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LONG PAPER

Beyond "do not touch": the experience of a three-dimensional printed artifacts museum as an alternative to traditional museums for visitors who are blind and partially sighted

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Abstract
Three-dimensional printing, or 3D printing, has been used toward the educational, cultural, and social participation of individuals who are blind and partially sighted (BPS) by providing sensory access by touch. This study describes an example of the use of 3D printing technology to make museums accessible to visitors who are BPS by creating a three-dimensional printed artifacts museum (3D-PAM) that exhibits 3D printed replicas of artifacts from famous museums around the world. Specifically, the aim of the study is to identify the definitions of museums and the general experiences of museum visits by people who are BPS, to have them visit a 3D-PAM, and to unravel their reactions to this experience and their future suggestions for 3D-PAM. Eleven individuals participated in this basic qualitative study. Semi-structured interviews were conducted to uncover their understanding of the experience. Results show that people who are BPS have a negative perception of museums because they are often inaccessible to this group and that the 3D-PAM in our study offered a pleasant experience that contributed to accessibility. These results suggest further that 3D-PAMs, either as an alternative and separate museum type or integrated into existing museums, are highly important for people who are BPS.

Keywords 3D printing · Visual impairment and blindness · Museums · Accessibility

1 Introduction

Three-dimensional (3D) printing, which emerged in the 1980s, is the process of creating an object from a 3D digital model by depositing material layer by layer [1]. Nowadays, 3D printing technology has become more widespread and is used in a wide range of fields, including the accessibility of museums. For example, the mission of Museum in a Box is to help museums increase their collections' accessibility and to connect people through shared histories. The company provides users a small-scale audio-tactile experience of museum objects. Museum in Box contains a set of postcards and 3D printed objects with a little metal sticker attached. When an object is placed on the Box, it reads the metal sticker and plays an audio description of the object. [2] In correlation with developments in 3D printing technology, different museums around the world have also made 3D printable models of their artifacts accessible since 2014. For example, the Scan the World project is

> a shared, open access museum of the future built by and for people all over the world with a mission to share 3D printable sculpture and cultural artefacts using democratised 3D scanning technologies, producing an extensive ecosystem of free to download digital cultural heritage. [3]

Scan the World is an example of initiatives that enable people to experience cultural artifacts in a remarkably tangible way. Hence, 3D printing technology can be considered

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a new, promising opportunity for museums to become more accessible to people who are blind and partially sighted (BPS).

People who are BPS perceive the world mostly through touch and hearing [4] and the importance of touch was emphasized by many museum visitors who are PBS [5–7]. Whatever their level of tactile acuity, for people who are BPS, the sense of touch is a key means of learning about artifacts [5]. Unfortunately, a common barrier encountered by people who are BPS in museums is the "Please don't touch!" rule. It is known that without touching, understanding the 3D properties of objects is burdensome for people who are BPS. Even with detailed and competent verbal descriptions, it is very difficult for this group to achieve the level of experience gained by manual explorations [6].

Handa et al. [7] note that although resources such as Braille labels, audio guides, and guided tours are provided to make the visit worthwhile and meaningful for them, people who are BPS would also need staff assistance and the availability of collections to be touched, heard, and smelled. They further add that even if visitors who are BPS are accompanied or are provided a companion by the museum, the need for such access to collections remains. Museums are acknowledging this urge to touch, and they are providing opportunities for their visitors to do so [5]. However, since museums face the dilemma of preserving their collections while meeting the need for access, their attempts to provide opportunities for their visitors to feel artifacts are restricted to selected items only. Three-dimensional printing technology alleviates the problem of making all artifacts accessible and touchable. With this technology, people who are BPS can touch and examine the 3D printed models of the artifacts from the collections of world museums. In this study, we created a touchable museum, which we call a 3D printed artifacts museum (3D-PAM). For the purposes of this study, we allowed people who are BPS to experience it. We define the 3D-PAM as an alternative museum that is created within the scope of the possibilities offered by 3D scanning and printing technology. Three-dimensional printable models of artifacts, which museums share on the internet for the purpose of education, research, conservation, restoration, and accessibility, are designed and constructed by using 3D scanning and printing technology. In this context, the aim of the study is to identify the definitions of museums and the general experiences of museum visits by people who are BPS, to have them visit a 3D-PAM, and to unravel their reactions to this experience and their future suggestions for 3D-PAM.

The current study is structured as follows. Section 2 presents the literature on the accessibility of museums to people who are BPS. This is followed by the description of the methodology and the creation of 3D-PAM. Subsequently, findings are presented with direct quotations from participants, followed by a discussion of the research findings in Sect. 5. Finally, the last section summarizes our conclusions and provides both the limitations of the study and future directions.

2 Related work

The universal accessibility of museums to all is an active area of research and practice. Researchers with diverse backgrounds and expertise are contributing to our knowledge of the subject. One of the specialized topics in this field is the improvement of museums' accessibility to visitors who are BPS. A remarkable amount of research on this topic is found in the literature. Some of these studies [7–15] focus on the experiences of people who are BPS during their museum visits.

Handa et al. [7] examined the potential of museums to better serve visitors who are BPS and investigated the priority needs of people who are BPS during their visits. The results showed that the priority needs for museum visitors who are BPS were (a) exhibitions and collections accessible, for example, tactilely or auditorily, and (b) assistance and interpretation by museum staff and volunteers. Istanbullu Dincer et al. [8] aimed to identify the needs, challenges, and satisfaction level of people who are BPS during museum visits. Findings showed that participants generally mentioned problematic accessibility issues such as the lack of multisensory experiences, that is, tactile, auditory, and olfactory access; the lack of arrangements allowing a museum visit without a companion; and the participants' expectations regarding the alleviation of these issues. Argyropoulos and Kanari [9] aimed to investigate the museum-visiting experiences of people who are BPS in Greece. The researchers' main goals were to identify the factors that facilitate or hinder access to museums for visitors who are BPS, their emotions during a museum visit, and their suggestions to improve the accessibility of museums to visitors who are BPS. The results revealed that escorts, tour and audio guides, and tactile access were considered as facilitating factors, whereas the unavailability of touching, the unawareness or unavailability of museum staff, limited or incomprehensible oral information, the architecture of the museum, and inaccessible museum websites were considered as impeding factors by visitors who are BPS. Argyropoulos and Kanari [9] observed that, during museum visits, participants had positive feelings, such as excitement, pleasure, and happiness, that related to their historical-cultural interest, curiosity, and family habits; in contrast, they had negative feelings, such as lack of motivation or disappointment and upset, which the participants attributed to the lack of accessibility. To improve the accessibility of museums to visitors who are BPS, participants suggested access through touch, training

of the museum staff, special museum programs, improved interior design of museums, and self-assessment of museums. Asakawa et al. [10] examined the previous museum-visiting experiences of people who are BPS, their motivation for visiting museums, and the accessibility issues they encounter. To this end, they surveyed people who are BPS in person. Results revealed that all participants showed motivation to visit museums, and they held both positive and negative perspectives regarding their previous museum-visiting experiences. Negative experiences were attributed to mobility issues and inaccessible content, while the ability to touch replicas or reproductions, even if they were limited in number, was considered a positive experience. Mesquita and Carneiro [11] aimed to identify strategies to increase the accessibility of museums to visitors who are BPS and assess the accessibility of 28 museums in 4 European cities. Observation and semi-structured interviews were carried out to identify the strategies adopted by museums to increase accessibility for visitors who are BPS. The researchers came to the conclusion that despite the broad spectrum of strategies that may be implemented to increase the accessibility of museum sites and exhibition objects to visitors who are BPS, the accessibility of the museums studied was found to be significantly limited, especially in respect of the exhibition objects and interpretation. Wakatsuki et al. [12] conducted a study aimed at determining how museums might assist visitors who are BPS or hard-of-hearing to enjoy a more educational and pleasant experience. Participants who are BPS or hard-of-hearing participating in the study were administered a questionnaire focusing on visitors' interest in museums, difficulties they encountered during their visits to museums, and alterations they expect to be made. The results revealed that museums are important places for both groups. The presence of museum staff with positive and understanding attitudes toward visitors who are BPS or hard-of-hearing was the most demanded feature with respect to museum services. Concerning the types of exhibitions or events, both groups wanted museums to offer exhibits or events enabling visitors to touch objects. Vaz et al. [13] examined the experiences of people who are BPS during their visits to museums in Portugal and their perceptions of accessibility resources. The study showed that people who are BPS had limited experiences during their museum visits, which the participants attributed in large part to not being allowed sensorial access through touch. Although the participants considered touch original pieces and touch replicas to be accessibility resources with high usefulness ratings, such objects or replicas to touch were largely unavailable. To co-create a framework that could be used to improve the experiences of visitors who are BPS in museums, Vaz et al. [14] investigated these visitors' perspectives. The findings revealed that sensory access to physical objects was an essential component of enhanced and meaningful museum experience for visitors who are BPS. To ensure sensory access, 3D replicas of exhibits were identified as of the utmost importance. In a recent study, during the first lockdown in the UK, Cecilia [15], using semi-structured interviews, examined concerns and expectations of visitors who are BPS regarding museum visits after the Coronavirus (COVID-19) pandemic. Highlighting the limited tactile access before the pandemic, museum visitors who are BPS expressed their concerns about losing even this access after the pandemic. The author, who argued for the necessity of eliminating these concerns, suggested using 3D printed replicas of objects to allow visitors who are BPS access tactilely.

These studies indicate that people who are BPS encounter many obstacles at museums. One of the common obstacles emphasized in these studies is the unavailability of sensorial access through touch. Consequently, a group of studies in the literature on the accessibility of museums to people who are BPS has focused on the elimination of this problem [16–23].

For example, to enable people who are BPS to understand visual artworks' pictorial environment in shape and depth, Rodrigues et al. [16] developed an assistive computational methodology that allows the creation of 2.5D or 3D representations of paintings. In a similar vein, to make 2D artworks accessible, Kwon et al. [17] developed a touchscreen-based online art gallery called AccessArt. Corresponding to the user's touch on his or her own device, this online art gallery provides verbal descriptions with three main modes—overview, object, and part mode—that allow the user to enjoy artworks from anywhere. On a somewhat different note, Balletti et al. [18], Montusiewicz et al. [19], and Neumüller et al. [20] discussed the possibilities of 3D printing in the field of tangible cultural heritage. Balletti et al. [18] presented a wide range of applications of 3D printing technologies in this field, and they supported reducing the costs and the time spent reproducing all types of cultural heritage, including archeological finds, sculptures, architectural elements, paintings, and artworks. They further suggested using 3D printed replicas to set up alternative museum exhibitions, such as tactile museum tours for visitors who are BPS. Montusiewicz et al. [19], highlighting the possibilities and role of 3D scanning, postprocessing, and 3D printing to improve museum experiences of visitors who are BPS argued the technical and organizational aspect of preparing tactile expositions by using 3D technologies. Neumüller et al. [20] highlighted the importance of touch in perceiving art and cultural heritage for a wide range of people, including people who are BPS, and noted that the advent of 3D printing has the potential to provide multisensory access in the field of cultural heritage for everyone. The authors also underlined that 3D printing promises a vital role in research, documentation, and education, referring to the potential of 3D printing to serve these purposes in an

accessible and inclusive manner. Moreover, recent studies [21–23] addressed the requirement for more research to fully understand the role of 3-D printing in designing replicas for audiences who are BPS in museums. From this point on in the current study, we aim to propose an alternative museum that is created within the scope of the possibilities offered by 3D scanning and printing technology, enabling people who are BPS to directly touch and experience 3D replicas of famous artifacts from museums around world, to unravel reactions of people who are BPS to 3D-PAM experience and their future suggestions for it. In this regard, creating an alternative museum type that exhibits 3D printed replicas of artifacts from museums around the world and being an empirical research to reveal experiences of people who are BPS this study aims to adding on current literature mostly comprising theoretical studies.

3 Methodology

This is a basic qualitative study—one of the most used forms of qualitative research—that is underpinned by interpretivism and constructionism. Merriam [24] asserts that, in other words, researchers conducting basic qualitative research are primarily interested in "how people interpret their experiences, how they construct their worlds, and what meaning they attribute to their experiences" (p.23).

This study was undertaken in order for people who are BPS to experience a touchable museum designed by using 3D scanning and printing technology. The study also aims to unravel participants' reactions to the experience. In this study, the way people who are BPS interpret and make sense of their 3D-PAM experience was the main interest. To uncover participants' understanding of these experiences, we asked them to characterize traditional museums and to relate their experiences there and in our 3D-PAM, and we invited them to make suggestions for improvements to the 3D-PAM.

3.1 Creation of a touchable museum, or 3D-PAM

For people who are BPS to experience a 3D-PAM, firstly, 3D printable models of some famous artifacts from world-renowned museums' collections were accessed and examined. During this examination, artifacts were selected based on several criteria, for example, being included in the collections of different museums, being of a different genre (e.g., mask, monument, coin), or being widely known, and the of 3D-PAM's collection was created. The selected artifacts were the mummy of Lady Tahathor at the Ipswich Museum, Ipswich; a monumental scarab beetle; the Mayan mask of a merchant god; a Macedonian warrior's helmet; a Nasca spout and bridge vessel in the shape of a man; a Wei State round coin and the Rosetta Stone at the British Museum, London; the bust of Nefertiti at the Neues Museum, Berlin; Visnuite Monument and Vishnu Garudasana at the Guimet Museum, Paris; the bust of Marcus Aurelius, bust of Emperor Constantine the First, Crouching Aphrodite figurine, and Hammurabi Code at the Louvre, Paris; and the head of Aphrodite through the Réunion des Musées Nationaux, Paris. The selected artifacts were printed using Cartesian 3D printers that used fusion deposition modeling (FDM) technology. The term FDM is often used as a synonym for 3D printing and is the most common method of fabrication [25]. It is used to produce plastic prototypes and structures with a

Table 1 Dimensions of the artifacts

Name of the artifact	Dimensions
Mummy of lady tahathor	180×78×39 mm
Monumental scarab beetle	91×177×138 mm
Mayan mask of a merchant god	200×159×183 mm
Macedonian warrior's helmet	194×141×197 mm
Nasca spout and bridge vessel in the shape of a man	180×123×157 mm
Wei state round coin	9×50×49 mm
Rosetta stone	237×146×59 mm
Bust of nefertiti	270×131×199 mm
Visnuite monument	280×109×113 mm
Vishnu garudasana	250×100×169 mm
Bust of marcus aurelius	250×160×94 mm
Bust of emperor constantine the first	250×102×178 mm
Crouching aphrodite figurine	250×121×171 mm
Hammurabi code	280×58×83 mm
The head of aphrodite	194×139×190 mm

fine degree of resolution, enabling complex designs [25–27]. White-color polylactic acid (PLA) filament was used to print all of the artifacts, and they were not colored.

All of the artifacts were printed straight from the archive of the Scan the World project. A recent study [23] revealed that many museum visitors who are BPS favor non-alteration in 3D printed objects and want to handle an accurate replica. Alteration is considered to be problematic because it can negatively affect user interpretations [23]. To stay as true as possible to the original forms, the artifacts were not altered and kept original features such as surface cracks. To remove the support material and smooth the layer lines on the surface, all artifacts were sanded manually. For the current study, the maximum print areas of the printers were $285 \times 153 \times 155$ mm and $250 \times 200 \times 200$ mm. Except for the Wei State round coin, all artifacts were printed as large as possible given the printers' maximum print areas. Information about the artifacts' dimensions is given in Table 1.

In addition, in line with the museums' websites and the literature review, informative short texts about each artifact were prepared. To this end, the authors firstly visited the websites of the museums that held the original pieces exhibited in 3D-PAM and searched their online collection if available. In this context information in online collection including curators' comments were shortened and converted into text. If there was no available information about the artifacts on the museums' website, the authors reviewed the literature about the artifacts and created the texts. They included the name of the artifacts and where it is held, the period it belongs to, and information about the artifacts' historical background and its actual dimensions, weight, and material. The texts were presented in the Latin alphabet and in Braille. The artifacts were exhibited on a platform that was easily accessible to visitors who are BPS. There were no obstacles around the platform. The platform was rectangular, which allowed visitors to realize that they were completing a tour around, thus examining all the artifacts. Moreover, Authors 1 and 2, together with one undergraduate and one graduate student, were present in the exhibition area and provided explanations and information. This helped the interviewers (Author 1 and Author 2) and participants to get used to each other and enabled participants to learn about how 3D-PAM and the research had evolved. The 3D-PAM was exhibited as part of the annual White Cane Accessibility Festival celebrated on October 15, 2016, White Cane Safety Day.

Table 2 Participants' characteristics

Participant ID	Gender	Age	Level of education	Field of education	Profession	Condition of vision*	Onset of visual impairment or blindness	Visited museums or not
P1	Male	42	Undergraduate degree	International relations and political sciences	Officer	Blindness (no light perception)	Innate	Visited
P2	Male	30	Undergraduate degree	Music education	Teacher	Blindness (no light perception)	8 months old	Visited
P3	Male	16	High school student	–	Student	Blindness (with light perception)	Innate	Visited
P4	Female	16	High school student	–	Student	Severe vision impairment	After the age of 14	Visited
P5	Female	22	Undergraduate student	Psychological counseling and guidance	Student	Blindness (with light perception)	Innate	Visited
P6	Female	34	Undergraduate degree	Early childhood education	Teacher	Severe vision impairment	Innate	Visited
P7	Male	21	Undergraduate student	Department of translation	Student	Blindness (with light perception)	Innate	Visited
P8	Female	28	Graduate student	Psychology	Product manager	Blindness (with light perception)	Innate	Visited
P9	Male	32	Graduate degree	Public relations	Officer	Blindness (no light perception)	4 years old	Visited
P10	Male	32	Graduate degree	School of law	Lawyer	Blindness (with light perception)	Innate	Visited
P11	Male	36	Undergraduate degree	History	Librarian	Blindness (no light perception)	Innate	Visited

*WHO International Statistical Classification of Diseases and Related Health Problems ICD-11[41] is referred

3.2 Participants

Participants were 11 individuals who are BPS and visited the 3D-PAM during the festival. A convenience sampling technique was used to determine them. Of the 11 participants, four were female, and seven were male. Their age varied between 16 and 42, and the mean age was 28. Of the participants, nine were blind and two were severely vision-impaired. Participants were instructed to use touch when exploring the 3D printed artifacts since the degree of vision impairment was very severe in partially sighted participants. All were Braille readers and had been to a museum in Turkey at least once, and several of them had visited museums abroad. More information about the participants is given in Table 2.

The study was approved by the Ethical Committee of Education and Human Sciences of Anadolu University. Participants were informed of the aim of the study, and their consent to participate in the study was obtained verbally. To this end, the interviewers asked participants whether they were voluntarily participating in the study. Participants were asked to verbally state their confirmation, which was audio-recorded. Two of the participants were under the age of 18. Their parents' approval was obtained in addition to their consent.

3.3 Data sources and collection

Semi-structured, in-depth interviews were conducted with the participants to uncover how individuals who are BPS define a museum, experience museums in general and a 3D-PAM, and their suggestions to improve the 3D-PAM. An interview guide was developed by the researchers. Three experts—a researcher with experience in 3D printing technology in education specifically for learners who are BPS, a researcher with experience in both qualitative methodology and educational measurement and evaluation and an educator who is blind—were consulted about this guide, and modifications were made based on the feedback. A pilot interview was carried out with a preservice social studies teacher with blindness. In the light of the experts' views and the feedback from the pilot interview, the semi-structured interview guide was finalized. The topics addressed in the semi-structured interviews were the following: participants' profile (gender, age, level and field of education, profession, condition of vision, onset of visual impairment and blindness, and whether the participant had visited a museum before), definitions of museum, experiences during their museum visits, assessment of their 3D-PAM experiences, and suggestions regarding 3D-PAM (see Appendix 1—Interview Guide). Author 1 and Author 2 carried out the interviews in a quiet place near the 3D-PAM exhibition. Interviews lasted between 8 and 31 min (mean ≅ 15 min) and were conducted in person. All individual interviews were audio-taped upon consent.

3.4 Data analysis

Qualitative content analysis, which attempts to identify core consistencies in the meanings, themes, and patterns in data [28], was used in this study. Authors 1 and 2 independently analyzed the data to distinguish patterns characterizing participants' definitions and experiences of museums in general, their experience of the 3D-PAM, and their suggestions to improve it. Because content analysts pay close attention to the nuances of every word in a data set [29], the researchers carefully read the text after all the interviews had been transcribed verbatim. In a qualitative content analysis, the research goal specifies the standpoint from which researchers examine their data [30]. In this study, our research interests were reflected in the semi-structured interview questions, regarding which the steps described by Schreier [30] were followed in the analysis: deciding on research goals, selecting the material, building a coding frame, dividing the material into units of coding, trying out the coding frame, evaluating and modifying the coding frame, main analysis, and interpreting and presenting the findings. To ensure reliability, the two researchers' analyses were compared. There was 92% agreement [31] between them. The disagreement was discussed, and the differences were eliminated and consensus obtained.

4 Findings

The study findings have been gathered under four themes: definitions of museums by participants, participants' previous museum experiences, participants' 3D-PAM experience, and future suggestions for 3D-PAM. The study findings are presented with direct quotations from the interviews conducted with the visitors of 3D-PAM who are BPS.

4.1 Museum definitions by people who are BPS

Within the scope of this study, the first thing to complete was to find out how the participants characterized museums and their previous museum experiences. A closer examination of their opinions revealed that their definitions were mostly based on experience and theoretical information. Those based on experience were distilled from participants' earlier museum visits, and the theoretical definitions were a result of learning experiences about museums that the participants had accumulated from different sources (e.g., teachers or books). An analysis of the findings yielded that

earlier experience played a primary role in how most of the participants defined museums.

4.1.1 Experience-based definitions

Various definitions provided by the participants about museums included "A place where I can touch nothing" (5 participants); "A place where information is limited to description" (4 participants); "A place with no accessibility" (2 participants); "Things behind glass walls" (2 participants); "Sad places" (1 participant); and "Boring places" (1 participant). Thus, it is possible to state that participants' negative experience influenced how they defined museums. Experiences regarding accessibility through touching or description, and the opinions derived from these encounters, seem to rest at the heart of all definitions. Thus, one can deduce that what a museum is for people who are BPS is affected by their previous experience. Below are some samples of experience-based definitions provided by the participants:

> "Museums are places where lots of artifacts are kept behind glass walls and where I can get information only if somebody bothers to describe the artifacts to me." (P1)
> "To me, museums and museum expeditions are the same as taking a walk. It feels like walking indoors or somewhere with a mystical atmosphere. It is sad that it has no meaning. Thus, museums are sad places for me." (P6).
> "I have always imagined museums as places where some things are kept behind glass walls and where my companion tries to explain things to me with his/her limited knowledge. I get bored of museums quickly." (P8).

As is obvious from the above quotes, participants' previous experiences with museums mostly point to sad and boring places where touching is not allowed, things are kept behind glass, information is limited to description, and accessibility is not fully developed.

4.1.2 Theoretical definitions

Among the theoretical definitions provided by the participants are descriptions such as "where artifacts are kept and examined" (1 participant); "a journey into history" (1 participant); and "time capsule" (1 participant). Below are relevant quotes from what the participants verbalized:

> "A place where mostly historical and famous artifacts are preserved and publicized." (P2)
> "To me, a museum means history. It is like being able to feel and see things that were in the lives of people in times past." (P5)

4.2 Previous museum experiences

A quick investigation of participants' earlier museum experiences yielded that all participants had been to a museum in Turkey at least once, and two had visited different museums in cities abroad. The reasons for the participants' museum experience included personal interest, touristic expeditions, school expeditions, and business travel. When the participants were asked to talk about their previous museum experience, they mostly listed the problems they encountered during their visits. These problems were "no touching" (8 participants); "inadequate descriptions" (4 participants)"; "poor accessibility" (2 participants); and "lack of guidance" (1 participant). Relevant quotes are as follows:

> "Sure, there is this museum atmosphere that you can't avoid. The historical ambience around you and the information you get, but still you don't get to live the feeling genuinely. You are lucky if you find someone to describe for you. Sometimes you can't ask what you want to learn; s/he gives the details s/he likes and makes you feel like you have to thank them for what they tell you. You do not get to touch anything. People look at them, but you just walk by the artifacts." (P2).
> "I wanted to touch, but they did not allow me. We couldn't overcome this problem, so I couldn't move beyond the problems because I was stuck with 'no touch.'" (P3)
> "If there hadn't been anyone with me during my visit, and if I had gone there as a blind individual alone, I would have understood nothing because there were no accessibility opportunities at all." (P5).

The quotes above indicate that the earlier museum experiences of people who are BPS are full of negative memories. The main reasons for such results are rules against touching and a lack of descriptions and accessibility opportunities for people who are BPS. The museums did not represent pleasant and useful places for the participants. Without proper accessibility improvements, their museum visits were instead meaningless experiences.

4.3 3D-PAM experiences

In this study, participants' opinions about their 3D-PAM experience were identified. Relevant responses by the participants include "I liked it" (5 participants); "stimulating" (2 participants); "accessible" (2 participants); "reinvigorating theoretical knowledge gained at school" (1 participant); "a special experience" (1 participant); and "exciting" (1 participant). Following are several quotes from what the participants stated:

"It is really pleasing; you can feel what people see with your hands. Hands are our eyes, you know. Thus, I'm not sure what actual seeing is, but I feel that I really saw these artifacts." (P2)
"I liked it. The models are exactly like the artifacts; there are fractures and cracks on the models as well. Imagine that I'm in a museum with a friend—I can tell him/her that there is a crack on the edge of the artifact. I guess this may be further developed, and this is really stimulating for people with visual impairment." (P1).
"When you hold a three-dimensional object in your hands, you feel like you're onto all relevant information about this object, and it's the case actually. Therefore, I was really happy during this visit. There is some sort of information there, and I can access the same information as other people, and this makes me happy." (P8).
"Three-dimensional models were enough on their own for me to understand everything. I liked it. This was the first time for me with such an experience—everything was fully accessible." (P5)

The participants stated that they became happy as their sense of touch was triggered. Moreover, they underlined that three-dimensional models reflected every detail of the artifacts, which led to a comprehensive examination of the artifacts and an increased feeling of the greatest possible accessibility. So, 3D-PAM can be considered a "stimulating" experience in terms of increasing the possibilities for people who are BPS at museums. In addition, the participants noted that a 3D-PAM has some other advantages, such as "touchability" (4 participants)"; "comprehensive examination" (3 participants); "perception of entirety" (2 participants); "concreteness" (2 participants); "knowledge gain" (2 participants); "visual memory initiation" (1 participant); and "cultivation" (1 participant). Some of relevant opinions recorded by the participants are as follows:

"You know that there is an artifact like that in the museum, and you touch the exact same model of that artifact. Maybe that specific artifact is behind a glass frame in the museum, not something anyone can touch. But you do not have to worry about that thanks to the 3D model. You can touch and examine it any way you like, and you gain knowledge about that." (P1).
"Since I haven't been able to touch such artifacts in museums, I had to learn about them from books, and words were the only things I could see about them. I have never had the chance to feel the artifact with my hands. Take the bust of Nefertiti, for example. I have read a lot about this historical figure and I know a bit about her, yet I had no chance to visualize her appearance. I always wished to be able to touch the artifact. Now, I've done that." (P7).
"There is a misconception, like visual memory does not work for the blind. It of course does work. We visualize things we touch in the eyes of our minds. For example, I had the chance to examine a replica of Aphrodite earlier, and I know that plump women were more attractive in the old days. Here, I had the chance to see that even better. In addition, the biggest difference is the perception of the entirety of the model. Let's say you touch something on a Vatican wall, and you can't reach some part of it. Here, you can manipulate the models any way you like." (P9).

As can be understood from the participants' opinions, the 3D-PAM experience provided people who are BPS opportunities such as touchability, concreteness, perception of entirety, comprehensive examination, visual memory initiation, and cultivation. The descriptions below show how the participants verbalized relevant opinions:

"In regular visits, there are guides, and they tell you stories about the artifacts. Here, you can directly feel the event. You can feel the surface, and you can touch." (P3)
"'No touching' is a serious problem in other museums. Everything is behind glass, but you can touch here." (P8)
"Many people die in Turkey without ever going abroad. I believe this experience is worthwhile for those people. Of course, it is not the same as a real visit, but sighted people can go on online museum tours and look at the pictures of the artifacts. They have lots of options in terms of visualization, and 3D printing gives the same opportunities to people who BPS." (P7).

4.4 Future suggestions for 3D-PAM

The participants made several suggestions based on their experience of the 3D-PAM. These suggestions were made for "improvement of 3D-PAM" and "propagation of 3D-PAM." The suggestions regarding improvement of 3D-PAM include "providing audio descriptions" (4 participants); "increasing dimensions of artifacts to show much detail" (4 participants); and "increasing diversity of artifacts" (3 participants). Following are several quotes from participants:

"To make it better… For example, on another stand there was a cell model that was describing the cell verbally when touched with pen. Such kind of applications, verbal descriptions can be added." (P4)

"The dimensions could be increased, the details could be clearer. For example, we saw a Chinese coin. If it was printed in exact size of the original we can enlarge it and make the details clearer. I mean if you say "Look this is the exact size of the artifact, we enlarged it for you to show the fine details on it" this could be pleasing for me." (P11).
"I suggest to include some complex construct such as big mosques, churches, towers, castles. Adding more complex things." (P8)
"Number and diversity of artifacts exhibited can be increased more. Of course, maybe you have other artifacts that you could not bring here now." (P6)

Among participants' suggestions to improve 3D-PAM, providing audio descriptions and increasing dimensions of artifacts were prominent. Specifically, the suggestion to increase dimensions of the artifacts were given to feel much detail on the artifacts. In addition, suggestions were made to increase the diversity of artifacts and to include more complex architectural constructs in 3D-PAM.

Besides suggestions for improvement of 3D-PAM, participants also made suggestions for propagation of 3D-PAM, which were clearly associated with integrating it into museums. The suggestions regarding propagation of 3D-PAM included "integration of 3D-PAM into all museums" (5 participants); "putting public pressure" (3 participants); "organizing events to introduce 3D-PAM" (2 participants). Below are relevant quotes:

"I wish we could touch every artifact, but we know that is not possible. If we can't do that, there are two options for all museums, and even better if they can do both at the same time. One, there should be verbal descriptions, and two, three-dimensional models should be incorporated." (P8).
"As far as I'm concerned, we could integrate this into every museum and anything visual. This could also work for art exhibitions." (P2)
"If you can make this standard for all museums, and if people can access all artifacts in this way, it will be tremendously helpful." (P7)
"Museums should learn such things to make artifacts touchable and realize that this is not a need, this is an accessibility right in fact." (P11)
"Such things do not happen because the authorities want them to; there should be a kind of public pressure. If we can start this in one or two museums, then we can ask the other museums to integrate such models into their collections as well. We can push them a little by saying how useful such technology is." (P7).
"Using media for such useful goals, more coverage, and introducing such experience with short public announcements like 'I can access information easily' or 'I walk around the museums freely.' This could stop people from belittling such efforts and could attract more attention. It matters a lot to discern the differences [between the 3D-PAM and traditional museums, for people who are BPS]." (P6).

According to the participants' opinions, they prefer three-dimensional models to be presented together with the real artifacts in museums, and they feel that the incorporation of verbal descriptions will be a major step toward enhancing accessibility options at museums. In this sense, the participants seem to expect museums to improve accessibility by using this technology. Furthermore, participants expressed the belief that this technology can be expanded to other visual fields, such as art exhibitions. The participants also felt that some kind of pressure should be put on policy makers and the public to enable the implementation of these suggestions. Below are some relevant quotes by the participants:

"Such things do not happen because the authorities want them to; there should be a kind of public pressure. If we can start this in one or two museums, then we can ask the other museums to integrate such models into their collections as well. We can push them a little by saying how useful such technology is." (P7).
"Using media for such useful goals, more coverage, and introducing such experience with short public announcements like 'I can access information easily' or 'I walk around the museums freely.' This could stop people from belittling such efforts and could attract more attention. It matters a lot to discern the differences [between the 3D-PAM and traditional museums, for people who are BPS]." (P6).

According to the participants, three-dimensional printable artifacts should be incorporated into the collections of every museum, some sort of public pressure should be created, and publicity activities should be organized. Stating that such efforts would improve the accessibility opportunities that museums provide, the participants felt that museums would become more interesting and worth visiting for them. Some of the participants noted that through such a transformation, they could either visit every museum or choose those offering three-dimensional printable artifact models and that museums would be more meaningful places for them, which gives them hope.

5 Discussion

The current study indicates that people who are BPS define museums based on their previous experience and theoretical knowledge. For most of the participants, the definition

of a museum was associated with their negative experiences. In this sense, museums were generally defined as sad and boring places where touching is not allowed, artifacts are kept behind glass walls, information is limited to descriptions, and accessibility is poor. As for participants' theoretical definitions, history and culture were underlined, and museums were defined as spaces that enable visitors to travel back in time and where historical artifacts are preserved and examined. The current study is in line with previous research. The results of Buyurgan [32] reached after studying the experience of university students who are BPS at the Museum of Anatolian Civilizations are consistent with those of this study. Buyurgan [32] also reported that people who are BPS people had poor background knowledge of museums, and the results of Garip and Bülbül's [33] study, which was conducted at the Science and Technology Museum of the Middle East Technical University (METU), indicate similar findings. In both studies, the barriers and showcases where artifacts are displayed were reported as major problems that people who are BPS have to tackle. As for suggestions, Buyurgan [32] and Garip and Bülbül [33] recommend converting science centers and museums into a hands-on format, which is expected to make the experience for people who are BPS more meaningful. Similarly, Handa et al. [7] revealed that collections for touch were one of the priority needs of people who are BPS during their museum visit. Additionally, Vaz et al. [13] described the limited experiences of visitors who are BPS at museums due to unavailability of objects or replicas to touch. The demand of visitors who are BPS for accessible replicas or objects to touch is also mentioned in other studies [11, 12, 14].

As mentioned, all participants in the present study had been to a museum in Turkey at least once, and several of them had visited museums abroad. They had visited museums for several reasons, such as personal interest, touristic expeditions, school expeditions, and business travel. Almost all participants faced challenges such as no touching, poor descriptions, and lack of proper guidance. Such barriers prevented participants from truly experiencing their visits at museums, and in turn, museums have become meaningless and troublesome places for them. Descriptions of museums provided by the participants help us imagine how poor their experiences were. Therefore, it is possible to state that both the negative experience of people who are BPS and their reluctance to visit museums stem from lack of regulations to change museums into interesting and experiential places for people who are BPS. These findings are in line with those of Yeşilyurt et al. [34], whose study was conducted to evaluate the museums in Izmir with respect to facilities and challenges for people who are BPS. The results of their study reveal that there is not a single museum that meets the needs of people who are BPS and that the reasons preventing these individuals from visiting museums are physical, personal, and interpersonal in nature. Similarly, Argyropoulos and Kanari [9] highlight the negative feelings of people who are BPS during their museum visits, such as disappointment and upset due to the lack of accessibility. Levent and Pursley [35] also underline that individuals who are visually impaired are reluctant to visit museums because these visits mostly turn out to be disappointing experiences for them.

Barkai [36] states that virtual reality and three-dimensional printable technologies may enrich such experiences for people who are BPS. Likewise, our results show that the 3D-PAM experience was a horizon-broadening exception to museum visits for people who are BPS. Moreover, the results of Kleege's [37] study, carried out at the Museum of Modern Art in New York, also show that touchable materials in museums add meaning to museum visits for people who are BPS. Another study, conducted by Buyurgan and Demirdelen [38], revealed compatible findings. In their study, a museum visit program was designed to teach the lifestyles, belief systems, and arts of Anatolian civilizations to a blind university student, and the student was taken to the Museum of Anatolian Civilizations. The museum visit program included opportunities such as touching replicas of pre-chosen artifacts, listening to audio descriptions, completing worksheets to evaluate learning, and participating in the educational workshop of the museum. Exciting and active learning was achieved by taking advantage of these opportunities.

Many studies in the literature point out that the unavailability of access through touch is one of the major barriers that people who are BPS encounter during their museum visits [7, 9, 12–14]. To overcome this challenge, 3D printing promises to play an important role. As Neumüller [20] states, 3D printing has the potential to alter the landscape of multisensory experiences in the field of cultural heritage and to play a vital role in research, documentation, and education. In this sense, it would not be wrong to conclude that a 3D-PAM, via touching and the perception of entirety, is a more educational and accessible museum experience for people who are BPS. Moreover, 3D printing is not limited to replicas of artifacts; it can also be used to meet specific needs. For instance, in the study by Urbas et al. [39], touchable floor plans were developed for people who are BPS.

Suggestions set forth by the participants after their 3D-PAM experience are directed to improve 3D-PAM and propagate 3D-PAM. Suggestions include the integration of three-dimensional printable artifact models into all museums, an increase of the number and dimensions of 3D printable artifact models, and the exhibition of 3D printable models side by side with the original artifacts. Other means to accessibility (e.g., verbal description, information cards in Braille) were also noted as a necessity. In addition, participants recorded that the use of 3D printing technology should not be limited to historical artifacts but should be integrated

into other visual fields as well. According to the participants, policy makers and the public will play a major role in this process; creating a sort of pressure mechanism by using publicity tools will be helpful in integrating 3D printable models into all museums. All participants felt that 3D-PAMs offer new opportunities to turn museums into more accessible, interesting, and pleasant places for people who are BPS.

Suggestions distilled from this research are as follows:

- Awareness-raising initiatives concerning a more active use of 3D scanning and printing technology in museums should be organized; these efforts should be supported by governments and the public.
- Museums should establish 3D scanning and printing units to turn their collections into 3D printable models, and they should make them accessible to people who are BPS by combining them with other means to access collections. Relevant training programs should be developed.
- Museums in Turkey and other countries should be encouraged to take part in the Scan the World project to enhance access to museums located in different parts of the world. On their websites, Turkish museums should make their collections accessible by 3D scanning technology.
- To expand the use of 3D-PAMs in education, the necessary infrastructure should be established to improve the knowledge and competence of teachers and school administrators regarding students who are BPS.

6 Conclusion, limitations, and future work

6.1 Conclusion

The research presented in this paper aimed to examine the potential of 3D printing technology to increase the accessibility of museums to visitors who are BPS. For this reason, we had 11 participants who are BPS experience a touchable museum, which we call a 3D-PAM, and tried to unravel how they experienced and reacted to it by conducting semi-structured, in-depth interviews with them. The qualitative findings of this study provide concrete evidence that 3D printing technology, a 3D-PAM in this case, is a promising opportunity for museums to become more accessible to visitors who are BPS. Our findings reveal that people who are BPS theoretically, according to their definitions, value museums because they enable visitors to travel back in time and examine historical and cultural artifacts; practically, however, people who are BPS experience museums as sad and boring places due to the accessibility barriers they faced during their visits, for example, the "no touching" rule, poor descriptions, and the lack of proper guidance. Additionally, findings show that by removing these barriers, specifically the rule against touching, the 3D-PAM offers new opportunities to turn museums into more accessible, interesting, and pleasant places for people who are BPS. Furthermore, the participants' suggestions for improving the 3D-PAM support its contribution to making museums accessible to visitors who are BPS.

6.2 Limitations

This study was conducted with a relatively small number of participants, which does not allow the generalization of the results. Future studies with diverse and large samples should be conducted. Furthermore, the average age of the participants in this study was 28, and their ages ranged from 16 to 42. The views of younger or older visitors were not available, but it is necessary to make 3D-PAMs accessible to people who are BPS of all age groups. Because most of the participants also held an undergraduate or graduate degree, it should be determined how 3D-PAMs can be arranged for visitors of different ages and diverse backgrounds and what needs and preferences such visitors may have. Research that differs in terms of the age groups and education level of participants should be conducted in the future. Furthermore, this study was conducted during the 3D-PAM's first exhibition. The artifacts were not colored, and any equipment for visitors to examine the artifacts more closely, such as magnifiers, were not provided. Because two of the participants were severely vision-impaired, the unavailability of colored artifacts and magnifiers may have constrained their experience. Thus, this study may be limited in what it reveals about potential museum experience of partially sighted visitors, which may in fact be richer. Additionally, individual semi-structured interviews were the only means of data collection in this study, and the data could not be triangulated. Future research using different data collection techniques and triangulating the data could approach the topic from a broader perspective.

6.3 Future work

This study shows that people who are BPS have a negative perception of museums due to their inaccessibility. Some museums around the world are trying to solve this problem by, for example, using 3D replicas of artifacts to increase accessibility. It is anticipated that these practices will become widespread in the near future. Nonetheless, 3D-PAMs are a very new topic, and research remains scarce.

In this study, the 3D-PAM emerged as an alternative museum type that makes the museum experience accessible for people who are BPS. Therefore, we believe that, besides its integration into museums, a 3D-PAM's existence as an alternative and separate museum type is highly important

for people who are BPS. We also suppose that this alternative museum type can prevent different access restrictions beyond visual impairment. As the research participants stated, for many people, it is very difficult for economic reasons to visit museums around the world. Although virtual museums partially solve this problem for sighted people, obstacles of access remain, especially for people who are BPS. 3D-PAMs also emerge as a solution for this problem. Moreover, 3D-PAMs have the potential to allow applications that do not have space constraints. For example, by making 3D-PAMs mobile, it is possible to reach more people, not only those who are BPS but also other disadvantaged groups, such as the elderly or people with a physical disability or in rural areas. For all these reasons, we consider it important to conduct future research on 3D-PAMs, continuing to contribute to it and improve it.

As mentioned, this study was conducted during the 3D-PAM's first exhibition, and the participants' suggestions and the authors' experiences were factored into improving the 3D-PAM. For example, in subsequent exhibitions of the 3D-PAM, audio descriptions that work with quick response (QR) codes were provided. In addition, magnifiers were made available for partially sighted visitors to examine the artifacts more closely, and the artifacts were colored manually by an expert in visual arts in accordance with the originals. Although the implementation of these recommendations ameliorated the 3D-PAM, it is still open for improvement with respect to both theory and practice. It is known that to enhance accessibility and to fight info-exclusion, there are some promising initiatives, for example, the integration of a mobile and adaptive augmented-reality navigation system for museums [40]. Future research might deal with improving the 3D-PAM by using other assistive technologies, such as talking kiosks and indoor navigation assistants, and test their effectiveness. Furthermore, because we used FDM 3D printers to print artifacts and set much store on tactile quality, we removed the support material and sanded the surface of the artifacts to smooth the layer lines. Given the possibility of damage in this process, and so as to create a tactile experience as complete as possible, Balletti et al. [18] suggested using printers with selective laser sintering (SLS) 3D printing technology. Future research might compare different 3D printing technologies, taking into account their pros and cons and evaluating visitors' experiences.

As stated by Wilson et al. [23], olfactory, optical, and acoustic properties are essential for perceiving and understanding objects and must be incorporated to help facilitate clearer interpretation, no matter the difficulty. However, the possibilities of 3D printing are currently insufficient to reproduce these authentic object properties [23]. With the advances in 3D printing technology, future studies might shed light on this issue.

We strongly advocate the potential of 3D printing to provide promising opportunities for museums, research, documentation, and education. As for our future plans, after enriching the 3D-PAM's collection and improving its design based on the suggestions of visitors and of experts in the field, we plan to integrate 3D-PAMs into education, specifically into history education for students who are BPS and sighted.

Appendix 1: Interview guide

1. What does a museum mean for you? Could you please explain?
2. Have you ever been on a museum visit? If yes, which museums did you visit? Was there any specific reason for these visits?
3. How did you feel during those museum visits you mentioned?
4. Were there any challenges during your museum visits? If yes, could you please explain?
5. What do you think about your 3D-PAM experience? Could you please explain?
6. How did you feel while examining 3D printed artifacts?
7. If any, what were the benefits of the 3D-PAM experience for you?
8. If any, what changes have occurred in your perspective on museums?
9. If any, what were the differences of your 3D-PAM experience from your regular museum visits? Could you please explain?
10. What are your suggestions to improve the 3D-PAM? Could you please explain?
11. Is there anything else you want to add?

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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