversion of the model to the layers of the fabricated 3D copy. Due to the decision to print the object in scale, some fragments, such as the eyebrows, were sized to match the resolution of the print. In such a small scale it is impossible to correctly form their shape. It was necessary to emphasise this part of the 3D grid so that the shape of the eyebrows would be noticeable after printing. The eyebrowswere raised above the surface of the face using the Sculpt [15] technique, editing the 3D grid (Fig. 5).

a) b)

Fig. 5. Sculpting of the eyebrow arch with the use of Sculpt [15]: a) model before modification, b) model modified.

a) b)

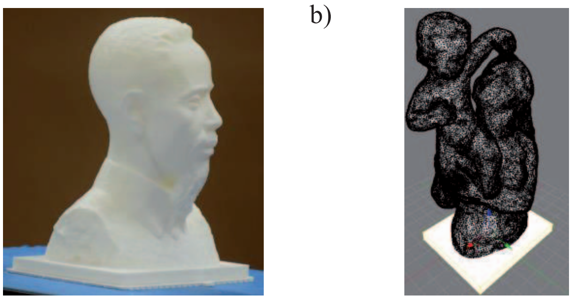

Fig. 6. Examples of the way of object presentation with added base: a) total print as a whole, b) partial print.

Due to the earlier decision to print only part of the object, the place of division was decided, as well as the base for stabilising the printed model.

The printed models were converted to layered ones with added support to outliers (Fig. 7). A typical "diamond" fill was chosen to provide the rigidity and lightness of the object. In order to ensure a good touch resistance, the outer surface was printed in the form of a triple layer.

Model prints were made and then their surfaces were cleared of the bracket remainders and unintentional surface irregularities (Fig. 8).

In the example described, the stage of preparing the exhibition was left to the museum, so the 3D technology mentioned earlier was not used at this stage.

a) b)

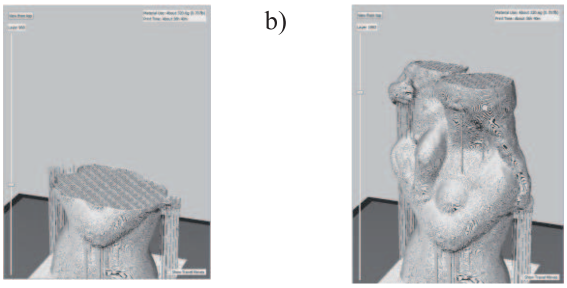

Fig. 7. Ready-to-print layered model of the object: a) at 30% of height, b) at 75% of height.

a) b)

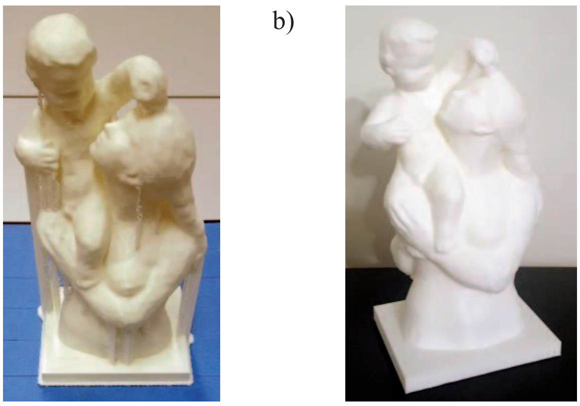

Fig. 8. 3D print of an example object: a) rough print (visible supports), b) polished print.

IV. Pilot Studies and Results

The research consisted in identifying and attempting to name details of three objects given to a person permanently blind from birth (Fig. 9b). The aim of the research was:

- checking the possibility of recognising the exhibit,
- assessment of the correctness of the 3D size of copies,
- assessment of the suitability and properties of the material used for 3D printing.

The research used printed copies in 3D technology of two objects created by 3D scanning (Fig. 9a – height 18 cm, and Fig. 9d – height 25 cm) and a 3D model of an architectural object (Fig. 9c – height 21 cm) obtained in the modelling process [16].

The research was carried out at the headquarters of the Polish Association of the Blind in Lublin. The subject was asked to comment loudly on the process of recognising the exhibits, and the entire course of the research was recorded in a film, which could later be studied. In the first phase, the tested person did not obtain any information about the objects beforehand, and in order to "mislead" him, a 3D model of a gothic defense gate was given as the second object. In the second phase, the person running the experiment asked questions, enquired about certain details of the object as well as the impressions of the person tested.

a) b) c) d)

Fig. 9. An example of a blind person (Z. Nastaj) interacting with a 3D copy of the exhibition and recognizing its details.

The obtained test results were as follows:

- details of the exhibits examined were mostly recognised correctly, e.g. when touching the bust's head, elements such as: ears, mouth, nose, beard, eyes, hair or lack of arms was recognised;
- details of the exhibits examined were mostly recognised correctly, e.g. when touching the bust's head, elements such as like on top;
- the respondent positively commented on the 3D printing material used (PLA type material), paying attention to the fact that it was nice to the touch, smooth and light, which would be important when children used such exhibits.

V. CONCLUSIONS

The use of the above 3D methods aiding the creation of exposition for the visually impaired has the many advantages. It allows to easily reproduce an exhibit by reprinting it and expanding its contents by adding newly prepared copies of an original museum object. It also significantly speeds up the process of producing a single copy and its multiplication and reduces the cost of the whole process of preparing an exposition.

The method of making copies of museum objects, developed at the LUT's Institute of Computer Science and presented in the article, provides a quick and non-invasive way of creating museum artifacts that can make up exhibitions for visually impaired people. Digitised with a 3D scanner, museum artifacts can be printed in 3D printing technology after special processing. The use of modern IT achievements greatly accelerates the process of making copies and is characterised by lower costs compared to alternative methods. The method discussed also makes it easy to duplicate copies of artifacts in situ for the purposes of presentation at various exhibitions. Digital copies of artifacts can be easily transmitted over computer a network, which promotes the dissemination of knowledge about museum objects.

Digital copies of museum artifacts may also be the basis for the creation of virtual 3D museums accessible via the Internet for people with good eyesight. The process of constructing an exhibition is an excellent training ground for the staff and students of the Institute of Computer Science. During the work, teachers and learners can acquire practical skills in a variety of contemporary 3D technologies from scanning through post-processing to printing physical 3D copies of museum artifacts.

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REFERENCES

[1] B. Pillow, M. Banks, and D.Reeves, "Equal access for all: Providing for impaired stakeholders in a museum setting," Retrieved September 30, 2017 from: http://www.byronpillow.com/uploads/7/6/7/9/76797585/disability_access.pdf

[2] B. Leporini and I. Norscia, "Translating museum visual contents into descriptions for blind users: A multidisciplinary approach,"[In:] V. López-Jaquero et al. (eds.), Computer-Aided Design of User Interfaces VI, Springer-Verlag, London 2009, pp. 47-57.

[3] "Smithsonian Guidelines for Accessible Exhibition Design," 2009, Retrieved Juny25, 2017 from: https://www.si.edu/Accessibility/SGAED

[4] T. L. Williams, "More than just a novelty? Museum visitor interactions with 3D printed artifacts," A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts University of Washington, 2017.

[5] D. Akça, A. Grün, B. Breuckmann, and C. Lahanier, "High definition 3d-scanning of arts objects and paintings," Optical 3-D Measurement VIII, Zurich, Switzerland, July 9-12, 2007, vol. II, p 50-58, Retrieved November 10, 2017 from: http://www.photogrammery.ethz.ch/general/persons/devrim_publ.html

[6] J. Montusiewicz, Z. Czyż, and R. Kayumov, "Selected methods of making three-dimensional virtual models of museum ceramic objects," Applied Computer Science, 2015, no 1, pp. 1-16.

[7] G. Tucci, V. Bonora, A. Conti, and L. Fiorini, "High-quality 3d models and their use in a cultural heritage conservation project," The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W5, 26th International CIPA Symposium, 28 August–01 September 2017, Ottawa, Canada.

[8] J. Montusiewicz, M. Barszcz, K. Dziedzic, J. Kęsik, M. Milosz, and M. Tokovarov, "The concept of a 3D game board to recognise architectural monuments," Proceedings of the 11th International Conference of Technology, Education and Development (INTED 2017), 2017, Valencia, Spain, pp. 8665-8674.

[9] B. Ginley, "Museums: A whole new world for visually impaired people," (2013) *Disability Studies Quarterly*, 33 (3), Retrieved November 15 from: http://dsqsds.org/ article/view/3761/3276

[10] G. Anagnostakis, M. Antoniou, E. Kardamitsi, T. Sachinidis, P. Koutsabasis, M. Stavrakis, S. Vosinakis, and D. Zissis, "Accessible museum collections for the visually impaired: combining tactile exploration, audio descriptions and mobile gestures,"Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct, MobileHCI 2016, September 2016, Italy, pp. 1021-1025.

[11] F. D'Agnano, C. Balletti, F. Guerra, and P. Vernier, "Tooteko: A case study of augmented reality for an accessible cultural heritage. Digitization, 3D printing and sensors for an audio-tactile experience," ISPRS Archives vol. 40, Issue 5, pp. 207-213, February 2015 [6th International Workshop on 3D Virtual Reconstruction and Visualization of Complex Architectures, 3D-ARCH, Spain].

[12] C. Balletti, M. Ballarin, and F. Guerra, "3D printing: State of the art and future perspectives," Journal of Cultural Heritage 26 (2017), pp. 172-182.

[13] B. Delaware, "3D Printing Allows the Blind to Experience Famous Artwork," Retrieved November 15 2017 from: https://www.pastemagazine.com/articles/2015/04/3d-printing-allows-the-blind-to-experience-famous.html

[14] Tactual museum, Athens,Retrieved November 15, 2017 from: http://www.tactualmuseum.gr/ html/muse.htm

[15] Blender Foundation, "Blender 2.79. Manual – Sculpting," Retrieved November 15, 2017 from: https://docs.blender.org/manual/en/dev/sculpt_paint/sculpting/index.html

[16] M. Milosz and J. Montusiewicz, "The 'Architectural Jewels of Lublin'; Game as a Tool for Collaborative Interactive Learning ofHistory," In: Auer M., Guralnick D., Simonics I. (eds) Teaching and Learning in a Digital World (ICL 2017), Advances in Intelligent Systems and Computing, vol. 715, 2018, pp. 96-105.