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Multisensory Augmented Reality in Cultural Heritage: Impact of Different Stimuli on Presence, Enjoyment, Knowledge and Value of the Experience

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ABSTRACT Little is known about the impact of the addition of each stimulus in multisensory augmented reality experiences in cultural heritage contexts. This paper investigates the impact of different sensory conditions on a user's sense of presence, enjoyment, knowledge about the cultural site, and value of the experience. Five different multisensory conditions, namely, *Visual*, *Visual + Audio*, *Visual + Smell*, and *Visual + Audio + Smell* conditions, and regular visit referred to as *None* condition, were evaluated by a total of 60 random visitors distributed across the specified conditions. According to the results, the addition of particular types of stimuli created a different impact on the sense of presence subscale scores, namely, on spatial presence, involvement, and experienced realism, but did not influence the overall presence score. Overall, the results revealed that the addition of stimuli improved enjoyment and knowledge scores and did not affect the value of the experience scores. We concluded that each stimulus has a differential impact on the studied variables, demonstrating that its usage should depend on the goal of the experience: smell should be used to privilege realism and spatial presence, while audio should be adopted when the goal is to elicit involvement.

INDEX TERMS Augmented reality in cultural heritage, multisensory augmented reality, presence in AR environments.

I. INTRODUCTION

The majority of archaeological sites exhibit the remains of lost ancient, stunning buildings as well as other cultural remnants from our ancestors. The information that is available to help visitors understand these sites is usually provided through texts and illustrations. Currently, there is a general tendency to use technologies to improve visits to cultural heritage sites, and these technologies, such as virtual reality (VR) and augmented reality (AR), have been important to engage visitors and enhance exploration [1].

While audiovisual approaches appear to be the most commonly used solutions in previous implementations and studies, multisensory approaches have arisen and indicated to further enrich users' experience in cultural heritage (CH) contexts [2], [3]. The recent literature has presented several multisensory strategies using virtual and augmented reality technologies for different types of heritage sites, such as the "Haptic Museum" [4], the "Museum of Pure-Form" [5], the "National Archaeological Museum of Marche" [6], "The Feelies" [7], or the "Tanning in Medieval Coventry" [8]. Some approaches are targeted explicitly for AR technologies, such as the "Zelige Door on Golborne Road" [9], the "M5SAR" [10], and the two case studies of AR multisensory approaches in CH exhibitions [3].

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These innovative implementations have revealed that users are willing to have multisensory experiences in CH contexts [5], as they have good impressions of multisensory interactions [11], they have increased feelings of presence [12] and they feel more involved during their visits [13]. Regarding the overall multisensory experiences, good results have been demonstrated regarding satisfaction [11]–[17], sense of presence (or immersion) [14], [15], [17]–[19], acquired knowledge and interpretation [15], [18], and value of the experience in different dimensions such as quality of the experience [11], [16], [17] or intercultural exchange [9].

In the literature, the evaluations of multisensory solutions in CH related to enjoyment have been very diverse. Enjoyment has been evaluated as part of usability tests as overall satisfaction [14], [15], using a single question rated on a 5-point Likert scale [11], [19], [20], using a questionnaire inspired by [21] with a 9-point Likert scale [16], and with 6 questions through a 7-point Likert scale [17]. Concerning the evaluation of knowledge, very little information was found on this topic, and only one method for evaluating knowledge has been identified. This evaluation was conducted by providing a pretest questionnaire combined with a similar posttest questionnaire to ascertain changes in users' knowledge [15]. These studies validated their hypotheses by demonstrating enhanced enjoyment and acquired knowledge caused by their multisensory systems, motivating subsequent researchers to continue to explore the addition of stimuli in the context of CH experiences.

Even though there is little consensus regarding concepts of immersion and presence, as well as the definition and the etymology of "presence" remains debatable [22], feeling present in virtual environments has been demonstrated to affect the success of virtual heritage applications [23], and has been defended as a central aspect of immersive AR, in particular, from the consumer perspective [24]. Presence is defined as a psychological construct wherefore self-report measures such as questionnaires seem to be a reasonable tool [25]. However, limitations regarding the use of questionnaires to evaluate presence have been described in the literature. Some limitations are associated with the fact that evaluations rely on participants' subjective opinions [26], are influenced by attempts of participants to guess what the researchers are examining or are attempting to assess the feeling of presence that occurs during the experience while the reports are made after the experience [25]. In addition to the stated limitations, the reliability of participants' answers has also been proven to be affected due to their frustration when answering long questionnaires or due to factors that can shift the participant's focus [27], [28]. In the literature examining multisensory experiences, presence was tested by enabling and disabling the multisensory approach [14], which results in better scores in the multisensory experience. However, the role of immersion in the AR context remains unclear [29].

Certain studies support VR methods to evaluate presence in AR environments. However, the disconnection from the real world that VR usually pursues is not intended in AR. Thus, examples in the literature that evaluate and analyze the sense of presence in AR have required awareness of the linkage that is maintained in the user experience between virtual and real environments. Nonetheless, benefits on sense of presence in AR experiments were identified as being linked in several contexts, such as phobia treatment [30]–[32], anxiety assessment [33], e-commerce [34], task performance [35], [36], and learning processes [37].

These insights regarding multisensory approaches targeted for visitors in CH sites do not provide solid knowledge and understanding regarding users' feelings since they have not compared the addition of each stimulus individually. Additionally, evaluations have frequently been limited to user tests carried out in controlled environments with preselected participants instead of end-users (e.g. [6], [14], [17], [38]), a fact also highlighted by [34]. In addition, few explorations have been made using AR as visual technology instead of VR across multisensory implementations, even if the literature presents AR as a technology that can be preferable when compared to some virtual reality solutions [39]. No information was found regarding end-users' evaluations when using AR and multisensory approaches [3], [9], [10]. Furthermore, none of the identified multisensory systems were designed for outdoor use, and therefore, it remains uncertain how an outdoor multisensory implementation performs and what influence it would provoke on users.

The challenges of evaluating an outdoor multisensory system based on AR with end-users are vast. In fact, the literature suggests that, in contrast to virtual environments, location-based AR is dependent not only on the virtual interface and content but also on the locality and context of the AR activity [40], [41]. Previous literature does not provide solid guidelines to carry out the implementation and evaluation of an AR multisensory system for CH contexts. Hence, the current study proposes one possible approach to accomplish this goal.

The main goal of this article is to investigate the impact of different sensory conditions by combining visual, audio, and smell stimuli on measures of the user's presence, enjoyment, knowledge, and value of the experience. As a secondary objective, we intend to identify correlations between the referred variables and certain individual characteristics of participants, such as age, sex, previous AR experience, and country of origin.

To depict our study, the methodology conducted for this evaluation is first explained, describing the participants who were involved in this study, materials and apparatus used, selected instruments for collecting results, procedures related to the experience, and statistical procedures. This pipeline provided the data and results that we subsequently analyze and discuss. The main conclusions and some notes for future work conclude this work.

II. METHODS

Inspired by previous work that outlined a multisensory AR system for archaeological sites [42], the current section clarifies the experimental methodology adopted for evaluating the impact of each stimulus on visitors using an AR multisensory system in an archaeological site. The study follows a quasi-experimental methodology with a quantitative focus.

A. PARTICIPANTS

All participants in this study were random visitors who were visiting an archaeological site and were invited to take part in the experiment as volunteers. A between-subjects design was adopted, making use of the nonprobabilistic convenience sampling procedure. Each condition was evaluated by 12 participants, with a total of 48 participants evaluated with the presence questionnaires across four conditions and 60 participants across five conditions for enjoyment, knowledge, and value of the experience. To be eligible, participants should not have hearing or smelling constraints – selections were made according to the user's answers on the questionnaires, where they were asked about smelling and/or hearing difficulties. In addition to age, sex, hearing or smelling difficulties – participants who reported hearing issues or smelling difficulties were discarded, country of origin was recorded. The questionnaire also included a query regarding previous experience with AR and an open question where participants could report any observations/comments.

The participants were randomly distributed across different experimental scenarios while ensuring that sex and age balanced, as described in table 1.

TABLE 1. Distribution of the participants by experimental scenario.

Condition	Sex	Age			Previous
		Range	Average	Std. dev.	AR exp.
None	6 female	[32-53]	44	8	*(n.a.)*
	6 male	[30-51]	42	8	
Visual	6 female	[30-62]	45	12	4 Yes
	6 male	[18-65]	40	17	8 No
Visual+Audio	6 female	[23-72]	50	22	7 Yes
	6 male	[25-61]	46	12	5 No
Visual+Smell	6 female	[23-59]	46	13	8 Yes
	6 male	[22-61]	49	14	4 No
Visual +Smell+Audio	6 female	[23-60]	45	16	5 Yes
	6 male	[24-66]	49	18	7 No

(n.a.) stands for not applicable.

For direct observation purposes, a subset of 34 random participants were observed, corresponding to seven experiences in the *Visual* condition, nine in the *Visual* + *Audio* condition, eight in the *Visual* + *Smell* condition, and ten in the condition with the three stimuli, *Visual* + *Audio* + *Smell*.

B. VARIABLES

The independent variable (IV) in this study was the stimuli combination of the experience (i.e., the condition), namely, *None* (baseline), *Visual*, *Visual* + *Audio*, *Visual* + *Smell*, and *Visual* + *Audio* + *Smell*.

The dependent variables (DV) in this study were presence – composed of the subscales spatial presence, involvement, experienced realism, and overall presence, enjoyment, knowledge, and value of the experience. An additional variable, behavioral presence, was studied to support the analysis of presence. Given the diversity of solutions provided in the literature to perceive enjoyment, the current study related enjoyment to feeling impressed, feeling amused and overall satisfaction. The perceived knowledge by users in relation to the archaeological site, hereafter referred to as "knowledge", was related to the archaeological site knowledge, knowledge about ancient inhabitants, and enrichment gained with the experience. The overall value of the experience related to the influence of this type of experience on interest for CH sites and the reliability of the information perceived during the experience.

C. MATERIALS AND APPARATUS

For this study, the SensiMAR prototype, described in [42], was used. Previously supported by an acceptance study partially published in [43], SensiMAR is an AR prototype designed for mobile devices that allows users to experience, in real time, additional information that complements their visit to archaeological sites by adding visual data, audio content, and releasing smells. The stimuli provided for the experiment were as follows::

1) *Visual*: A 3D reconstruction of a wealthy house, the Cantaber House, some animated characters (such as people talking), and a passing wagon were presented.
2) *Audio*: A soundscape track was available at the beginning of the experience–more explicitly, during the guided visit. In this manner, participants could make some connections about the presented information and the sounds that they were hearing, e.g., the water fountains, the blacksmith working. Another soundtrack started as the AR experience began to have sounds synchronized with the animations.
3) *Smell*: During the guided visit, the participants were invited to smell the garum since it was very often used in Roman cuisine. According to their transportation habits, it was widely carried in amphorae. The smell was the same smell that was later provided during the AR experience with the smell dispenser.

The conditions with SensiMAR that were under evaluation were as follows:

1) *Visual* – this condition allowed the participant to receive a visual stimulation during the experience.
2) *Visual* + *Audio* – this condition allowed the participant to receive visual and audio stimulation during the experience.
3) *Visual* + *Smell* – this condition allowed the participant to receive visual and smell stimulation during the experience.
4) *Visual* + *Audio* + *Smell* – this condition allowed the participant to receive visual, audio and smell stimulation during the experience.

5) *None* (baseline condition) – this condition did not consider the addition of any added stimuli from SensiMAR; only a guided tour was provided.

The experimental condition in the archaeological site, comprehensively discussed in [42], is briefly illustrated in figure 1. The system allowed a 360-degree exploration by having the user in the center of this experience and accessing AR visual contents with a mobile device (indicated in figure 1 with letter A), the sound through four speakers (indicated by the letter B) and the smell released in his/her vicinity (specified with the letter C).

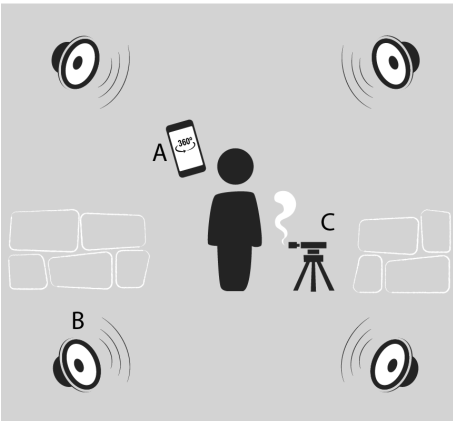

FIGURE 1. Schema of SensiMAR implementation for user evaluation.

To present the visual stimulus, we used a Samsung Galaxy S9 smartphone that features a 5.8'' AMOLED display that supports 16 million colors with a resolution of 1440 × 2960 pixels. The audio stimulus was delivered via an Ambisonics surround sound system based on four Mackie CR4 speakers. The smell was delivered via a custom-made smell dispenser machine based on an Arduino that controlled an electrovalve attached to a compressed air system.

We performed all precautions to assure that the current evaluations with end-users would not be influenced by any usability issues.

D. INSTRUMENTS

The current study gathered data using different instruments from end-user experiences in situ related to presence, enjoyment, knowledge, value of the experience, and behavioral presence.

1) PRESENCE

Questionnaires: To measure the sense of presence, the *igroup* presence questionnaire [44] (IPQ) was used, which was composed of the subscales spatial presence, involvement, experienced realism, and overall presence.

As participants could be native English or French speakers, the appropriate translated and validated versions for each of the languages were used, thus complying with the *igroup* project consortium guidelines [45]. The Portuguese version was a translated and validated Portuguese version authored by Vasconcelos-Raposo *et al.* [46]. Due to the particularities of the instrument, it was only applied when an AR scenario was presented (i.e., it was applied during all conditions except for the baseline condition).

Following the literature suggestions for awareness of evaluating and analyzing the sense of presence in AR environments, we included ethnographic research in our study to analyze behavioral presence. In addition to the provided questionnaires, this qualitative method was conducted to deepen our understanding of users' feelings regarding presence, as well as the other dependent variables enjoyment, knowledge, and value of the experience. To measure behavioral presence, the research team registered by direct observation the reaction of users, their interactions, and what questions arose during and after the experience. Comments expressed by participants were registered as well.

The baseline for direct observation took into consideration active social presence, defined by Lombard *et al.* [47] as an indicator of users' sensitivity to media content, combined with body responses as indicators of presence [48] and people's reactions as an objective measure of presence [49], [50]. Thus, an observation grid was developed based on observations through users' responses towards virtual content, namely, making a sound out loud, such as laughing or speaking, and smiling in response to the media environment.

In addition to the observation grid used for behavioral presence, the observation process also included taking notes of behavior regarding participants' comments, questions, and expressions, as well as a small discussion at the end of the experience with them.

2) ENJOYMENT, KNOWLEDGE, AND VALUE QUESTIONNAIRE

The research team developed the questionnaire used to collect data regarding enjoyment, knowledge, and value of the experience. For this purpose and based on the literature [51], [52], the research team has designed and validated a questionnaire with several questions aimed to assess each of the referred components. The items used to classify enjoyment, knowledge, and value of the experience are summarized in table 2. Questions #4, #5, and #6 were administered before and after the experience, and their scores were calculated by calculating the difference between these two scores.

E. PROCEDURE

The experience took place at the Monographic Museum of Conimbriga-National Museum (Portugal), more specifically in the ruins of a wealthy house–the House of Cantaber.

All participants in this study were random visitors to the archaeological site who, during their visit, were invited to participate in this study. Each participant who accepted the invitation consented to participate in this study after being informed about the context of the current research and how they would participate in the study. The first step was to provide a guided visit in the vestibule of this house, as illustrated in figure 2. The information given to visitors in this short-guided visit was the same for all participants,

TABLE 2. Part 1 of the questionnaire assessing enjoyment (questions 1, 2, and 3), knowledge (questions 4, 5, and 6), and value (questions 7 and 8).

#	Dimension	Question
1	Enjoyment	Tell us about how bored/amused you were during this experience.
2	Enjoyment	Tell us about how disappointed/impressed you were during this experience.
3	Enjoyment	Classify your level of satisfaction regarding the overall experience.
4	Knowledge	Classify your knowledge about this archaeological site.
5	Knowledge	Classify your knowledge about how people were back in Roman times.
6	Knowledge	Classify how enriching your visit to this archaeological site was.
7	Value	Did this experience increase your interest in this archaeological site?
8	Value	How reliable (in other words, how close to reality) do you think the information you obtained through this experience was?

FIGURE 2. Photograph taken during one of the experiments, while the guided visit was occurring.

being provided in Portuguese, English, or French, depending on the language that they preferred.

The selection of a given condition was randomly selected, and then, the mobile device was handed to participants with the multisensory AR application already running so they could experience the AR content. The participants were free to explore the site by themselves, as illustrated in figure 3. Only when requested did the researcher intervene in the experience to answer questions or exchange information related to what participants wanted to share at that moment of the experience.

The duration of the AR experience lasted five minutes. After the experience, the participants were asked to complete the questionnaires related to the dependent variables in the study (due to the particularities of the DV presence, the presence questionnaire was only applied when an AR scenario was presented, i.e., in all conditions except for the baseline condition). The following step was to have the participants complete the generic sociodemographic questionnaire at the end of the survey, as suggested in the literature [53], [54]. Finally, a short debriefing/discussion regarding their thoughts and feelings about the experience was carried out by the researcher.

FIGURE 3. Photograph taken during one of the experiments, while one participant was participating in the experiment.

The whole procedure took approximately 20 minutes per participant.

F. STATISTICAL PROCEDURE

Descriptive and inferential statistics were computed using SPSS 23 software, with a confidence level of 95%. The normal distribution of the data was assessed by applying Shapiro Wilk's test. The Shapiro-Wilk test to assess the normality of the data for each of the DVs revealed that they were not normally distributed ($p < 0.05$) and as such, nonparametric tests were selected to compare the different conditions, namely, the Kruskal-Wallis H test. In the cases in which statistically significant differences were found after the Kruskal-Wallis H test, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. The significance probability (p-value) for checking the evidence against null hypotheses was considered for alpha levels of 5% (0.05). For all rejected hypotheses, to guarantee reliable conclusions, the strength of the relationship between the IV and each of the DVs is presented as *Cohen's d* (effect size calculated for nonparametric Kruskal-Wallis-H tests), the observed power is also identified, and 95% confidence intervals for the mean are presented.

For the correlation analysis between constructs and moderators, these were performed according to the normal distribution of the variables under study. Parametric Pearson's correlation coefficient tests were performed for normally distributed variables, and for free distribution, a nonparametric Kendall's tau-b (τ_b) correlation coefficient test was conducted, as it has been shown to be more robust and slightly more efficient than Spearman's rank correlation [55].

III. RESULTS

This section presents the statistical analysis of the data obtained in the experimental study.

A. PRESENCE

As mentioned in subsection II-D1, the dependent variable presence comprises the subscales spatial presence,

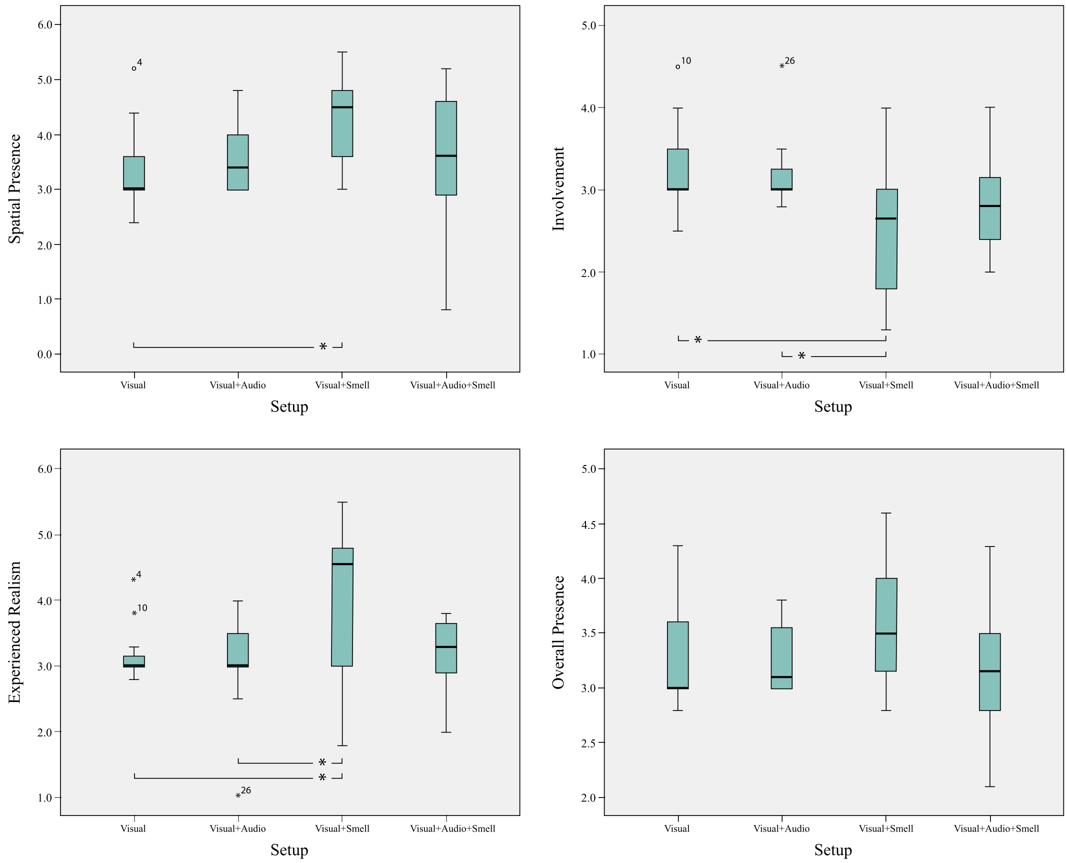

FIGURE 4. Means and 95% confidence intervals for spatial presence, involvement, experienced realism, and overall presence. The links marked with * represent significant differences found across conditions at $p < 0.05$.

involvement, experienced realism, and overall presence. The Kruskal-Wallis-H test for each of the subscales revealed that there were statistically significant differences between conditions for spatial presence ($\chi^2(3) = 7.1482$, p = 0.06732, $\eta^2 = 0.114$), involvement ($\chi^2(3) = 9.1584$, p =.02726, $\eta^2 = 0.159$), and experienced realism ($\chi^2(3) = 3.4624$, p = 0.32568, $\eta^2 = 0.032$).

The post hoc analysis with spatial presence revealed statistically significant differences between *Visual* (mean rank = 18.46) and *Visual + Smell* (mean rank = 33.25), with a stronger influence in this last condition, with a p-value of 0.008.

Regarding involvement, significant differences were found between *Visual + Smell* (mean rank = 16.12) and two other conditions, namely, a stronger influence for *Visual* (mean rank = 31.75) with a p-value of 0.006 and for *Visual + Audio* (mean rank = 28.88) with a p-value of 0.025.

Considering experienced realism, significant differences were found between *Visual* (mean rank = 20.38) and *Visual + Smell* (mean rank = 33.17), with a stronger influence in this last condition, with a p-value of 0.021. Significant differences were also found between *Visual + Audio* (mean rank = 21.42) and *Visual + Smell* (mean rank = 33.17), with a stronger influence in this last condition, with a p-value of 0.034.

Figure 4 illustrates an overview of significant differences found across the presence variables, when found, between conditions including the means and 95% confidence intervals calculated for each DV – IV pair.

1) BEHAVIOURAL PRESENCE

It was possible to identify the number of reactions registered for each group of participants, divided by condition, as illustrated in table 3. Note that the reaction defined as "interacted" indicates a behavior related to making a sound out loud or pointing at the screen.

TABLE 3. Summary of some reactions registered during the experiences *in situ.*

Visual		
interacted	*smiled*	*average*
4/7	4/7	57%

Visual + Audio		
interacted	*smiled*	*average*
7/9	9/9	89%

Visual + Smell		
interacted	*smiled*	*average*
7/8	4/8	69%

Visual + Audio + Smell		
interacted	*smiled*	*average*
9/10	8/10	85%

B. ENJOYMENT

The Kruskal-Wallis-H test revealed that median scores for enjoyment were significantly different between the different experimental conditions ($\chi^2(4) = 16.3504$, p = 0.00258, $\eta^2 = 0.238$).

The post hoc analysis revealed statistically significant differences between *None*, with a mean rank of 13.38, and all other conditions. In particular, a stronger influence was found in the conditions using *Visual* (mean rank = 32.08) with a p-value of 0.008; *Visual + Audio* (mean rank = 40.58) with a p-value of 0.000; *Visual + Smell* (mean rank = 34.50) with a p-value of 0.003; and *Visual + Audio + Smell* (mean rank = 31.96) with a p-value of 0.009.

Figure 5 illustrates an overview of significant differences found in enjoyment between conditions, including the means and 95% confidence intervals calculated for each DV - IV pair.

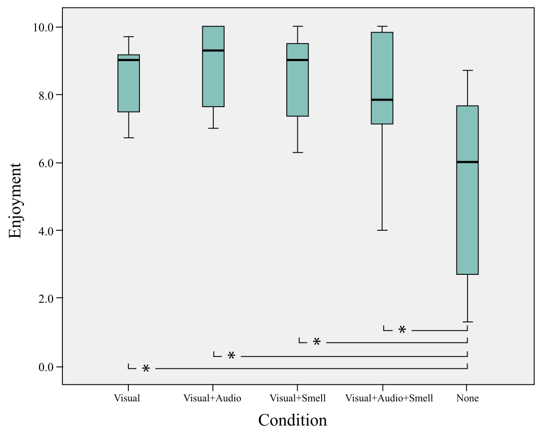

FIGURE 5. **Means and 95% confidence intervals for enjoyment. The links marked with * represent significant differences found across conditions, for p < 0.05.**

C. KNOWLEDGE

Regarding the variable knowledge, the Kruskal-Wallis-H test revealed that median scores were significantly different between the different experimental conditions ($\chi^2(4) = 14.7217$, p = 0.00531, $\eta^2 = 0.209$.

The post hoc analysis revealed statistically significant differences from *None* (mean rank = 19.42). Namely, stronger influences were found with *Visual* (mean rank = 43.79) with a p-value of 0.001 and with *Visual + Audio + Smell* (mean rank = 33.50) with a p-value of 0.048. Significant differences were also found between *Visual + Smell* (mean rank = 22.79) and *Visual* (mean rank = 43.79) conditions with a p-value of 0.003.

Figure 6 illustrates an overview of significant differences found in knowledge between conditions, including the means and 95% confidence intervals calculated for each DV - IV pair.

D. VALUE OF THE EXPERIENCE

For the scores obtained for the value of the experience, the Kruskal-Wallis-H test revealed that median scores were not significantly different between the different experimental

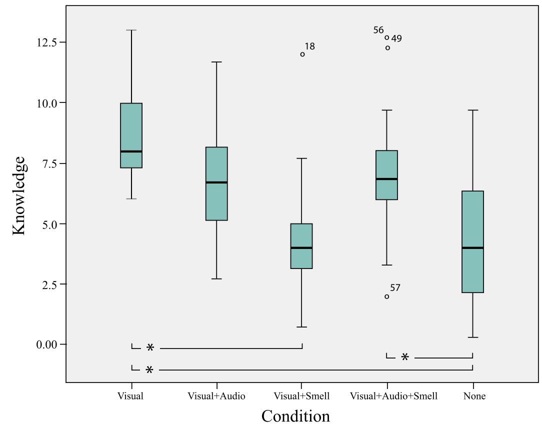

FIGURE 6. **Means and 95% confidence intervals for knowledge. The lines marked with * represent significant differences found across conditions, for p < 0.05.**

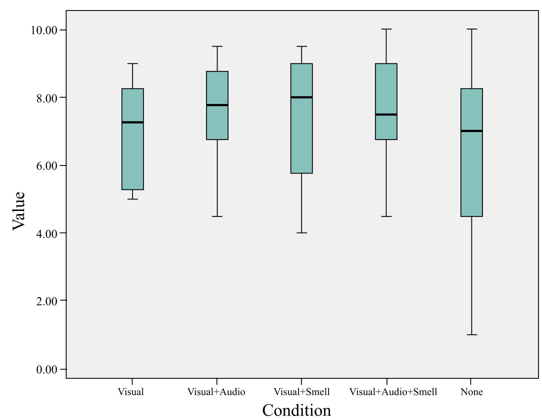

FIGURE 7. **Means and 95% confidence intervals for value of the experience.**

conditions ($\chi^2(4) = 2.207$, p = 0.69775, $\eta^2 = 0.014$). Thus, the collected data do not support the rejection of the null hypothesis $H3_0$. Figure 7 illustrates the means and 95% confidence intervals for each DV - IV pair.

E. CORRELATION RESULTS

Considering the variables spatial presence, involvement, experienced realism, overall presence, enjoyment, knowledge, and value of the Experience, with individual characteristics such as age, sex, country of origin, and AR previous experience, we performed Kendall's tau-b (τ_b) ccorrelations across all of them, looking for significant correlations (for p-value < 0.05) among 48 participants.

We observed that spatial presence had a strong, significant correlation with age ($\tau_b = 0.208$, p-value of 0.050) meaning that spatial presence was stronger for older people. We also noticed a strong, positive significant correlation between overall presence and age ($\tau_b = 0.210$, p-value = 0.046). These results showed that overall presence was also stronger for older people.

We observed that enjoyment had a strong, positive significant correlation with spatial presence ($\tau_b = 0.271$, p-value of 0.013), meaning that the enjoyment perceived by users was stronger for people who reported higher scores of spatial presence. Enjoyment was also identified with a strong, positive significant correlation with overall presence ($\tau_b = 0.273$, p-value $= 0.012$), meaning that the enjoyment perceived by users was stronger for people who also reported higher scores of overall presence.

We observed that knowledge had a strong, positive significant correlation with enjoyment of the experience ($\tau_b = 0.255$, p-value of 0.006), and a strong, positive significant correlation with involvement ($\tau_b = 0.228$, p-value of 0.034). Thus, the acquired knowledge perceived by the users was stronger for people who reported higher values for their perceived enjoyment and for people who reported higher values for their involvement. It was observed that knowledge had a significant positive correlation with previous experience with AR ($\tau_b = 0.283$, p-value of 0.021), meaning that the knowledge perceived by the users was stronger for people who had never tried AR technology before.

We observed that value of the experience had a strong, positive significant correlation with enjoyment of the experience ($\tau_b = 0.478$, p-value of 0.000), meaning that the value perceived by the users was stronger for people who reported higher scores for enjoyment. Value of the experience was also identified with a significant positive correlation with spatial presence ($\tau_b = 0.240$, p-value $= 0.029$) and with experienced realism ($\tau_b = 0.224$, p-value of 0.042), meaning that the value perceived by users was stronger for people who reported higher scores of experienced realism and higher scores of spatial presence.

IV. DISCUSSION

The goal of this study was to investigate the impact that visual, audio, and smell stimuli have on presence, enjoyment, knowledge and the value of experience when using AR applications in a CH context, and this section advances a discussion on the aforementioned obtained results.

A. IMPACT OF STIMULI ON SENSE OF PRESENCE

According to the results, spatial presence was significantly different between the *Visual* and *Visual + Smell* conditions, such that the experience with the two stimuli resulted in higher scores for spatial presence than the experience with the visual stimulus alone. The *Visual + Smell* condition that appeared to have a positive influence on spatial presence is the same that had the opposite effect on involvement, where the *Visual + Audio* condition was more influential on the feeling of involvement in the experience. Thus, visual and audio stimuli together provided more involvement than visual and smell together. Note that *Visual + Audio + Smell* was not found to be significantly different, which suggests that when the three stimuli were presented together, the increased spatial presence when the smell stimulus was presented and the increased involvement when the audio was available were not noticeable. This suggests that the impact of adding a given stimulus is also related to the combination with other stimuli being presented in the experience.

Regarding experienced realism, another contradictory situation occurred in which the *Visual + Smell* condition resulted in higher values than the *Visual + Audio* condition. Here, the *Visual + Smell* condition also provided more experienced realism than the *Visual* condition. The results did not show any evidence that all stimuli together, i.e., *Visual + Audio + Smell*, led the participants to a better sense of spatial presence, involvement or experienced realism.

Behavioral presence results showed that people smiled more, made more sounds out loud more often, and interacted more by pointing at the screen when audio was being added to the experience. The addition of smell did not appear to interfere with smiling reactions to the application but triggered even more talking interactions. Thus, the observational analysis suggested a stronger behavioral presence for the *Visual + Audio* and *Visual + Audio + Smell* conditions.

The lack of AR studies related to multisensory implementation does not allow us to relate the results with results obtained using other AR systems. Previous analyzed work targeted multisensory AR exhibitions to increase the sense of presence did not present evaluation data or allude to the impact of each stimulus in the experience [3], [9], [10]. Considering VR multisensory systems, the results obtained in the current study are not exactly in line with the literature, which highlighted that users stated that sense of presence was improved when using the multisensory approach instead of the regular, visual-only, approach [14]. The results demonstrated differences among presence-related variables but did not show overall presence being influenced by the different stimuli in the experience.

B. IMPACT OF STIMULI ON ENJOYMENT

According to the collected and analyzed data, a multisensory AR experience in situ led to more joyful visits. However, changing the number of stimuli did not appear to make significant differences in the user's experience. Comparisons of the baseline condition designated *None*, where only a guided visit was provided, with all other conditions, i.e., those that added the visual stimulus without or with audio and/or smell stimuli, confirmed that the participants enjoyed the second group of conditions more. The high and tight scores obtained, as shown in the confidence intervals (figure 5) established the tendency for more satisfying experiences when AR – multisensory or not – was provided.

These results are in line with the literature that highlighted that users were more satisfied when they were able to explore the surroundings with the multisensory approach but were not as high as they expected, probably due to comfort issues and intimidation towards the used technologies [14]. Although users of the evaluated systems did not point out any comfort issues or report feeling intimidated by any component, enjoyment did not appear to be higher across the conditions with more or fewer stimuli.

The direct observation provided relevant insights: it was noticed that the participants who experienced the SensiMAR prototype with the sound smiled more, exhibited more surprising expressions, and interacted more with their partners in the experience and with the researcher who was carrying out the research. This was mainly during a scene where the two Romans appeared and talked between them in Latin. In several cases, the participants were speculating about what topics they could be talking about, suggesting amusing topics and laughing. Thus, even though no significant differences were found between conditions with or without sound, this qualitative data – where participants seemed more amused and more impressed – suggested higher levels of enjoyment when compared to the participants who did not listen to sounds.

Regarding the smell experiences, direct observations revealed the moment when they were asked to smell the *garum* as a pivotal moment to interact more with the researcher that was conducting the experience and the guided visit. This interaction led to more exchange of information, and the participants expressed more interest in being there since they were speculating and asking about what would *garum* taste like and how it was made, and therefore, spent more time in place by their own will. Once again, although no significant differences were found between conditions with or without smell, qualitative data suggested increased willingness to be there in these conditions when compared to experiences without the smell stimulus.

In general, it was observed that people were amazed about the possibility of exploring ruins outdoors by being able to listen to sounds related to the Roman Era and to have something to smell regarding their habits and culture (such as the provided smell of *garum*). This helps to understand why participants who were not able to listen to sounds or to smell did not present significant differences when compared to those who had the chance to be engaged with these stimuli: people are not used to having more than visual stimuli in these places. Thus, they are not prepared to imagine a multisensory experience and, in this line, they do not consider it when they express their enjoyment because they convey their gratification with the chance of viewing the place how it used to look. They do not raise the hypothesis of having more than that, and those who tried the audio and the smell experiences (besides their astonishment with that possibility) also speculated about how great it could be to have these stimuli in other heritage sites.

Corroborated by previous literature [56], one fact that could contribute to a negative impact on presence scores was the existence of minor tracking issues and, in some cases, the inaccurate position of the virtual elements due to participants accidentally covering the smartphone camera with their hands and when participants moved the smartphone too fast.

C. IMPACT OF STIMULI ON KNOWLEDGE

When observing knowledge across the different conditions in our evaluation, more knowledge was perceived by the participants who experienced multisensory AR with the *Visual + Audio + Smell* condition than with the *None* condition. Thus, the conditions with only one or two stimuli (*Visual*, *Visual + Audio*, and *Visual + Smell*) did not show significant differences in relation to the baseline condition *None*.

It is curious though to observe that the condition where the visual stimulus alone was added to the experience provided higher values for knowledge than the *Visual + Smell* condition. We raise here some concerns related to the addition of smell as a distracting element, as suggested in the literature [57].

During the experiment, it was noted that the participants made correlations between the guided visit and what they perceived in their experience – depending on which condition they were experiencing. Moreover, the number of correlations made depended on the number of stimuli to which the people were being subjected. For example, the garden fountains were noticed by users only when the audio stimulus was also present, even though they were identically visible in both scenarios (i.e., with and without sound).

Another relevant fact noticed during the experiences that should be connected to the achieved knowledge is related to the questions that the participants asked. When experiencing the conditions *None* and *Visual*, the participants raised fewer questions than in the *Visual + Audio*, *Visual + Smell* and *Visual + Audio + Smell* conditions. For instance, the *None* and *Visual* conditions triggered questions such as, if the columns were in that place when they discovered the house and what was the utility of the hole at the entrance of the house (a hole used to drain the water). None of these questions was related to what was being said during the guided visit or with what they observed on the AR application. However, with more stimuli presented, more questions were raised. In experiences with the audio available, the people started to ask more questions such as "what language did they speak" and "how did they manage to bring water to the city?". The experiences with the smell stimulus also appeared to trigger more questions than without it, such as "how did they make the fish sauce?", "was the fish sauce tasty?", or "where did the fish come from?"

Comments made by the participants who experienced a multisensory condition demonstrated a deeper understanding about the archaeological site than with conditions including more than one stimulus, as the participants shared their achievements by saying "this should be very crowded by then", "there were more male people in the streets", and "they used to have so many and beautiful gardens". These reactions suggested that the addition of stimuli in a visit contributed to obtaining more knowledge.

D. CORRELATIONS DISCUSSION

In accordance with the significant differences identified in the conducted correlations, we observed that spatial presence was stronger in the older participants as well as overall presence, which was also reported to be stronger for older participants. Observing older people as more susceptible to presence-related feelings sparks interest in understanding the relationship between sensitivity to perceive the stimuli – where older people are frequently demonstrated to be less capable of identifying smells [58], [59] and with increased impairments related to auditory processing [60], [61] – and the impact of these stimuli in the experience – which, according to our results, were revealed to have a greater impact on older people. In fact, these results are consistent with the findings of a recent study that demonstrated multisensory integration as being enhanced in older adults [62].

When observing correlations between the users' feelings of presence – across its subscales spatial presence, involvement, experienced realism and overall presence–and their enjoyment, knowledge, and value of the experience, interesting correlations were found in our collected data. Additionally, it is interesting and important to highlight some noncorrelated variables that have frequently been identified in the literature as being correlated. The literature suggests several determinants for perceiving smell according to demographic differences – females tend to have a closer perception of smells [58], and younger people appear to be more acuate [63] –, individual differences, and cultural factors–olfactory acuity scores of Europeans were demonstrated to be significantly lower than the scores of an indigenous society [59].

We observed that sex and country of origin–or continent (divided by Europe, America, or Oceania), which aims to detect cultural factors [59] – were not correlated with any of the variables analyzed. Age was identified as being correlated to spatial presence and overall presence, revealing that older people reported higher levels, and people who had never tried AR technology before reported higher values for knowledge acquired in the experience.

E. OVERALL DISCUSSION

The results demonstrate the importance of the role of each stimulus, as raised in our thesis, by aiming to comprehend their impact in a multisensory experience. The addition of smell can enhance some feelings when exploring a CH site, such as spatial presence or experienced realism but can have a contradictory effect when observing its impact on other variables, such involvement and in acquired knowledge perceived by the users, which seems to be lower when smell was added to the experience. These insights, beyond expressing the importance of the positive or negative effect when adding a given stimulus to a multisensory experience, reveal a great opportunity for deeper research on the impact of different stimuli when used together. That is, in analyzing these results, we observed the role of a specific stimulus as having a different impact when combined with others. Previous research provided knowledge of the impact that a single stimulus can have in an individual when it is added to the experience. For example, smell is undoubtedly linked to personal memories [64], [65], moods [66], and other feelings as stated in a literature review. Sound is widely known for creating feelings and emotions [67], [68]. However, the results obtained with the current research suggested that the impact of these stimuli on the overall experience can change according to the presence (or absence) of other stimuli.

Hence, our research answers the question related to the impact of different stimuli on the presence, enjoyment, knowledge, and value of experience regarding visitors' experiences as follows: the addition of smell in a CH visit can increase presence-related variables such as spatial presence and experienced realism but can hamper the perception of the presence-related variables involvement and knowledge; the addition of audio can increase involvement perceived by participants. The addition of all analyzed stimuli (visual, audio, and smell) can increase knowledge, and the addition of any of these stimuli can increase enjoyment. Behavioral Presence was higher when the experience was conducted with all three stimuli. Behavioral presence was also higher with the addition of audio than with the addition of smell.

V. CONCLUSION

This study presented results related to presence, enjoyment, knowledge, and value of the experience obtained by an evaluation *in situ* with end-users. This AR multisensory system allowed the presentation to participants the senses of sight, hearing, and smell following modular stimulation, which is rare [3]. The current study supports its implementation *in situ*, i.e., outdoors, presenting new results from its usage with random participants from an archaeological site, namely, the Roman Ruins of Conimbriga.

The impact of adding different stimuli in an AR experience in CH on users' presence differs according to the added stimuli and to the variable under study – the presence-related variables studied were spatial presence, involvement, experienced realism, and overall presence, complemented with a behavioral presence observation. These conclusions reinforce the need for evaluating the addition of each stimulus individually as well as for evaluating them together as they evoke distinct feelings. Note that, for example, significant differences were found when analyzing involvement, between the addition of smell and the addition of audio, with audio resulting in higher values, and the opposite was verified for experienced realism. The subscales of presence analyzed as a whole, according to the IPQ group questionnaire, demonstrated overall presence as not being affected by changing the conditions.

Conclusions resulting from the conducted correlations between analyzed variables and individual characteristics, revealed that spatial presence and overall presence feelings are stronger for older people. Higher levels of enjoyment were expressed by participants who also reported higher scores of knowledge, higher scores for value of the experience, stronger feelings of spatial presence and of overall presence. These correlations also revealed that higher knowledge scores were detected for people who also reported higher values of involvement, in particular for people that never had tried AR technology before. It was also verified that participants who reported higher scores of value of the experience were those who expressed stronger feelings of spatial presence.

This research demonstrated experiences with more enjoyment and more acquired knowledge when using multisensory AR in archaeological sites. The noticed surprise among participants who tried this technological solution, i.e., using AR outdoors, reveals this as a novel approach for visitors to cultural heritage sites that raises interesting insights for using multisensory AR in CH contexts.

Direct observation records showed evidence to support the multisensory AR approach instead of the traditional AR. The knowledge acquired also proved to increase with the multisensory AR solution, since the participants were more dynamic and interacted more, e.g., by raising further questions and discussing the Roman culture and architecture more.

The current research provided novel answers that contribute to a better understanding of the impact of adding stimuli in AR multisensory solutions and can trigger future work. Following literature concerns related to evaluating presence in AR environments as in VR, the results obtained among the subscales of sense of presence when using our AR multisensory prototype evinced the need for analyzing the subscales individually. Based on this demand, we suggest an opportunity for further research related to the improvement of evaluation tools targeted for evaluating presence in AR environments. The dualities found in the different subscales that represent the sense of presence suggest that different stimuli evoke specific impressions but, together, do not confirm an increased sense of presence–since different stimuli have distinct impacts on the different subscales. This evinces the distinct impact that each stimulus can cause, and a deeper understanding of how we can combine them to enhance a specific feeling remains.

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