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Evaluation of augmented reality communication using the visual framing methodology

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ABSTRACT

Augmented Reality (AR) and Virtual Reality (VR) technologies have been increasingly employed in exhibition communication in the last decade. These tools may also be used to assess the results of museum learning. Despite growing adoption, little research has examined how AR/VR technologies convey exhibition content and support interpretation. Museum exhibitions catalyse aesthetic enjoyment, but they are also sophisticated learning environments that are sources of knowledge, like learning tools or textbooks. Furthermore, museums may be interpreted as specific learning spaces where basic concepts, value structures and interpretive models of relevant shared culture are articulated. This paper presents usability studies of AR-based exhibition guides developed by the first author. Three visitor studies (pilot, improved version, optimized tool) in different exhibition settings with 142 students were designed. Our objective was to assess how AR-based guides enhance communication and visitor experience. To this end, we developed an evaluation tool grounded in visual framing theory, aimed at measuring how effectively these tools convey curatorial messages and support interpretive engagement in exhibition contexts. The results of this study showed the successful application of the guide and the high potentials of virtual technology for visitor engagement and museum learning.

Abbreviations: AR: Augmented Reality; CTS: Control-Group Task-Sheets; ETS: Experimental-Group Task-Sheets; VR: Virtual Reality

KEYWORDS

Visual framing; augmented reality; exhibition communication; museum learning; framing theory

Introduction

The increasing use of augmented reality (AR) technologies in museum settings offers new opportunities to enhance visitor engagement and support learning processes. Numerous studies have examined the usability and educational potential of AR-based tools in exhibitions (Kuttner & Kárpáti, 2023), but little attention has been devoted to the role these tools play in interpreting exhibition content and how they facilitate its reception. The application of AR technology does not always make it clear whether the conveyed content significantly contributes to the understanding of the exhibition. This question is particularly important when AR is not merely a visually striking supplementary attraction, but actively shapes the interpretive framework of the exhibition.

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The practical motivation for the research stems from the recognition that there is currently no tool available to systematically examine the content and interpretive impact of museum AR applications. It is important for both curators and developers to know whether AR tools actually support the communication of exhibition messages or distract attention from the exhibited objects. The aim of this study is therefore not only theoretical but also relevant from a practical point of view: it can contribute to more conscious, content-focused AR development in the museum sector.

This study aims to fill this gap in research and practice by developing a research method based on the theory of visual framing, which allows for the examination of the processes of interpreting content conveyed by AR devices. Bock's (2020) theory of visual framing was adopted in this study as the primary analytical and methodological foundation, due to its emphasis on multimodal meaning-making and material aspects of visual communication. Rodriguez and Dimitrova's (2011) model also informed the study by offering a structured framework for analyzing different levels of visual interpretation. The four-level model is particularly relevant for the study of exhibition communication, which is fundamentally based on the principle of visibility (Hooper-Greenhill, 2000), as well as multimodal but strongly visually based augmented reality. The theory of visual framing serves not only as a theoretical starting point for the present research, but also as a methodological basis: it provides an opportunity to systematically explore how AR tools contribute to the communication of the intended messages of an exhibition and how they shape visitors' interpretation processes. Furthermore, it is also suitable for exploring how the exhibited objects structure visitors' interpretations and how they influence their thinking, attitudes, or emotional reactions. By analyzing the levels of the model, it is possible to examine the extent to which the content conveyed by AR tools is coherent with the intended messages of the exhibition and how visitors decode them.

Building on this gap, this study proposes an assessment tool grounded in visual framing theory, designed to enable the systematic analysis of AR technology-mediated interpretive processes in exhibition contexts.

Objectives and research hypotheses

The primary objective of this study was to develop a measurement and evaluation framework suitable for examining the impact of AR technologies on visitors within the context of exhibition communication. The system is intended for use primarily in exhibition environments where the curatorial concept, as well as the selection and display of objects, is based on a predefined meaning or interpretive framework. The central research question was whether the AR-based exhibition communication tool is capable of effectively conveying the intended message, and whether the interpretive frames of the content presented can be identified in visitors' responses. We formulated three research hypotheses, related to the three educational experiments through three museum Visitor Studies:

- In Visitor Study 1, the pilot experiment, we used the first version of the survey tool and analyzed its applicability.
- In Visitor Study 2, the improved version of the tool was assessed.
- In Visitor Study 3, we optimized the tool for easier use in museum education settings.

Theoretical framework

Visual framing in relation to digital guide and visitor study

Modern technologies like mobile or wearable devices, offer '*new ways for the people to connect with their environments and share their experiences*' (Hughes & Moscardo, 2017, p. 47). The development of an AR-based exhibition guide and the visitor study to test its effects was based on the theory of framing. Robert Entman (1993) considered framing a model that may grasp the 'power' of the communicated text to show exactly how communication influences the human mind. Angela Bock (2020) described framing as the conceptualization of metaphors, in which we isolate concepts, themes or problems through frames. This procedure helps us identify the constituents of events, and thus channel cognitive activities of the audience towards certain interpretations or moods (Entman, 2004; Harley, 2022). Previous research shows that framing is a reliable method of analysis for text and media messages as well (Burgers et al, 2016; Ottatti et al., 2014; Semino et al., 2018). In the context of exhibition communication, framing constitutes a particularly valuable analytical framework, as it facilitates the exploration of how visitors interpret the exhibition's message, as well as which meanings are foregrounded and which are marginalized in the process.

In exhibition communication, predominantly visual forms of communication are employed to transmit messages about visual objects. Unlike text-based discourse, visual communication employs phenomenological and material effects to attract attention (Bock, 2020). Visuality, however, does not guarantee explicit and exact explanation like the generally accepted layers of meaning of textuality, formed through social discourse. Explanatory images, on the other hand, are usually based on similarity or analogues (Ahn et al., 2015). Therefore, images are not always able to explain complex causal relationships (Rodriguez & Dimitrova, 2011).

Visual framing may also be applied for the interpretation of objectives and functions of museums. While studying research on visual framing, Bock (2020) identified three operational constructs. The first, *selection,* shows how an image is recontextualized by its environment and in symbiosis with words, transmits meaning. The second, *creation*, decontextualizes the pictorial reality with the help of visual conventions like distance between formal elements and their interrelationships in the composition. Bock presumes that this second construct resembles the narrator of a theatrical play – an actor who may not be visible, still plays an important role in the narrative. The third construct, *solution*, appears in the mind of the spectator as a revelatory experience, the moment of deep understanding.

These constructs of visual framing may be compared to the classic task system of museums: the *collection and safekeeping* of objects; *collections research* and creation of new knowledge based on this research; and *presenting* the collection and thus disseminating achievements of human culture (Rea, 2008).

The levels of visual interpretation are important for the use of digital guides. The major benefit of AR digital guides is their multimodal nature: they can integrate textual information with related imagery and anchor them to works of art through place-sensitive recall. In contemporary exhibition environments, we experience the exponential growth of such digital applications. In terms of communication, AR/VR applications integrated in these digital sources of information can be considered

multimodal (Ruttkay & Bényei, 2018). Supported by technology, metaphoric messages may be conveyed in images, oral or written text, sound, music, even gestures (Forceville, 2015). Expanding Erwin Panofsky's three-step method of visual interpretation: (1) primary or natural subject matter; (2) secondary or conventional subject matter, the field of iconography; (3) tertiary or intrinsic meaning or content, the field of iconology (Panofsky, 1932/1970), Rodriguez and Dimitrova (2011) suggests studying these complex media texts through a framing model that identifies four levels of visual frames. According to their model, on the first level, the representational visual image is presented as a denotative system that helps us answer questions like 'Who or what is represented?' The second level shows the image as a stylistic-semiotic system that helps us identify how certain pictorial styles and conventions gain social significance. The third level identifies the image as connotative system that explains the meaning of persons, objects and concepts. At this level, we discuss signs and metaphors. The fourth level shows the image as an ideological representation that provides information about social, cultural foundations of an age. Here, viewers are likely to rely on cultural and emotional factors (stereotypes, beliefs) more than economic or political facts and data, when forming an opinion about a contemporary problem or judging a historic period. The example used by Rodriguez and Dimitrova (2011) is the overwhelming use of images of African Americans in magazines when discussing poverty issues, disregarding household statistics. The authors claim that the four-level model may be applied for the analysis of any visual media content and its reception by viewers.

Building on Entman's (1993) foundational definition of framing, Bock's (2020) model was adopted as the primary analytical framework for this study, due to its strong emphasis on the multimodal and material dimensions of visual framing. While Rodriguez and Dimitrova's (2011) four-level model provided a valuable coding scheme for structuring visual content, Bock's approach better aligned with the immersive, technologically mediated nature of augmented reality in exhibition settings (see Table 1). Her framework recognizes that meaning is constructed not only through visual signs, but also through spatial positioning, user interaction, and the material presence of digital elements – features that are central to the functioning of AR-based guides. Therefore, Bock's theory offered the most suitable foundation for examining how framing devices embedded in AR applications contribute to the communication of curatorial messages and the structuring of visitors' interpretive processes.

Educational role of museums

The use of museum spaces as educational venues dates to the art academies of the 19th century, where compositional structures and other stylistic features of masterpieces were studied by aspiring artists on site through copying and paraphrases. The museum space has become a non-formal learning environment through the initiatives of the Reform Pedagogy movement at the beginning of the 20th century. The concept of the 'active learner' by Dewey (1900/1990) that emphasizes activity-based teaching and learning, or the discovery learning model by Jean Piaget and Bärbel Inhelder (1966/2012) influenced the way museums engaged their audience at exhibitions. Bloom's (1956) taxonomy emphasized the importance of affective and psychomotor

Table 1. Comparison of framing models applied in the study.

Author(s)	Focus	Modality	Key features	Interaction level	Suitability for AR
Entman (1993)	Political / media discourse	Textual	Provides theoretical grounding (e.g. selection, emphasis)	Low – passive audience	Limited relevance for AR; offers general framing principles
Rodriguez and Dimitrova (2011)	Visual journalism	Static visual content	Four levels of visual framing	Medium – viewer interpretation	Useful for coding visual depth and narrative structure
Bock (2020)	Visual communication in digital environments	Multimodal / spatial	Emphasizes materiality, spatiality, user interaction, digital metaphor	High – user movement, touch in AR	Highly suitable for AR's immersive, interactive context

enhancement in synergy with cognitive development also affected the way exhibitions were supported through more and more interactive and multisensory guidance.

At George Hein's practice-based model of the constructivist museum, knowledge acquisition is less important than the organization of previous information and connecting it to new experiences (Hein, 1998). Falk and Dierking (2011) focus primarily on visitor experience and develop their exhibition communication model on the basis of research about the constituents of the museum experience as conceptualized by Jensen (1994). This summary is intended to indicate the profound change in the perception of the optimal visitor behaviour: from passive recipients to active participants in the meaning-making process, who conceptualizes, shares and reconceptualizes the cultural experiences provided by the exhibition (Simon, 2016). Therefore, museums should become relevant venues for the visitor, meaningful spaces that support the interpretation of contemporary existence (Bishop & Perjovschi, 2014). Virtual technologies offer authentic and effective tools to support contemporary cultural encounters (Kuttner & Kárpáti, 2023).

The museum as a venue of cultural communication

A museum can be considered as a medium that using objects as signs (Maroević, 2005), and museum communication may be perceived as an information system operating with objects. In this context, the exhibition is the main interface that creates an environment for the encounter of objects with visitors. The first and most important phase of exhibition design is the formulation of major messages, that must be considered when selecting objects (Kárpáti & Vásárhelyi, 2013). Objects interact with each-other and the exhibition space on the symbolic and semantic level and must be in harmony with the previously defined communication objectives (Bogle, 2013). During the development of the exhibition, curators and experts of science or art communication must develop a complex system to turn messages into experiences, interpretations, and the creation of new meaning (Roldan et al., 2019), that engage the viewer's attention (*wonder*) and evoke the complex, dynamic cultural forces (*resoaonce*) from which the exhibition emerges (Greenblatt, 1990).

Methodological considerations: evaluating museum communication through qualitative and quantitative analyses

The evaluation of museum communication should focus on the perception of messages turned into experiences and interpretations to reveal the process of the creation of new meaning. Qualitative methods seem to be more authentic for the study of the characteristics of museum communication because they reveal the social context as the stage for action while observing cognitive and behavioural processes (Eyisi, 2016). Datasets obtained through the observation of visitor behaviour, however, mostly contain information about the experiences and results of the meaning-making behaviour of visitors. Such qualitative studies are often criticized for difficulties of reproducibility, reliability and applicability. Their results are important, but exhibition planners also need data about the comprehension of their messages that may provide generalizable conclusions for exhibition communication (Eyisi, 2016; Hammarberg et al., 2016).

Data control is difficult, as the participants of visitor studies are the only sources of their experiences and emotions that they may recall and render differently at another time (Atkins & Wallace, 2012). Several researchers consider the intense and often emotionally charged relationship of the data collector and the study participants a hindering factor for the objectivity of the study. Generalizability of results of qualitative studies is restricted also by the subjective interpretation of data, and time-consuming open text analysis results in small sample sizes (Bryman, 2008; Eyisi, 2016; Hammarberg et al., 2016; Johnson & Christensen, 2014; Woksepp & Olofsson, 2008).

To ground the development process of the assessment tool in research on museum communication, we prepared a systematic literature review on the use of Virtual Reality technologies in exhibition communication (Appendix Figure A1). The analysis of studies showed that qualitative measures were used to present the results of tool development, focusing on the technological aspects of the project (Barbieri et al., 2018; Clini et al., 2018; Comes, 2016; Duer et al., 2020). Through quantitative assessment, positive or negative effects of VR technology on visitor experiences were revealed (Falconer et al., 2020; He et al., 2018; Trunfio et al., 2020). In a few cases, surveys were supplemented by narrative studies and on-site observation Knowledge gain may be less important for the average museum visitor than aesthetic experience but informed visitors appreciate works of art or objects of scientific importance when they are furnished with ideas about their context. Therefore, the major benefit of digital guides supported by AR/VR technology is their edutainment quality (Aguayo et al., 2020; Hammady et al., 2020).

Research corpora and method of research

The major benefit of the AR platforms is an intuitive walk through the exhibition, using a well-known device owned by the visitor, their own smartphones, as a digital guide (Kang et al., 2018). The technology allows designed sounds and soundscapes to integrate into the exhibition spaces, which enhances the visitor experience and enhances a sense of immersion in virtual environments (Rudi, 2021). This research is based on three data sets, each of which corresponds to one of the three Visitor

Studies conducted at different exhibition sites and times. We prepared a digital exhibition guide based on Augmented Reality (AR) technology, using videos integrated in AR platforms for each of the studies. In the first experiment, we used the *Arivive* software, in the second and third, *Arloopa* (The reason for changing the platform is a functionality of Arloopa: this software makes it possible to continue screening the AR content even after the camera of the mobile device loses the trigger focus and the trigger image is blurred.)

We asked visitors to come to the exhibition with fully charged smartphones and earpieces. The guide was installed on the phones before entering the exhibition space (This preparatory phase ran smoothly, with only one participant out of 142 encountering problems because his device was not a smartphone and had to borrow one.) After installing the software, the functions of the guide were explained, and the art works it contained supporting information about were indicated in the exhibition halls. No information outside the guide was available for the visitors, as no interpretive texts were available in the exhibition spaces.

Students of three schools participated in the visitor study. The characteristics of the participants and the exhibitions are summarized in Table 2.

In 2022, 702 exhibition facilities (museums, galleries and other venues with a regular exhibiting activity) recorded 9.9 million visits in Hungary. 33% of the visitors were adult Hungarian museum goers, 36% students (on an educational visit organized by their schools), 10% foreign tourists. Our experiments were aimed at developing tools that might deepen the experiences of this substantial group of visitors whose knowledge and interests are different from those of adults and who are rarely targeted by special explanatory devices.

According to size, Hungarian exhibition spaces may be grouped into three categories: national, regional and local institutions. For our experiments, we selected one of each type. The contents of the exhibitions were the same at all venues: contemporary visual arts. The exhibition communication of modern art in Hungary generally lacks explanatory texts and relies on the effects of the works themselves and the reference materials and catalogues made available in the museum shop – bulky

Table 2. The research corpora and the exhibitions where visitor experience data were collected.

Exhibition title and venue	Participants		Age groups			Date of the study
	Male	Female	15–18 years	19–35 years	36–50 years	
Time Machine – a new selection from the collection. Ludwig Museum – Museum of Contemporary, Budapest	9	38	0	26	21	July 2021
Contemporary private art collections XIX: Péter Kacsuk's collection. Godot Gallery, Budapest	4	11	0	9	6	January 2022
SPACE-MOTION-GAME. Móra Ferenc Museum, Szeged	33	46	69	6	4	June 2022

volumes that students rarely feel inclined to consult. Thus, in the evaluation of the results of the retention studies, the effects of on-site information boards did not have to be filtered out as they were not available.

Schools were approached to delegate groups of students to participate in the experiments were selected from those in the vicinity of the exhibition venues to avoid commuting problems. Art teachers from the selected schools were motivated by our selection of exhibitions of modern art and volunteered to organize the school trips as they found an important learning experience for their students. In accordance with the regulations of ethical research of our university, teachers were asked to obtain parental consent and furnished background information about the students who had been identified by codes for safe data processing and storage. The museums and galleries provided free access to the exhibitions and venues for taking the knowledge assessment tests.

In the first and second visitor study, the participants were students at a post-secondary vocational school for graphic arts and photography. There is an introductory art history module of 26 lesson hours in their training program that briefly summarizes the history of visual arts from the beginnings of artmaking till the present day. Two secondary grammar schools (without art specialization) joined the third museum experiment. These institutions prepare for the baccalaureate (secondary school leaving examination) required for studies in higher education. Secondary school students participated in the visitor study as part of Visual Culture (the discipline for art education in Hungary).

During the experiments, students were randomly assigned to the experimental groups, visiting the exhibitions using the AR guide and control groups who did not use this tool. All groups filled in task sheets during and after their visit. Task sheets of the control group were always evaluated before those of the experimental group, because their answers were included in the survey of the experimental group. Results of the experimental group were compared with those of the control group to reveal the effects of the AR guide as a tool of exhibition communication.

Presentation of the visitor studies

First visitor study at the Ludwig Museum Budapest

The Ludwig Museum – Museum of Modern Art, Budapest is a national institution for the preservation, study and exhibition of modern and contemporary works of art. This impressive exhibition site was the venue of the pilots of our AR museum communication tool. The first visitor study was undertaken at the permanent exhibition of the Ludwig Museum in Budapest, in the summer of 2021 (Figure 1). We have selected photographs of the NeoAvantgarde movement, a stylistic trend that is part of the learning program of future media workers. The content of the digital guide was based on the catalogue of the exhibition and previously discussed with a museum educator and an art teacher for accuracy and educational relevance. The AR application contained 1-minute explanatory videos about five NeoAvantgarde photographs (Appendix Table A1). The text included information about the genesis of the works and the ideas they expressed.

Figure 1. Visitor study at the Ludwig Museum Budapest. *Source:* Photograph by the first author.

Participants of this experiment were 47 students from a post-secondary vocational school for media, 38 women and nine men. As this training program is open to adults, ages ranged between 18 and 50. Every participant finished secondary school with a baccalaureate and spoke at least one foreign language. Only three participants have visited the Ludwig Museum before the experiment.

Second visitor study: Godot Gallery, Budapest

The experiment at the Godot Gallery of contemporary art was the first experimental introduction of the tool after its pilot testing at the Ludwig Museum. The second visitor study was undertaken at the Godot Gallery in Budapest, in a small gallery space of about 50 square metres. 16 paintings of the Concept Art movement were exhibited from the collection of Péter Kacsuk, professor of information technology and owner of an outstanding collection of more than 300 works of contemporary art. Mr. Kacsuk was the curator of the exhibition (Figure 2). His collection contains socially sensitive figurative works that may be perceived as documents of our times, reflecting on sociocultural and political issues in a ironic or even grotesque style.

This exhibition presented the works in pairs, matched up by the collector, who based his selection on visual or content-based cues. The pairs of images represented connections among artists working independently based on technique, colour composition, formal arrangements, messages etc.

The AR guide included multimedia content and narratives by the collector about the way he acquired and matched the works and their expressive qualities (Appendix Table A2). This exhibition guide was also directly related to the study program of the school as it helped students prepare for two topics of their final examination: interpretation of works of contemporary artists of their choice and presentation of an exhibition venue for contemporary arts.

Figure 2. Visitor study at the Godot Gallery. *Source:* Photograph by the first author.

In this experiment, 15 students from a post-secondary vocational school for media participated, 11 women and four men. Every participant finished secondary school with a baccalaureate and spoke at least one foreign language. None of the participants has ever visited Godot Gallery or seen works from the collection of Péter Kacsuk.

Third visitor study: Móra Ferenc Museum, Szeged

The venue of the third experiment was the museum of a county seat in Southern Hungary. The main objective of this experiment was the optimization of the AR museum communication tool for easier use in museum education (Figure 3). The exhibition we targeted with new content was a special event: the results of the collaboration of a scientist-craftsman-museum educator and a contemporary artist. The paintings by Tamás Konok were juxtaposed by wooden constructions representing and explaining scientific phenomena that were inspired by the paintings and created by the biologist and museum educator Tamás Vásárhelyi. The wooden structures were innovative tools of science communication, crafted with great care and talent by the museum educator and scientist. They demonstrated laws of natural science that could be connected to the Constructivist works by the painter.

We prepared a 30-minute AR guide that included explanations of 15 'twin creations' (paintings and constructions) narrated by Tamás Vásárhelyi (Figure 4), their designer and developer. The guide also included explanatory videos and scientific visualizations prepared for the visitor study and inaccessible elsewhere. We evaluated the effects of the AR guide using five pairs of art works and constructions that the creators considered most important (Appendix Table A3).

This visitor study involved 79 participants. Members of the control group were 10 students from a post-secondary vocational school, and the experimental group consisted of 69 students from a secondary grammar school. Many students have already

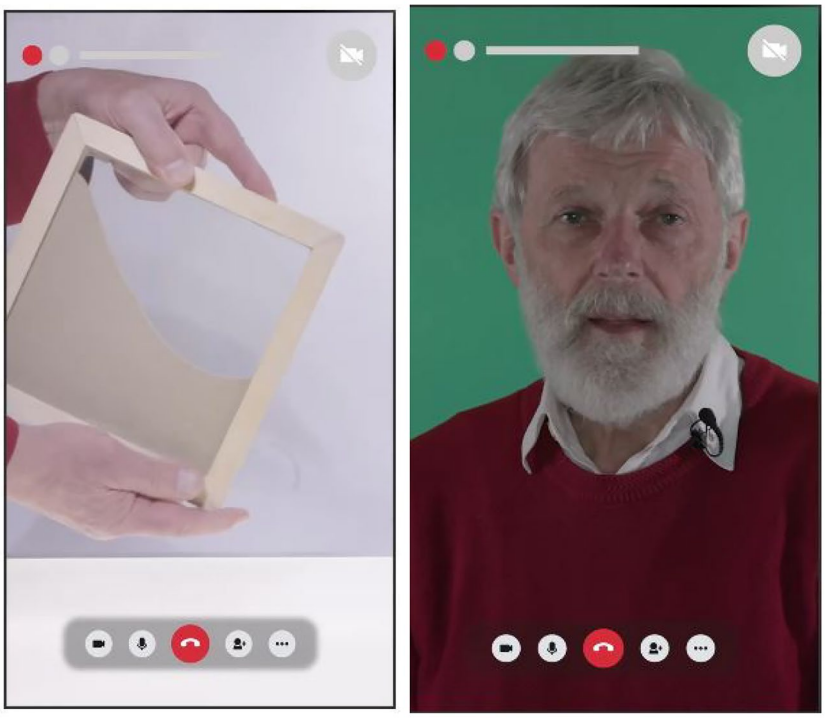


Figure 3. Screenshots from the AR tour guide. Tamás Vásárhelyi narrates and demonstrates an experiment. *Source:* Photograph by the first author.

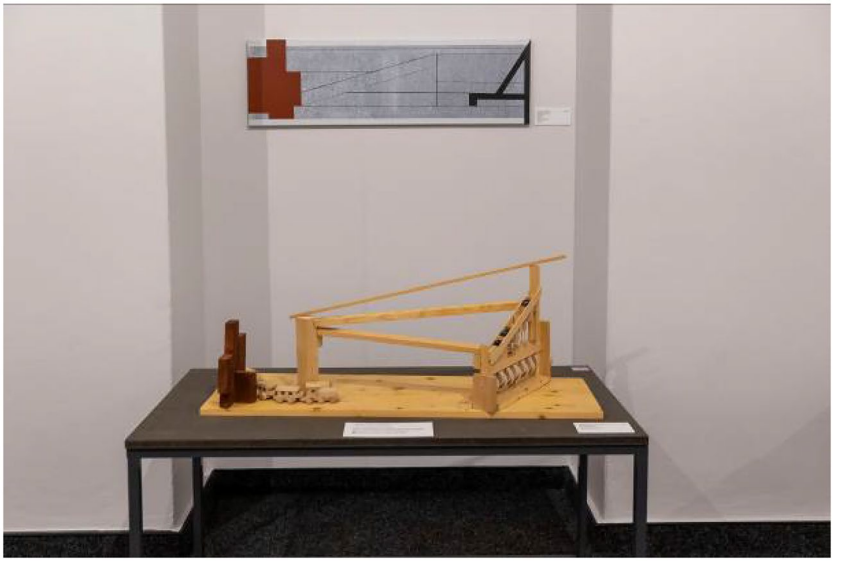


Figure 4. Acrylic painting by Tamás Konok and interactive wooden game by Tamás Vásárhelyi at the exhibition of the Móra Ferenc Museum, Szeged. *Source:* Photograph by the first author.

visited the Móra Ferenc Museum but have never seen works by the exhibiting artist and scientist. Interrelations of science and art are not part of the compulsory school curriculum, but the analysis of artworks and scientific visualizations provided students with innovative methods of art appreciation. Integrating science and art experiences led to new insights about the meaning and significance of the paintings.

Methods of the visitor study

In educational research, there are several verified methods to explore the effects of an exhibition and reveal if the visitor understands and retains information and experiences after the museum visit (Hein, 1998; Hooper-Greenhill, 2000). However, most of these methods of capturing knowledge and emotions are not adequate to reveal the complex process of exhibition communication. Carey (2008), Sakalauskaitė (2015) and Sen (2017) emphasizes that the most important objective of museum communication should be the construction of a personal reality and the sustainable support of integrating the individual in the collective experience, not the transmission of facts and data. Exhibition communication should contribute to social cohesion through transmitting cultural experiences and interpretation strategies. Therefore, visitor studies should be focused on meaningful experiences and not knowledge retrieval (Hooper-Greenhill, 2000).

Our evaluation method developed for testing the usability of the AR museum guides specially developed to enrich visitor experience in selected exhibitions is the transient, fluid nature of mental frames. Research indicates that they may be modified within a short time period due to different interventions or events (Benczes & Benczes, 2018). Visual content may significantly affect behaviour (Powell et al., 2015) and assume a key role in messages (Bock, 2020). Therefore, we decided to use visual framing to reveal changes in the interpretation of works of art and evaluate whether the messages of the exhibition are adequately transmitted through the exhibition. The first visitor study at the Ludwig Museum was the piloting phase of the AR guide for framing visitor experiences, and the second study at the Godot Gallery was designed to verify the findings of the first experiment. In the third study at the Móra Ferenc Museum, the usability of the tool was improved, and its regular applicability tested.

Initially, the development of the AR guide as visitor-experience framing-tool was the concise and clear formulation of the messages that the selected artworks intended to communicate. The source of this information was the curator, art critic, museum educator or other specialist involved in the exhibition design or publications with analyses of the works selected for the visitor study. Later, based on this information, we developed the AR guides. Visitor feedback was collected through task sheets that were different for the control and experimental groups. They will be referred to as Control-Group Task-Sheets (CTS) and Experimental-Group Task-Sheets (ETS) in this paper. The CTS contained two open-ended questions, related the levels of the visual framing model based on Panofsky's ideas (1932/1970) that were expanded and applied for classifying framing activities by Rodriguez and Dimitrova (2011) and introduced in the discussion of the theoretical framework of this paper. The first question: *What do you see on this image?* refers to the first level of the model: the representational

visual image is presented as a *denotative system*. This question provides data about the correct identification of the image at the exhibition and filters out random answers. The second level of the model – the stylistic-semiotic system – was not applied in this study, as the research did not aim to examine formal visual conventions or compositional stylistic features. The second question: *What are your thoughts about this artwork?* refers to the third level of the framing model, the image as *connotative system,* identifying the meaning of the constituents of the image, the moment of deep understanding.

The ETS also includes the question: *What do you see on this image?* to filter out random responses. The second question from the CTS: *What are your thoughts about this artwork?* referring to the third level of the framing model, is presented in the ETS as a multiple-choice question. The responses to choose from include interpretations by museum experts and the most frequent answers given by the control group on the CTS. These texts were included to increase objectivity and avoid interpretations relying only on expert opinion. We presented the responses of experts and laypeople as equally valid interpretations of the artworks and allowed the choice of multiple responses to this question. We wanted to suggest the plurality of valid viewpoints and emphasize that encounters with works of art are not like school examinations with only one correct answer.

To retain the flexibility of the visitor-experience evaluation and increase its relevance to reveal cognitive processes of viewers, we included a third, open ended question that refers to the fourth level of the visual framing model: the interpretation of the image as an *ideological representation* of social, cultural, or ideological foundations of an age. The question: *Why did you select exactly these answers for the previous question?* enables us to filter out irrelevant (unrelated to the artwork) responses and collect more data about visitor behaviour and cognitive style. Random answers could also be identified. An example from the answers to this question, revealing a random response: '*I picked from the alternative answers at random, as I liked them all*'.

We used the framing model for the assessment of responses and focused on the content of visitor responses to see whether they select (ETS) or write (CTS) the ideas formulated by the experts as major messages of the exhibitions. One point was given for every idea appeared in the response of the student visitor. Individual opinions were noted and later appreciated during the discussion with students, but no points were given for personal remarks and associations, because the aim of the assessment was to evaluate the instructional value of the exhibition communication tool by the test score that reflected expert-defined knowledge acquisition only. Points were summarized and a percentage of answers reflecting new knowledge gained through the educational tool was calculated. This scoring system does not mean a devaluation of expressing personal opinion and sharing associative remarks. On the contrary: these were recognized and, if relevant and interesting, duly praised. But the validation of an educational tool of knowledge dissemination should be assessed based on successful transmission of authentic information.

We would considered the AR guide appropriate if the members of the experimental group using the guide selected more messages on the ETS that were formulated by experts than the responses of the control group.

Analysis of the visitor studies

The following chapters provide specific details on the implementation, findings and conclusions of each of the three Visitor Studies.

Visitor Study 1 at the Ludwig Museum – Museum of Contemporary Art, Budapest

Research design

The experiment at the Ludwig Museum was executed in four stages to verify the visitor study methodology and reveal eventual problems with the AR tool and the task sheets. Participants of the four stages were randomly selected (Table 3). The focus of this experiment was the evaluation of the transmittance of the key messages of the exhibition. The effects of AR technology on visitor experience were not studied.

Group A and C were control groups. Both visited the exhibition without the use of the AR device, but Group C received the task sheet developed for those who did. This control group was organized to prove that the type of the task sheet that contained multiple-choice questions including messages formulated by experts, if introduced only after the visit, did not influence the quality of visitor feedback.

Group D consisted of the same participants as Group A, who returned to the exhibition for a second visit. During this second visit, they used the AR guide and completed the experimental task sheet (ETS). This design enabled a direct comparison of visitor responses under two different conditions: traditional museum visit (Group A) and AR-supported experience (Group D). The purpose of this setup was to isolate the effect of the AR tool and verify that the observed differences in interpretation could be attributed to the use of augmented reality, rather than participant characteristics.

Results

This assumption was verified: Group C performed only slightly better than Group A, showing that the decisive factor in understanding the messages of the exhibition was the use of the AR guide. Groups B and D understood the messages of the exhibition on a much higher level than any of the control groups. Expert answers provided on the task sheet did not significantly influence results (Figure 5).

In this visitor study, we also verified that it was the AR guide that made the difference in identifying the messages of the exhibition that curators and exhibition designers intended to communicate. As previously described, Group D consisted of the same participants as Group A, who revisited the exhibition under different

Table 3. Groups of participants of the 1. visitor study, Ludwig Museum Budapest.

	Group A	Group B	Group C	Group D
Number of participants	16	21	10	11
Type of the task sheet	CTS	ETS	ETS	ETS
Using the AR guide	no	yes	no	yes
Number of museum visits by the group	1	1	1	2

conditions. This setup enabled a direct comparison between traditional and AR-supported experiences. Their results are shown under Group D. When we compare results of Group A and D, same participants but different treatment, we can see an increase in performance. Group D members have seen the artworks before, without the AR device, and formed an opinion that some of them adhered to, despite interpretations offered by the guide (As one of the members remarked: '*I circled the answers that I remembered from my first visit*'.) In sum, Groups B and D, who used the exhibition guide, performed significantly better than Groups A and C who did not (Figure 5).

In the case of the third artwork (Figure 6), the control group (Team A) performed somewhat (2.8%) better than the experimental group. The reason for that is the

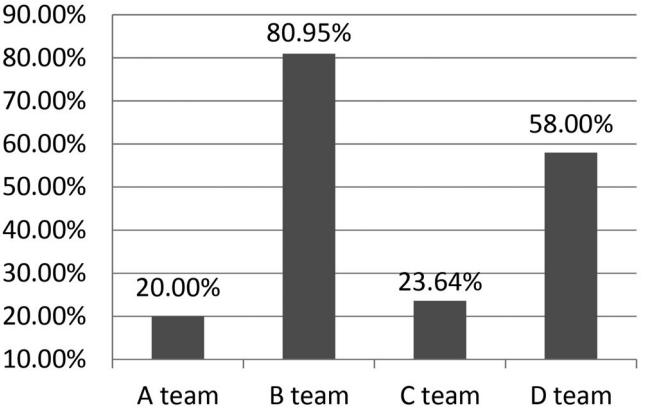
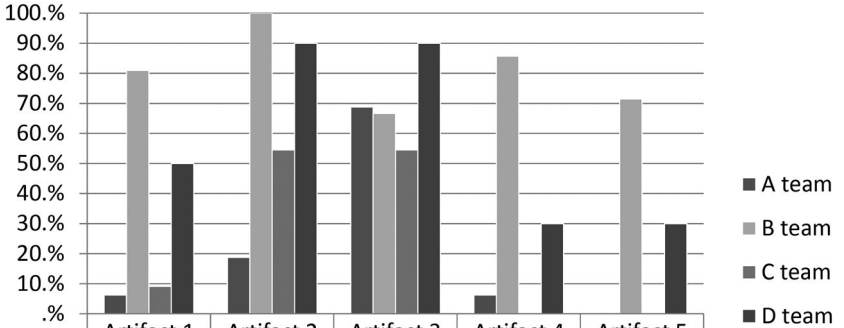


Figure 5. Percentage of suitable answers (exhibition messages intended by curators and exhibition designers) by groups on the task sheets of Visitor Study 1 at the Ludwig Museum Budapest.



	Artifact 1	Artifact 2	Artifact 3	Artifact 4	Artifact 5
A team	6.25%	18.75%	68.75%	6.25%	0%
B team	80.95%	100.%	66.67%	85.71%	71.43%
C team	9.09%	54.55%	54.55%	0%	0%
D team	50%	90%	90%	30%	30%

Figure 6. Results of Visitor Study 1 at the Ludwig Museum: percentages of suitable interpretation of artworks by control and experimental groups. The sum of each team divided in five parts gave the average percentage of teams, according to Figure 7, A = 20%, B = 80.95%, C = 23.64%, D = 58.00.

inferior content of the AR tool that did not transmit the educational content appropriately. This feedback is useful for two reasons: firstly, it shows the sensitivity of the tool for content. The thrill of the novelty of the AR application does not automatically result in more focused attention and better knowledge acquisition than traditional guiding methods. Secondly, the knowledge test reveals deficiencies of the tool and thus supports further development of the content and the application.

Analysis of the question on the ETS about the reasons why certain answers were preferred by visitors included reflections on the emotional states evoked by the artworks: *'I wanted to identify the impact of these paintings on my mood'. 'The painting has an aesthetic appeal, but it is also depressing'. 'Looking at this picture, I felt moody'. 'This was the only positive image at this exhibition'.*

Interpretations of artworks were often linked to personal narratives: '*I do not see the vulnerability of the soap bubbles! I perceive them the way I saw them in childhood: they are amusing and beautiful'.* Another interesting association was shared by a woman who remembered how highly her family valued canned meat in the 1980s. This memory came back and overshadowed other interpretations. When explaining their associations, some participants forged new relationships among works of art, completing ideas heard from the guide with references to paintings not included in it, or recalled previous visits and art lessons. In these cases, the guide served as a catalyst of connecting memories with the current art experience.

In the course of the experiment, we witnessed that participants observed the artworks more profoundly and lingered on after the explanation provided by the AR tool had finished. One of them described this after-effect on the test sheet: '*I kept on thinking about what I have just heard and tried to imitate the movement of the work several times. Each time the effect was the different, the feelings were different*'.

Conclusion

The first research hypothesis was confirmed: the initial version of the survey tool proved to be applicable for examining visitor responses to AR-supported exhibition content. The pilot study provided a solid basis for further refinement.

Visitor Study 2 at the Godot Gallery, Budapest

Research design

This study was executed in a smaller exhibition space with fewer artworks, so we could make more acute observations about the effects of technology use. We wanted to find out if the AR guide that proved to be an effective tool of museum communication in the first study, does not disturb the visitors in experiencing the works. Results of the control and experimental groups are indicated in Table 4.

Table 4. Groups of participants of the 2. visitor study at the Godot Gallery Budapest.

	Group A	Group B
Number of participants	4	11
Type of the task sheet	CTS	ETS
Using the AR guide	yes	no
Number of museum visits by the group	1	1

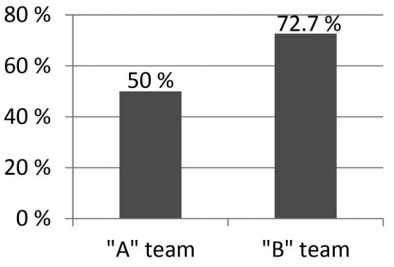


Figure 7. Percentage of suitable answers (exhibition messages intended by curators and exhibition designers) in the Control Group A and the Experimental Group B on the task sheets of Visitor Study 2 at the Godot Gallery Budapest.

Results

Results of the experimental group were significantly better than those of the control group (Figure 7).

Visiting a smaller gallery with a smaller, more focused exhibition that is easier to oversee proved to be a rewarding experience for our participants – a result that art educators who normally organize visits to big and complex collections should consider. Here again, assessment results have proven that the transmission of the messages of the exhibition is significantly facilitated by the contents of the AR guide.

Remarks of the experimental group showed that technology use did not distract or disturb other visitors. The AR guides were downloaded on the smartphones of the visitors, so no light effects were observable in the exhibition space. They used earphones to avoid disturbing others with noise. Participants found the AR guide easy to handle, as the application was part of their most often used digital device.

As in a marketing environment, where AR devices significantly contribute to user satisfaction and increase their attention span (Vieira et al., 2022), AR technology had the same effect with artworks. Participants remarked that they would not have been able to understand and enjoy some of the works without them. Works of art in this exhibition reflected on burning social issues, and the young visitors perceived their significance: *'these paintings show ideas that occupy us, too, but are not expressed'.* Another visitor used the metaphor of the distorted mirror to characterize discussions inspired by the works of art. This remark indicates the function of this pictorial device often employed by Andersen, Orson Welles, Hitchcock André Kertész, Manet, etc., to use the filtering function of the absurd effect to reflect social values (Pollay, 1986).

Conclusion

The second research hypothesis was supported by the findings of the second Visitor Study. The improved version of the tool enabled a more detailed and reliable assessment of how visitors interpret curated content, confirming its enhanced effectiveness.

Visitor Study 3 at the Móra Ferenc Museum, Szeged

Research design

In Visitor Study 3, only the Experimental Group B visited the exhibition and members of Control Group A were shown the works during a lesson of Visual Culture, the

Hungarian discipline for art education (Table 5). This experiment showed the deficiencies of a frequent educational solution, introducing an exhibition through a slide show: results of the members of the control group performed worst in comparison to the experimental groups across the three studies.

Understanding the messages of the exhibition that included Constructivist paintings and wooden constructions to be used as 'scientific toys', demonstrating a concept or phenomenon associated with the works of art was a difficult task for both groups. The visitor study was undertaken a few days before the summer holidays, when motivation for school tasks rapidly diminishes and the exhibition materials were not part of the art education curriculum. The abstract images were more difficult to interpret than the representational ones featured in the two preceding experiments. Considering all these factors, we allowed participants to see the works and then fill out the questionnaires in teams of two and three. This type of small group visit is characteristic for museum experiences and therefore we considered teamwork as a more authentic way of meaning making than individual observation and reflection.

Altogether 35 task sheets were submitted, out of which we had to exclude 11 sheets with incomplete and/or random answers.

Results

Data analysis of the 24 sheets submitted shows the better performance of the experimental students (Figure 8).

On the task sheets we found interesting remarks about the appreciation of artworks in general. One student team added a new message to those we offered, another team circled all the answers and explained that these interpretations all contained an element of truth. After selecting the appropriate answers that experts supplied about the focal points of the exhibition, a student remarked. '*I do not think these*

Table 5. Groups of participants of the 3. visitor study at the Móra Ferenc Museum, Szeged.

	Group A	Group B
Number of participants	10	69
Type of the task sheet	CTS	ETS
Using the AR guide	Yes	No

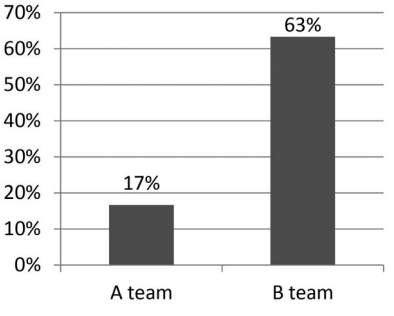


Figure 8. Percentage of suitable answers (exhibition messages intended by curators and exhibition designers) in the Control Group A and the Experimental Group B on the task sheets of Visitor Study 3 at the Móra Ferenc Museum, Szeged.

options grasp the focal point of the exhibition, which is the integration of art and science'. Here again, we found that the guide does not only teach, it also motivates students to confront the ideas expressed and express new ideas.

Conclusion

The third research hypothesis was also supported by the findings of the third Visitor Study. The optimized tool proved to be more adaptable for use in museum education settings, improving usability without compromising the depth of interpretive analysis.

Concluding remarks

Based on our results, we may formulate some general assumptions about the use of AR technology. The major benefit of AR solutions as museum guides is that they may integrate the benefits of audio and video guides with multimedia information systems. AR-based guides can include 2D or 3D visual content without the need of installing a console or other device in the exhibition space. AR guides may be place-sensitive and start exactly when the visitor starts looking at the work of art with linked content in the AR guide. Thus, they support visiting the exhibition in a self-directed manner, choosing walking speed and direction. This technology offers easy personalization options, so the content designer can target a wide range of different visitor groups. The objective of the series of experiments reported here was the development of an assessment tool that can reveal the usability of an AR-based museum communication tool. The results suggest that this objective was successfully fulfilled.

From an educational point of view, the three visitor studies that tested the potentials of AR technology for exhibition communication is, that this device can be applied effectively according to the experimental group activities in order to communicate the messages of an exhibition with good retention results. This assumption has often been voiced but rarely tested before. Yoon et al. (2012) has found that the enhancement of a science museum exhibit device using AR technology might lead to an improvement in conceptual understanding and cognitive skill development, given the specific nature of informal science learning environments. In our research, students who received AR-based support for their museum visit, were better able to interpret scientific phenomena. In this way our research hypotheses were verified:

- The first version of the survey tool can be analyzed regarding its applicability through the Visitor Study I.
- The improved version of the tool can be assessed through the Visitor Study II.
- The survey tool can be optimized for easier use in museum education settings through the Visitor Study III'.

We accept the partially subjective nature of the artistic experience (formulated by one of our participants as '*Everyone develops his or her own interpretations and associations about works of art*'). Nevertheless, we can enrich these interpretations to include ideas communicated by experts behind an exhibition, developing. Our methodology, described in this paper, involves the inclusion of ideas and thoughts of

laypeople in the post-hoc visitor survey that is not used for a simple recall of knowledge elements related to the works exhibited. We have developed an educational tool that reveals the usability of museum-communication devices and indicated unsuitable responses related to their development.

The inclusion of the fourth level of visual framing in the assessment makes it possible to discuss the cultural and emotional ideas of museum visitors. For example, in the first experiment, one of the artworks that our participants studied was a tin canister (Appendix Table A1). Participants interpreted this object as a 'symbol of poverty', 'a valuable gesture' and many participants thought it was 'a representation of society'. The cultural background to these remarks is a charity act that is much more popular in Hungary than donating money: to purchase and present canned food to people in need. No reference to this tradition was included in the AR communication tool or on the label of the work of art. The fourth level of visual framing helps us identify and include into the levels of interpretation social and emotional messages – narratives related to shared and individual experiences.

In order to preserve the focus of the research, it was not feasible to engage with a number of issues that are closely associated with the practice of exhibition communication – such as conducting research into the various dimensions of the museum experience or examining the relationship between contemporary learning theories and museum education. Due to limitations in scope, participants' prior knowledge of the artworks could not be assessed in advance, nor was it possible to extend the study to include conditions in which control groups received alternative forms of support, such as written materials or audio guides. Consequently, a comparative evaluation of the effectiveness of these different approaches could not be undertaken.

This method may be applied as an extension to non-art exhibitions also to evaluate the effects of museum communication with an educational angle, through a blended methodology, employing both quantitative and qualitative response analysis. We hope that our method of analysis summarized here will contribute to the development museum communication devices that are more efficient in transmitting more than facts: ideas and messages that may leave the visitor with more lasting impressions. When suited to the main messages of contemporary art exhibitions that may be more difficult for young visitors to decode, exhibitions become easier understood and deeper appreciated. Concluding AR guides based on visual framing may contribute to one of the major objectives of museums: to become a public space relevant for visitors of all ages and cultural backgrounds, a venue of building and sharing knowledge and experiences.

Disclosure statement

No potential conflict of interest was reported by the authors.

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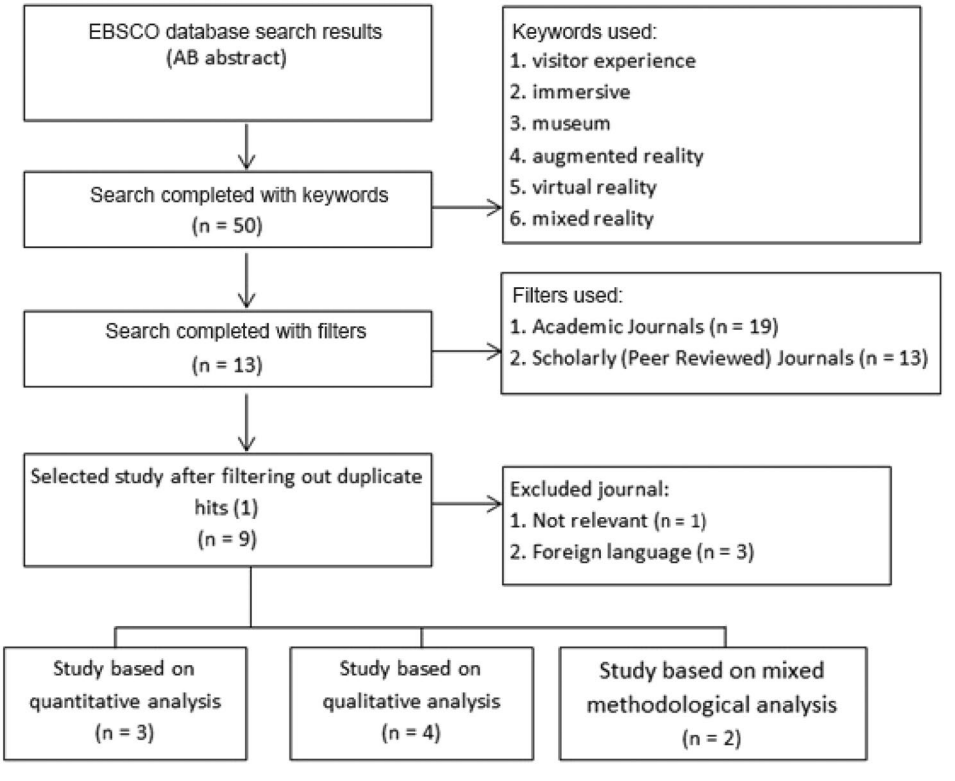
Appendix



Appendix Figure A1. PRISMA flowchart of the systematic literature review.

Appendix Table A1. Artworks included in the first visitor study.

	Artist	Title	Year	URL
1.	Perneczky, Géza	*Art Bubble 1*	1972	https://www.ludwigmuseum.hu/en/work/art-bubble-1-2-3
2.	Türk, Péter	*Treadmill I-II.*	1975/ 1981	https://www.ludwigmuseum.hu/en/work/treadmill-i-ii
3.	Maurer, Dóra	*Reversible and Interchangeable Phases of Motion (etude No. 3)*	1972	https://www.ludwigmuseum.hu/en/work/reversible-and-interchangeable-phases-motion-etude-no-3
4.	Csiky, Tibor	*Globus tin*	1973	https://www.ludwigmuseum.hu/en/work/globus-tin
5.	Attalai, Gábor	*RED-Y MADE*	1976	https://www.ludwigmuseum.hu/en/work/red-y-made-galerie-loa-harlem

Appendix Table A2. Artworks included in the second visitor study.

	Artist	Title	URL
1.	drMáriás	*George Soros seeking investment opportunities at the Hungarian National Park*	https://drmarias.hu/en/art/hollywood-behind-the-iron-curtain/
2.	Fajgerné	*Compromise*	https://www.fajgerne.com/index.php/works/34-sadudaerdna/portfolio/108-married-life#gallery8ffcd50968-4
3.	Galambos, Tamás	*Gold Rush*	https://www.godot.hu/post/kort%C3%A1rs-mag%C3%A1ngy%C5%B1jtem%C3%A9nyek-xix-kacsuk-p%C3%A9ter-gy%C5%B1jtem%C3%A9nye2022-01-05-2022-01-29
4.	Société Réaliste	*Camouflage of the United*	https://www.godot.hu/post/kort%C3%A1rs-mag%C3%A1ngy%C5%B1jtem%C3%A9nyek-xix-kacsuk-p%C3%A9ter-gy%C5%B1jtem%C3%A9nye2022-01-05-2022-01-29
5.	Nagy-Tereshkova, Kriszta	*Damien collection*	https://www.facebook.com/photo/?fbid=5043957562283734&set=a.5043961408950016

Appendix Table A3. Artworks included in the third visitor study.

	Artist	Title	Year	Medium
1	Konok, T.	*Stairs I–III*	2016	Acrylic on canvas
	Vásárhelyi, T.	*Wooden frame house?*	2019	Interactive wooden toy
2	Konok, T.	*Mikroludium*	2019	Acrylic on canvas
	Vásárhelyi, T.	*Two thomas*	2018	Interactive wooden toy
3	Konok, T.	*Striped blue pyramid*	2010	Acrylic on canvas
	Vásárhelyi, T.	*Missing pyramid*	2019	Interactive wooden toy
4	Konok, T.	*Diomedea*	2018	Acrylic on canvas
	Vásárhelyi, T.	*Albatross*	2018	Interactive wooden toy
5	Konok, T.	*Collage*	2007	Mixed technique, cardboard
	Vásárhelyi, T.	*I feel it in my feet*	2019	Interactive wooden toy

Available: Kaposi, D., & Varga, L. (Eds.). (2019). Tamás Konok & Tamás Vásárhelyi: SPACE – MOTION – GAME [Exhibition catalogue]. Deák 17 Youth and Children's Art Gallery, ISBN 978-615-80650-8-5