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AR and Gamification in Museum Apps: Current Challenges and Opportunities

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Abstract. There have been numerous attempts to apply augmented reality (AR) and gamification in a museum context. Many of these have been as part of research projects, attempting to understand the potential benefits and issues of these approaches in a museum setting. Others have been rolled out as museums' own projects for enhancing the visitor experience. Despite this rich history of attempts to utilise AR and gamification in museums, there are still many challenges and issues – and it is not uncommon for the apps and experiences in museums that apply AR and gamification to be relatively short-lived. As part of a larger research project guided by Design-Based Research (DBR) and Mixed Methods Research (MMR) to explore improved design recommendations for AR-based and gamified museum apps, we conducted surveys in both English and Chinese with young adult visitors and museum professionals to identify the current challenges and opportunities for such apps. We present the results of the survey with museum professionals, highlighting the four key challenges they identified in successfully adopting AR and gamification in museum apps. This further guides the focus of follow-up interviews currently being conducted with museum professionals, some initial feedback from this is also presented. Lastly, we conclude with a discussion on our next steps and procedures as we work towards developing professional guidelines for the design process and improved design recommendations for such apps.

Keywords: AR, Gamification, Museum Learning, Visitor Experience, Museum Apps.

1 Introduction

In recent years, the value of museums as important informal learning spaces has been widely recognised. With the advancement of technology, the importance of digital technology for museums has become increasingly significant, and its benefits to museums have been more extensively discovered. Some studies indicate that museums play a crucial role in preserving cultural heritage [1] and providing educational opportunities for visitors [2, 3], allowing visitors to engage with collections and gain insights into culture, science, and history [4]. Notably, scholars have emphasised that new technologies have influenced and enhanced people's experiences, behaviours, and thinking, and their application in the cultural heritage field has gained greater recognition [5, 6]. As some studies have pointed out, museums are increasingly adopting a visitor-centred approach [7], striving to implement digital technologies to create engaging and meaningful experiences that cater to visitors' preferences and needs [4, 8]. Moreover, with younger generations showing a preference for digital technologies, the trend of integrating emerging digital tools with the traditional resources of museums has become evident [1]. As [7] found, there has been a rise in the use of smartphones and apps within museum environments. Additionally, some scholars have emphasised that interactive digital technologies and devices can establish connections between visitors and digital content, thereby enhancing visitor experience [9]. Furthermore, digital technology holds tremendous potential for promoting museum development and enhancing visitor experience [6].

Currently, AR and gamification are receiving widespread attention in museums, and their positive effects are increasingly being recognised. Some scholars have emphasised the great potential of AR and gamification to enhance entertainment and improve the learning experience in museums [10]. Regarding AR, several studies, after experimenting with its application in museums, have identified its potential advantages and positive impacts [2, 6, 8]. Similarly, there have been studies exploring the use of gamification in museums, which have highlighted its

benefits and positive effects [1, 11]. Notably, some research suggests that AR can provide valuable support for the application of gamification in the cultural heritage sector [12]. It is undeniable that AR and gamification can serve as key elements in museums' innovative digital strategies.

However, although AR and gamification are important tools for museums' digital innovation, museums continue to face numerous issues and challenges in their application. As some scholars have found, museums face two major challenges now, one is attracting and retaining visitors, and the other is integrating new digital technologies [13]. In the context of museums' digital innovation, developing targeted strategies for visitors interested in digital technologies is necessary. For engaging visitors, some studies have shown that the usability of mobile applications varies across different age groups [3], and others has also been found that younger audiences show an increasing tendency to incorporate their smartphones into museum interactions [9]. However, some scholars have noted that museums do not always succeed in attracting young people and, in some cases, even neglect them [4], while this group tends to have little interest in museums [14]. Furthermore, it has been emphasised that learning occurs when museum exhibitions resonate with visitors' interests [1]. In terms of integrating digital technologies, some scholars have pointed out the drawbacks and challenges associated with applying AR [3, 6] and gamification [12, 14, 15]. Others have noted that there are still significant gaps and ambiguities in how AR can be effectively applied in museums [16]. Additionally, much of the research on applying gamification or game elements in the cultural heritage sector to enhance user learning experience focuses on games rather than gamification itself [11, 17, 18]. Notably, it has been found that there is a lack of research examining the combined application of AR and gamification in museums and its impact on visitor experience and learning outcomes [10]. These challenges highlight the absence of effective strategies for museums in engaging visitors interested in digital technologies and in utilising AR and gamification.

Certainly, museums are currently eager to leverage digital practices with AR and gamification to provide visitors with enhanced museum experience and improve their learning outcomes. However, both in academic understanding and industry practice, there remains several significant gaps in knowledge regarding how AR and gamification can be more effectively integrated within museums – particularly in museum apps, and how they impact visitor learning experience – especially for young adult visitors who are more receptive to new trends. Beyond the previously mentioned issues related to engaging visitors and integrating digital technologies, further challenges arise as museums increasingly attempt to utilise digital technologies.

To address the existing gaps, we propose the core research question, that is how can museums effectively design AR-based and gamified museum apps to enhance the learning experience of young adult visitors? Subsequently, we conduct the relevant research guided by DBR and MMR. Firstly, this research highlights the foundational role that DBR plays in the research design. DBR is characterised by an iterative cycle of analysis, design, implementation and reflection in real-world settings, and this approach collaboratively develops solutions that can practically address complex problems, in order to create powerful and effective educational interventions based on existing theories, and to further advance the development of theories [19]. Secondly, this research values the positive contributions of MMR to the successful conduct of DBR. MMR ensures that the research results are fully analysed and provides a comprehensive understanding of the research questions, and it uses both qualitative and quantitative research methods, making full utilisation of the strengths of the two methods by collecting, analysing and synthesising the qualitative and quantitative data from a single study or a series of studies at different stages of the research [20]. Furthermore, the ultimate aim of this research is to provide effective design recommendations for AR-based and gamified museum apps for museums, helping museums follow reliable design recommendations in a reasonable design process to design such apps that can enhance the learning experience of young adult visitors.

The research activities described in this paper are the first phase of a larger research project guided by DBR and MMR. In order to clarify the iterative cycle of the entire larger research project, we briefly describe the research activities that need to be proceeded in the four phases, as shown in Fig. 1 below:

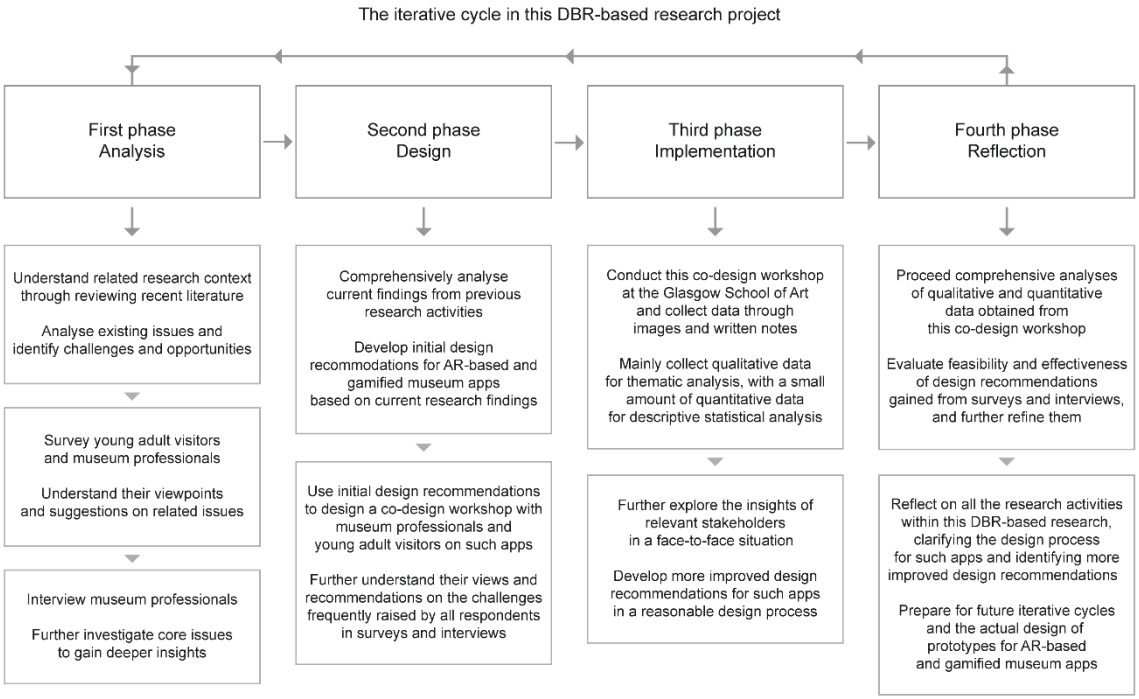

Fig. 1. The iterative cycle with four phases in this larger DBR-based research project.

This paper presents the research findings from the survey conducted with museum professionals, as well as some discussion from the completed follow-up interviews with museum professionals, which are elaborated in detail in Section 3. Finally, Section 4 of this paper concludes the research activities that have been analysed so far and discusses the next steps and procedures required in the larger research project to develop professional guidelines for the design process and improved design recommendations for AR-based and gamified museum apps. Significantly, all research activities constitute a complete iterative cycle under the guidance of DBR, which promotes the continuous development of the design process and design recommendations for such apps as educational interventions.

2 Research Methodology

In order to address the research question and achieve the ultimate research aim, and given that the focus of this research spans interdisciplinary fields, this research integrates DBR and MMR, combining their key characteristics – iterative research processes and the comprehensive analysis of both qualitative and quantitative data. This integration provides crucial guidance and academic support for the continuous refinement of design recommendations for AR-based and gamified museum apps aimed at effectively enhancing the learning experience of young adult visitors.

At the phase presented in this paper, we conducted online surveys targeting young adult visitors and museum professionals, and the design of the surveys was based on the findings from the review of previous research. These surveys are done to further understand their views and suggestions on the relevant topics and to explore the potential of effectively designing AR-based and gamified museum apps to enhance the learning experience of young adult visitors, as detailed below.

We designed two versions of the semi-structured online questionnaires on the Jisc Online Surveys platform to survey young adult visitors and museum professionals in order to collect the necessary data. The main focus is on collecting qualitative data, with a small amount of quantitative data embedded. Given that this research aims to analyse the views and suggestions of young adult visitors and museum professionals from different economic and social contexts, and considering the location of this research, the researchers' nationality and the prevalence of different languages, we further divided the online questionnaires targeting these two different groups into English and Chinese versions, with consistent content, only differing in language. Due to the page limit, the full question lists are not presented here. Before implementing the surveys, we clearly identified the specific target groups. For the survey targeting young adult visitors, the focus was on young adults residing in the Europe and China. For the survey targeting museum professionals, the focus was on those working in or having served museums located in

Europe and China. Furthermore, to ensure the relevant and in-depth feedback, we employed purposive sampling and snowball sampling to identify suitable participants among young adult visitors and museum professionals.

Subsequently, we conducted a comprehensive analysis of the qualitative and quantitative data collected from the online surveys of both groups, aiming to identify the challenges and potential opportunities that museums face in utilising AR and gamification and designing museum apps. We also explored the issues visitors encounter and the benefits they gain when engaging in museum learning and using museum apps. The key challenges to the successful integration of AR and gamification in museum apps, as recognised by museum professionals particularly, further clarified the focus of the current and ongoing follow-up interviews with museum professionals. Follow-up interviews with museum professionals are beneficial to gain a deeper understanding of the perspectives of professionals in related fields on current key challenges, as well as their insights into addressing these challenges, in order to help this research explore more effective design recommendations for AR-based and gamified museum apps, as described below.

Again, purposive sampling and snowball sampling methods were used to identify museum professionals to participate in the follow-up interviews. As all the interviewees are based in Europe, the interview question lists were presented exclusively in English. To accommodate interviewees' daily schedules and geographical constraints, interviews were conducted through online video meetings via Zoom. The core questions for the follow-up interviews were designed based on the key challenges identified in the surveys regarding the successful utilisation of AR and gamification in museum apps. Additional questions were incorporated, informed by recent studies on related topics and aligned with the research aims. All the questions in the interviews were open-ended. Again, the full question list used for the follow-up interviews is not presented here due to space constraints.

A comprehensive analysis of the qualitative data collected from the interviews, delving deeply into key issues is ongoing, with preliminary notes presented here. This contributes to a deeper understanding of the key challenges museums may face in successfully designing AR-based and gamified museum apps, as well as the effective strategies to address these challenges. This also facilitates a progression from broader reflections, which are encompassing a review of recent studies on related topics and the research findings from the surveys conducted with the two target groups, to narrower reflections on the core concerns. This research has undergone review by the Ethics Committee of the Glasgow School of Art, from which approval was received.

3 Research Findings and Results

As of the time of writing , the data collection for the survey targeting young adult visitors is still ongoing. Specifically, the English version of the survey is still in progress, while the Chinese version closed on 14th September 2024. A total of 19 young adults responded to the English survey and submitted complete and valid responses, a response rate of 8% against the 280 who responded to the Chinese survey, a response rate of 28%. Although the total number of responses from the two language versions of the survey targeting young adult visitors meets the requirements of this research, the substantial imbalance in the number of valid responses between the two versions may introduce bias into the research findings for this research activity. Therefore, further efforts are ongoing to enhance the distribution of the English version of the online survey targeting young adult visitors. In this paper we will focus our discussion on the results from the survey and interviews with professionals instead.

Both language versions of the online survey targeting museum professionals closed on 30th July 2024. Overall, 14 museum professionals responded to the English version of the survey, a response rate of 28%, while 25 responded to the Chinese version of the survey, a response rate of 50%, submitting complete and valid responses. After translating and cleaning all the data obtained from the survey for museum professionals, we ultimately collated the original 14 English datasets and 25 Chinese datasets into 38 English datasets. These 38 English datasets represent the final data obtained from the survey and required to be analysed.

In addition, regarding the follow-up interviews with the selected museum professionals, as of the writing of this paper, we have completed online interviews with three of them. Given that the questions used in the online interviews were all open-ended, we employed thematic analysis to qualitatively analyse the collected data.

3.1 Findings from Surveys for Museum Professionals

It should be noted that, due to page limit, this paper only presents some of the relatively significant findings and results derived from key questions in the survey conducted with museum professionals. The emphasis is placed on the key challenges they identified in the successful design of AR-based and gamified museum apps.

Firstly, we conducted a descriptive statistical analysis of the quantitative data collected from the closed-ended questions in this survey. The data, in terms of proportions and percentages, provide a preliminary understanding of the reliability of the data collected in this survey and the museums' attempts at AR and gamification. For Q6

and Q8 in this survey, these two questions are 'Multiple-choice' questions, which are intended to understand the length of the respondents' experience in the museum industry and the size of the museums they work for or serve. From the data obtained from Q6, it can be seen that 47.4% of the respondents in the surveys have less than 5 years of relevant experience in the museum industry, and 23.7% of the respondents have more than 10 years of relevant experience in the museum industry, indicating that the level of experience of the respondents has a large span. From the data obtained in Q8, it can be seen that the scale of the museums in which the respondents of the survey work or serve has a large span and a balanced proportion, with half of the museums being small and medium and half being large and huge. The data obtained from Q6 and Q8 is shown in Fig. 2 and Fig. 3 below:

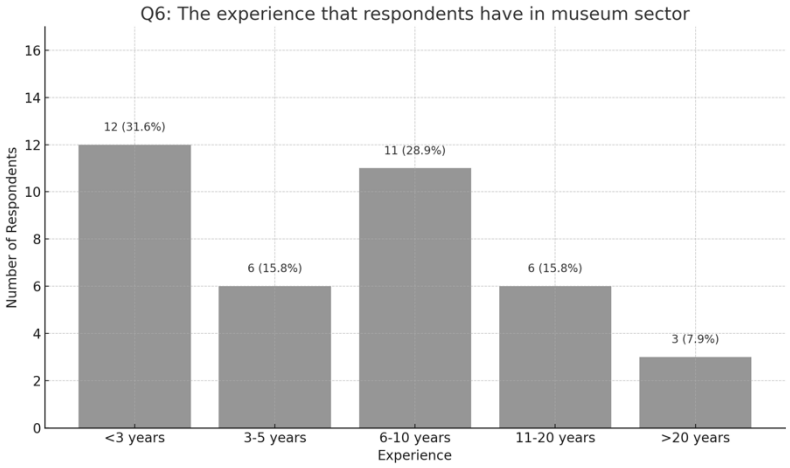

Fig. 2. Q6 is about the experience that respondents have in museum sector.

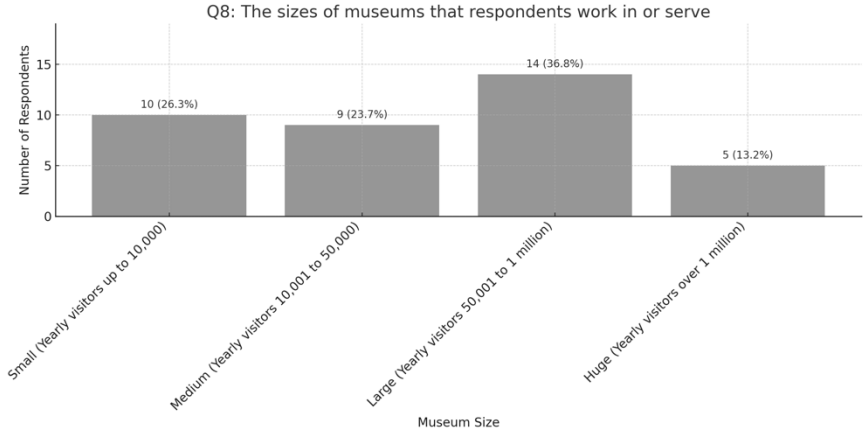

Fig. 3. Q8 is about the scale of museums that respondents work in or serve.

The data obtained from these two 'Multiple-choice' questions conform to the expectations of purposive sampling for this survey targeting museum professionals. By engaging museum professionals at different levels of experience in the museum sector across a wide range of scales, we can obtain valid, comprehensive and relevant answers to the research topics, which lays the foundation for the credibility of this research.

We then carried out a descriptive statistical analysis on Q12, Q14 and Q19, which are 'Yes or no' questions, to understand whether the museums where the respondents work or serve specifically attempt to attract young adult visitors, and whether the respondents have experience in using or developing AR-based museum apps and gamified museum apps. From Q12, 65.8% of respondents indicated that their museums specifically attempt to attract young adult visitors or organise events and activities primarily aimed at young adults. This suggests that attracting more young adult visitors is currently a goal for the majority of museums. From the data for Q14, 39.5% of respondents have experience in using or developing AR-based museum apps. This indicates that AR is a technology that has been applied within the museum sector, with over one-third of museum professionals having encountered AR in their work, pointing to its potential for further growth in the industry. As for Q19, only 15.8% of respondents have experience in using or developing gamified museum apps. This suggests that gamification is rarely applied in the museum sector and has significant potential for development. Among the six respondents who indicated experience with gamified museum apps in Q19, two referred to 'serious games', one mentioned

'game-based' experience, and another referred to 'interactive exhibits'. This raises questions about how many museum professionals and museums are actually using gamification in its precise sense, as opposed to other work using games in a museum context. Moreover, there seems to be some conceptual misunderstanding of gamification between academic research and industry practice. The data from Q12, Q14 and Q19 is presented in Fig. 4 as follows:

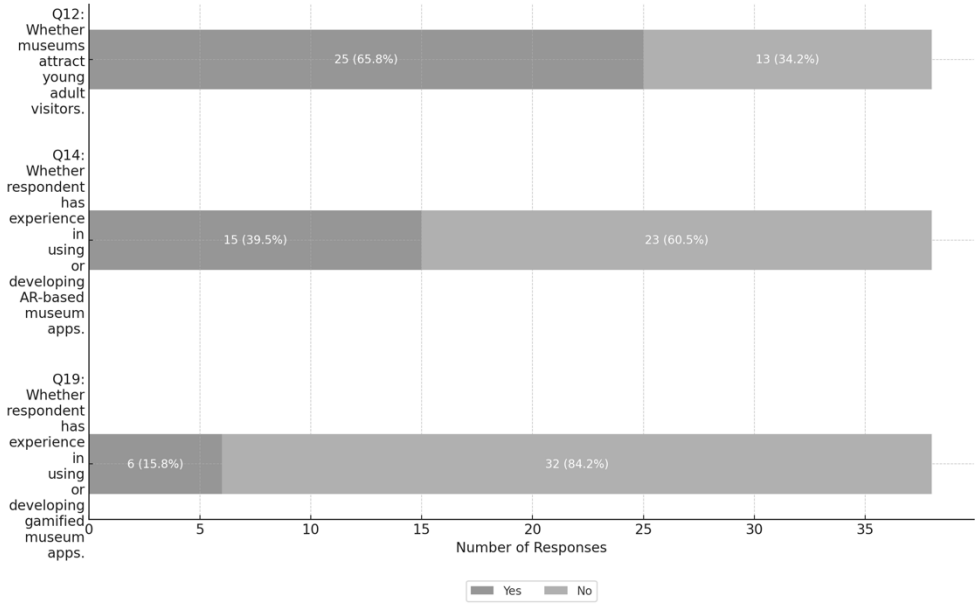

Fig. 4. Q12 is about whether museum attracts young adult visitors. Q14 is about whether respondent has experience in using or developing AR-based museum apps. Q19 is about whether respondent has experience in using or developing gamified museum apps.

With the help of the quantitative data obtained from these three 'Yes or no' questions, this research reveals that the issues observed in industry practice are related to the gaps in academic research. While most museums aim to effectively attract young adult visitors, the application of emerging AR technology and popular gamification strategies remains limited. Particularly, gamification is not only rarely applied, but the professionals have differing views over what gamification is.

Subsequently, we mainly collected qualitative data through 'Open-ended' questions to gain in-depth and comprehensive insights into museum professionals' views and suggestions on relevant issues. Thematic analysis was conducted on these qualitative data to identify themes and corresponding codes, supporting this research in exploring design recommendations for AR-based and gamified museum apps. It should be noted that the themes and codes obtained from the qualitative data collected from different open-ended questions often overlap in their definitions and scope. Therefore, it was necessary to organise these themes and codes. Based on the similarities and differences in their definitions and scope within the context of this research, adjustments were made by combining similar themes and codes, while separating distinct ones. Then we identified six domains, encompassing themes and codes with different focuses, and presented the frequency and proportion of each code. It should be explained that given the steps outlined above, in simple terms, the respondents' answers to the open-ended questions constitute qualitative data requiring thematic analysis, and these responses serve as a database of raw data. Thus, to assist with the analysis of this qualitative data, we utilised 'Chat GPT 4o' for initial thematic analysis. After obtaining the outputs, we manually reviewed all of them and iteratively refined the commands provided to 'Chat GPT 4o' until the manually verified results were accurate and reasonable. Overall, the domains, themes and codes are presented in Table 1 below:

Table 1. Themes, codes, frequencies and proportions within six domains from the survey targeting museum professionals.

Domains	Themes	Codes (Frequencies and Proportions)
1	1.1	1.1.1 Enhance visitor learning
Visitor	Enhancing	(Frequency: 10, Proportion: 10/38≈26.32%)
Engagement	Visitor	1.1.2 Increase visitor engagement
And	Experience	(Frequency: 6, Proportion: 6/38≈15.79%)
Learning		1.1.3 Fun and engaging content

		(Frequency: 4, Proportion: 4/38≈10.53%)
		1.1.4 Provide immersive experiences
		(Frequency: 2, Proportion: 2/38≈5.26%)
	1.2	1.2.1 Improve understanding of exhibits
	Improving	(Frequency: 3, Proportion: 3/38≈7.89%)
	Understanding	1.2.2 Make intangible concepts tangible
	Of	(Frequency: 2, Proportion: 2/38≈5.26%)
	Exhibits	1.2.3 Balance AR and traditional exhibits
		(Frequency: 1, Proportion: 1/38≈2.63%)
		1.2.4 AR supplements traditional content
		(Frequency: 1, Proportion: 1/38≈2.63%)
2	2.1	2.1.1 Appeal to tech-savvy youth
Audience	Engaging	(Frequency: 6, Proportion: 6/38≈15.79%)
Preferences	Specific	2.1.2 Meet high expectations
And	Audiences	(Frequency: 3, Proportion: 3/38≈7.89%)
Accessibility		2.1.3 Meet high expectations
		Optimise for personal devices
		(Frequency: 2, Proportion: 2/38≈5.26%)
	2.2	2.2.1 Ensure accessibility for all
	Inclusive Access	(Frequency: 2, Proportion: 2/38≈5.26%)
	And	2.2.2 Multilingual & multi-format
	Alternatives	(Frequency: 2, Proportion: 2/38≈5.26%)
3	3.1	3.1.1 Intuitive design with fewer barriers
Implementation	Usability	(Frequency: 2, Proportion: 2/38≈5.26%)
And	And	3.1.2 Minimise technology distractions
Technical	User	(Frequency: 2, Proportion: 2/38≈5.26%)
Considerations	Experience	3.1.3 Avoid technology obscuring content
		(Frequency: 1, Proportion: 1/38≈2.63%)
	3.2	3.2.1 Apps errors and technical bugs
	Technical	(Frequency: 5, Proportion: 5/38≈13.16%)
	Reliability	3.2.2 Alternative approaches to app delivery
		(Frequency: 1, Proportion: 1/38≈2.63%)
4	4.1	4.1.1 Lack of budget and high cost
Financial	Budget	(Frequency: 14, Proportion: 14/38≈36.84%)
And	Considerations	4.1.2 Dependent on sponsorship or external funding
Resource		(Frequency: 3, Proportion: 3/38≈7.89%)
Constraints	4.2	4.2.1 Museum have limited resources to allocate
	Resource	(Frequency: 3, Proportion: 3/38≈7.89%)
	Allocation	4.2.2 Lack of clarity on resources
	And	(Frequency: 3, Proportion: 3/38≈7.89%)
	Clarity	4.2.3 Plan for hardware and infrastructure needs
		(Frequency: 2, Proportion: 2/38≈5.26%)
5	5.1	5.1.1 Involve target audiences in design
Collaborate	Coherent	(Frequency: 4, Proportion: 4/38≈10.53%)
And	Support	5.1.2 Support from stakeholders
Co-Design	And	(Frequency: 3, Proportion: 3/38≈7.89%)
With	Participation	5.1.3 Receptive decision-makers
Stakeholders		(Frequency: 1, Proportion: 1/38≈2.63%)
	5.2	5.2.1 Partner with tech providers and academia
	Partnerships	(Frequency: 3, Proportion: 3/38≈7.89%)
	And	5.2.2 Engage interdisciplinary collaboration
	Shared Expertise	(Frequency: 2, Proportion: 2/38≈5.26%)
6	6.1	6.1.1 Plan for ongoing maintenance and updates
Sustainability	Maintenance	(Frequency: 6, Proportion: 6/38≈15.79%)
And	And	6.1.2 Hardware or device management
Long-Term	Viability	(Frequency: 4, Proportion: 4/38≈10.53%)
Operation		6.1.3 Reduce technology obsolescence

	(Frequency: 4, Proportion: 4/38≈10.53%)
	6.1.4 Monitor and evaluate app performance over time
	(Frequency: 2, Proportion: 2/38≈5.26%)
6.2	6.2.1 Prepare for potential platform shutdowns
Potential	(Frequency: 3, Proportion: 3/38≈=7.89%)
Risk	6.2.2 Consider scalability and future updates
Management	(Frequency: 2, Proportion: 2/38≈5.26%)
	6.2.3 Long-term plan for resource allocation
	(Frequency: 1, Proportion: 1/38≈2.63%)

Through analysis, we can get initial guidance and recommendations for the design of AR-based and gamified museum apps. Furthermore, we selected four domains from the six identified, which were mentioned relatively frequently by the museum professionals who participated in the survey, for narrative synthesis. Additionally, these frequently mentioned domains serve as key focuses for the follow-up interviews, reflecting the narrowed scope of this research. The four key domains and their initial guidance and recommendations for the design of AR-based and gamified museum apps are outlined as follows.

Firstly, we prioritised Visitor Engagement and Learning. This highlights the need for museums to design such apps with the primary aim of enhancing the user experience and deepening their understanding of exhibits. By employing engaging and enjoyable content, museums can simplify complex concepts, make intangible concepts tangible, and provide immersive interactive experiences that enrich visitors' understanding and learning outcomes. Additionally, it is important to strike a balance between AR and traditional exhibits, utilising AR primarily as a supplementary and supportive tool to traditional content.

Secondly, we focused on Financial and Resource Constraints. This emphasises the importance of museums considering budgetary limitations and effectively utilising resources when designing such apps. Cost-effective solutions should be prioritised, striking a balance between investment and expected outcomes while ensuring alignment with financial constraints. In addition, museums can maximise the use of resources, identify the types of resources available, minimise additional expenditure, and seek partnerships and external funding such as sponsorships and grants.

Thirdly, we emphasised Collaboration and Co-Design with Stakeholders. This guides museums in coordinating unified support and participation from stakeholders while enhancing collaboration and the sharing of expertise. Curators, educators, technology providers and target audiences should be involved throughout the design process to ensure alignment with the museums' objectives and the visitors' demands. Additionally, interdisciplinary expertise can be achieved through partnerships with academic institutions and technology developers.

Fourthly, we highlighted Sustainability and Long-term Operation. This requires museums to focus on the sustainability and long-term viability of such apps. Effective measures should be implemented during the design process to control potential risks, ensuring scalability, platform reliability and compatibility with emerging technologies to minimise the risks of technological obsolescence or platform shutdowns. Additionally, museums should develop plans for ongoing maintenance and updates, manage hardware or devices effectively and allocate resources for long-term monitoring and evaluation of the apps' performance. This approach ensures sustained relevance and continued impact on visitors.

3.2 Initial Findings from Interviews for Museum Professionals

As noted previously, interviews with museum professionals are ongoing. Here we present some initial observations and discussion from the concluded interviews.

These insights contribute to a more detailed understanding of the key challenges museums face in successfully designing AR-based and gamified museum apps and the strategies experienced professionals adopt to address these challenges. Ultimately, this provides our research with more refined guidance and recommendations for designing such apps.

The three professionals interviewed to date have distinct backgrounds in the sector. P1 is a partner at a design agency that regularly, collaborates with museums and other institutions as a third-party design studio, bringing extensive expertise in immersive media and interactive installations. P2 is an academic who also has a lead role in a company that acts as a third-party technology platform partner with museums and similar institutions, focusing on integrating AR, XR and gamification features for both on-site and remote visitors. P3 is a digital interpretation specialist within a regional museum service and is directly involved in development and operations as an in-house expert, leading digital interpretation initiatives and having considerable experience in using games to engage

young audiences. These distinct roles make them tend to offer perspectives that align with their respective professional backgrounds and work experiences when looking at related issues in the same museum sector.

Regarding the relatively broad question of providing design recommendations for AR-based and gamified museum apps to enhance visitors' engagement with museum education and their learning experience, the three interviewees offered insights from multiple perspectives. Briefly, P3 emphasised the importance of usability when designing such apps, ensuring visitors face minimal learning curves. He also encouraged museums to involve visitors in the co-design process. P1 described AR as a 'medium of delivery' and gamification as a 'system'. He also highlighted that the content design must be intuitive and require minimal instructions. He also stressed that points and leaderboards may not effectively motivate visitors, as they prioritise the extension of their experience over competitive elements. P2 underscored the significance of providing immersive experiences, employing storytelling techniques, integrating reward mechanisms and incorporating AI-driven personalised services when designing such apps. It can be seen that all three agree on the potential synergy between AR and gamification, recognising how these two can complement each other. They also unanimously highlighted the importance of apps delivering an immediately engaging experience, as visitors are prone to quickly losing motivation. However, there are some divergences in their views. P3's understanding of gamification may be more biased towards games, whereas P1 and P2 offered more nuanced definitions of gamification. Furthermore, P1 argued that reward mechanisms such as points and leaderboards might not effectively promote visitors' engagement. In contrast, P2 suggested that combining AR with gamification elements like badges and collectibles could sustain visitors' active engagement.

On the two questions concerning the impact of involving young adult visitors in co-design and the effect of interdisciplinary collaboration with curators, educators and technology experts, the three interviewees shared their perspectives. P3, drawing on his experience of co-design with teenagers, highlighted that enabling them to create stories related to exhibits has effectively transformed the museum's design approach. He also emphasised the importance of interdisciplinary collaboration, which allows the integration of diverse expertise. P1 emphasised that strict age divisions for adults should be avoided and that co-design workshops need to be carried out with mixed user groups. Additionally, he pointed out that managing a large number of experts in interdisciplinary collaborations requires structured processes or strong leadership. This is essential to avoid situations where numerous ideas are generated but no progress is made. P2 noted that age is a key factor for segmenting user groups and argued that involving younger audiences in co-design is an effective strategy. He also highlighted the benefits of interdisciplinary collaboration, especially involving all stakeholders at an early stage can avoid later modifications, and frequent communication can save time from repeated adjustments. It can be seen that all three interviewees valued regular communication with stakeholders and stressed the importance of involving interdisciplinary teams and target users early in the design process. This approach helps reduce friction and the need for significant changes during later stages of development and design. However, notable differences emerged in their views. P1 and P2 disagreed on whether adult user groups should be divided based on age, and P3'sexperience with age-based user groups is only with underage teenagers. Additionally, P2, serving on a third-party technology platform, specifically recommended that collaborating museums designate a single point of contact to streamline communication processes.

Additionally, regarding financial and resource constraints, all three interviewees agreed that museums face tight budgets for designing such apps, making it a priority to find solutions that minimise ongoing costs. Individually, P3 suggested using a simple technology stack and planning for backup hardware in advance to reduce the costs and resource demands of design and maintenance. P1 proposed three design approaches, which are in-house development, adopting white-label solutions and utilising public platforms. He viewed white-label solutions as the most cost-effective and also highlighted external sponsorships as an option. P2 recommended third-party technology platforms, such as his own, which aligns with P1's white-label approach. Museums can subscribe to such platforms to access services. P2 also emphasised the strategy of pre-built templates to reduce development time and costs for each new exhibition. On the issue of sustainability and long-term operation, all three interviewees emphasised the critical importance of maintenance, and museums must plan for updates and maintenance from the outset. They also admitted that technology advances rapidly and will become obsolete without effective support. Then they offered recommendations based on their respective professional perspectives. Finally, we would like to raise one more question, concerning the connection between designing such apps and theories and models. All three interviewees noted that industry practices rarely adhere strictly to academic theories and frameworks. Instead, iterative user testing, observation and practical evaluation serve as core strategies. Notably, P2 mentioned referencing some academic theories and frameworks but acknowledged that most cannot directly guide the realities of the industry. He stressed the importance of effectively integrating old theories and frameworks with modern technologies and tools in sector practice.

4 Conclusions and Further Research

Overall, from the analyses we have conducted so far through descriptive statistical analysis and thematic analysis of the data collected from the survey targeting museum professionals, we have identified challenges and opportunities within the relevant areas, along with valuable insights and recommendations for designing AR-based and gamified museum apps. The narrative synthesis of these research findings, organised into domains, themes and related codes, and particularly in the four key areas identified above, plays an important role in the phase of developing initial design recommendations for such apps.

Furthermore, we have conducted an initial qualitative analysis of the data collected from the follow-up interviews with the three museum professionals. Based on these initial research findings, we can gain a more detailed and in-depth understanding within the narrower scope of several key issues. This contributes to a better comprehension of the challenges museums face in designing AR-based and gamified museum apps, as well as how experienced experts in the industry perceive and address these challenges. These research findings also play a crucial role in the development of initial design recommendations for such apps.

Thus, the preliminary conclusion is that the application of AR and gamification in museums receives broad support from museum professionals, and both hold significant potential and benefits for museum education. Currently, the definition and positive impact of AR are more consistently recognised by museum professionals. However, there is still a lack of consensus regarding not only the benefits, but the very definition gamification, as many museum professionals appear to understand gamification largely in terms of serious games. This indicates some potentially significant challenges in supporting and establishing use of gamification within museums. Museum professionals indicate many difficulties and challenges in the design of AR-based and gamified museum apps. In particular, certain critical issues have been identified as key areas requiring focused attention in this research.

The work presented here is still ongoing. Following the guidance of the four phases within DBR's iterative cycle, during this current analysis phase, the data collection and analysis for the survey targeting young adult visitors still need to be completed. We also need to complete the interviews with the remaining museum professionals and complete the data analysis.

Subsequently, during the design phase, we plan to synthesise the research findings obtained from earlier activities to inform the design of a co-design workshop for such apps, involving both museum professionals and young adult visitors.

Following this, in the implementation phase, we aim to conduct the co-design workshop in the studio at the Glasgow School of Art, collecting qualitative data, which is primarily for thematic analysis, alongside a small amount of quantitative data for descriptive statistical analysis.

Finally, during the reflection phase, given the ultimate research aim of providing a robust design process and effective design recommendations for AR-based and gamified museum apps that enhance young adult visitors' learning experience, we plan to synthesise the data collected from the co-design workshop. This further synthesis will enable us to evaluate the feasibility and effectiveness of the initial design recommendations and refine them to a greater extent.

Additionally, we intend to reflect on all research activities to clarify the design process for such apps and establish improved design recommendations. These outputs will lay the groundwork for future iterative cycles and the practical prototyping of AR-based and gamified museum apps.

It is foreseeable that this research can provide guidance and recommendations for both the academic research and industry practice, helping to address the existing gaps and shortcomings in the design of AR-based and gamified museum apps that can effectively enhance visitors' learning experience.

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