Designing Context-Aware Mobile Systems for Self-guided Exhibition Sites

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Abstract. This study examines the design of digital systems created to support users in self-guided exhibitions (i.e., sites without human personnel to support the users). We developed a location-aware smartphone guide called *Aratag*, which utilizes Bluetooth beacons to serve contextual information at the user's request. Using this guide, we conducted a user study to investigate what types of content institutions perceive as relevant versus the kinds of content users actually find relevant. The study also contributes to our understanding of users' attitudes toward using smartphones to support their self-guidance in exhibitions. Our results provide insights into designing for interplay between the physical setting of the exhibition and the digital platform, so as to inform the utility, desirability, and usability of mobile guides. Based on these findings, we present the following two design insights that should be considered when designing future mobile systems for self-guidance in exhibitions: 1) multi-level content to accommodate individual user interest by scaffolding information layers from glimpses to an increasingly immersive experience and 2) real-time location tracking with clear visual feedback.

Keywords: Mobile guide · Human–computer interaction · Exhibition site · Context-aware · User experience · Self-guided

1 Introduction

Mobile guides have become synonymous with communication technology relevant to exhibitions ever since the first electronic audio guide was presented at Amsterdam's Stedelijk Museum in 1952. This guide was a shortwave radio system that used a handheld receiver with a connected headset, approximately the size of a current-day smartphone, to link the user to the exhibits through voice-recorded expositions of presented items [1]. Since the introduction of such technologies for exhibitions, the long and tempestuous history of technology's role in this context has shaped present-day usage. In some cases, the technologies are perceived as being disruptive for the social experience and thus as detrimental to the overall visiting experience [2, 3]. In other cases, such technologies can provide interactive experiences that support users in social and practical situations [4, 5] and even attract new users with novel ways of experiencing exhibitions [6–8].

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This study began as a collaborative design process among five diverse institutions, namely, cultural heritage sites, museums, zoos, and outdoor nature parks responsible for attractions and exhibition sites around Denmark. One of the (perceived) key challenges articulated by the participating institutions was wayfinding. The desire to devise a wayfinding solution by introducing self-guided systems, such as a mobile application, was tempered by concerns about negatively impacting visitor experience. Many exhibition sites have "so much" content that some users experience it as "noise," which could contribute to physical fatigue [9]. Adding another digital layer could easily be perceived as "more noise." Further, many exhibitions are very authentic and visceral, and the governing institutions do not desire digital tools or experience designs to take center stage. A comparative study [10] addressed visitors' preferences of how to deliver the same content across a mobile phone application, smart cards, and smart replicas: cards and replicas were favored by visitors of all ages over the app [10]. However, interactions featuring tangible objects pose other challenges; their design should take into account the risk of limited lifespan due to wear and tear, replacements, sanitization protocols, and added security, which can add to the workload and cost of exhibitions.

In recent years, smart devices and mobile technologies have attracted much attention because they are context-aware technologies capable of communicating location-specific content through multiple media formats (e.g., text, audio, and video). As such, exhibitions are in a process of deep transformation as a result of these technologically mediated forms of communication [11]. However, the increased focus on new technologies does not come without criticism, as practitioners and scholars are concerned about shifting the focus on the digital technologies instead of the knowledge that is to be communicated [11, 12].

Digital technologies, however, are critical to the latter. As exhibitions have struggled to retain users and their attention throughout a visit, novel mediation techniques with a strong technological focus have been tried and tested as solutions to invite, educate, and entertain visitors. In addition, users are influenced and shaped by the technological advancements in their everyday life, which affects their perceptions and expectations of exhibitions. Thus, the "right" communication strategy at any given time will change because the specifications and requirements associated with it will also change over time, as would human–computer interaction paradigms. Accordingly, communication strategies for today's world must investigate current and future trends in technology to arrive at a new status quo that can support communication for contemporary exhibition visitors.

Studies show that digital technologies can substantiate knowledge acquisition [13–16]; however, knowledge about the educational effect of digital technologies is limited [17], and that about how visitors understand, apply, and respond to new digital technologies, even more so [18, 19]. The research arena for digital mediation in museum exhibitions is expanding, and with novel and emerging technologies, existing mediation, facilitation, and communication strategies are being re-evaluated and explored, thereby indicating the growing interest for knowledge about communication strategies via emerging digital technologies [11, 20, 21].

1.1 Mobile Exploration Systems

Today, the smartphone is a ubiquitous tool in our working and social lives. It is also used for personal entertainment [22]. It can augment, extend, and support the cognitive capacities of humans through computational capabilities that support habit changing, problem solving, learning, or performing a skill, among others [23], spanning areas such as healthcare, education, entertainment, tourism, banking, and governance. The past decade has witnessed a massive worldwide expansion in smartphone use, and the widespread adoption of these devices marks them as one of the most prominent, pervasive, and ubiquitous platforms in the world, which is evident from many recent market reports [24–26].

Lately, many sites and landmarks have experienced severe long-term challenges due to economic and political reasons [27–29]. This has led to the implementation of centralization strategies and efficiency measures, such as decommissioning smaller exhibition sites [30] or reducing the number of personnel in order to free up resources. In response to these rising challenges, institutions have considered automation and self-guided strategies (e.g., introducing mobile guides for extant exhibitions) [30]. Given the rising challenges due to budget cuts and a shift toward more automation and self-guidance, the "BYOD" or "bring your own device" concept has become part of the digital communication strategy that exhibitions are keen on implementing [31, 32]. According to existing surveys, each incremental iteration of mobile technologies helps improve and expand computational capacities and context-sensing capabilities, in turn driving topics on emerging challenges into the research arena on mobile guides [33–35].

Modern mobile phones offer a link between physical places and digital spaces because of their mobility, application ubiquity, and sensitivity to the context in which they are used [36]. This close coupling has enabled the development of many applications, both in the research and the commercial sectors. Games can penetrate the digital–physical barrier to offer new ways of exercising, for instance. A mixed reality, location-based game can target users with sedentary lifestyles to increase their physical activity through pervasive and persuasive play [37, 38]. Such games are referred to as exertion games [39]. Other mobile applications target tourism to assist exploration and guidance [40, 41]. A myriad of smartphone services and systems focus on human–exhibition interaction [42], such as the markerless augmented reality application MovieMaker [43], which uses the exhibition as a backdrop to enable users to shoot a movie with digital augmented layers to enrich their visiting experience through explorative exhibitions.

Guided tours have become an expected visitor service at exhibition sites. Although guided tours are a common feature at most exhibition sites, not nearly as much research has been devoted to this topic compared to visitor and educator studies in the context of exhibitions [44–49]. While particular types of guided tours, such as guided safaris and guided holidays [50, 51], have been explored in detail, guided tours at museums have not been studied to a similar degree [52].

As mentioned in Sect. 1, audio guides were one of the earliest examples of electronically enhanced exhibition technologies. They opened up the future of technological mediation with the change from the analog to the digital format. Although several ways exist to implement and integrate any technology, the mobility aspect continues to be a core component of exhibition-related communication.

The more recent developments in the field of digital technologies mark an aggressive expansion into context-aware guides that retain the mobility aspect while linking the user with the exhibit. Indeed, this expansion is evident in both the literature and practice. For example, the past ten years have seen an increase in research projects that utilize global positioning, Wi-Fi meshes, and Bluetooth beacons to improve or modify the user's experience through location-specific content [1, 4, 35, 52, 53]. Likewise, recent developments in augmented reality, which are supported by technology providers such as Apple and Google, have led to an abundance of mixed reality experiences in the realms of research as well as commercial services.

While the literature advocates guided tours due to their increased learning potential, it also provides critical insights into the drawbacks of such tours, as they limit users' freedom to engage with the exhibition [54, 55]. We notice a gap here that could be bridged with mobile-enabled smart guides, as seen in the system presented by Tallon and Walker [1]. Removing the role of guidance could prove detrimental to the user's experience, whereas shifting away from human-facilitated guidance could be beneficial to users who want to take control of their own visit and choose how and when they want to access information pertinent to the exhibition. Tallon and Walker presented a system that builds on the notion of exhibitions as "free-choice learning environments" [1] for visitors without any specific objectives. This is interesting because the technology imbues the user with freedom; the system offers structure as well as self-facilitated exploration of the exhibition. To the best of our knowledge, past studies on self-guided exploration tended to focus on systems such as REXplorer [56] and Kurio [7]; the technology of the time imposed a learning curve on the user and also required device maintenance. These variables have changed as an increasing number of users now own capable mobile devices and the institution's workload of maintaining devices is eliminated in self-guided situations that facilitate increased automation.

As argued by Best [52], the relevance of facilitation guidance is clearly a required attribute for exhibitions, but it is unclear how the current practice of guided tours can properly support this aspect through digital technologies [52]. It also raises the question of content preference from a user's perspective. The literature is ripe with examples of content designed around testing a specific type of technology; for instance, the past decade has seen a massive resurgence in augmented reality applications for mobiles in the exhibition space [6, 57–59]. However, we are yet to witness an updated articulation of the key aspects affecting self-guidance in exhibitions. Admittedly, a thorough analysis of the challenges presented by many of the existing services and systems could narrow this gap, but no study has investigated this topic thus far. In particular, to the best of our knowledge, none of the previous studies have examined the content preferences or preferred media modalities of content (e.g., long text, short text, audio book, and video snippet) for mobile guides from both sides of the screen; namely, users' actual preferences and the exhibition personnel's perceptions of appropriate content need to be explored. Thus, it is important to generate knowledge about how fact-based content is best delivered and communicated through this type of location-aware and mixed reality media.

1.2 Research Question and Hypotheses

The current state of art in both academia and practice suggest that mobile self-guided exhibition design is still challenging to implement successfully; the challenge lies not in creating the digital component itself, but rather in making it useful, usable, and desirable enough to ensure a widespread use by visitors. This is evident in the growing literature that investigates different mediation techniques in combination with past, current, and emerging technologies. For example, the technical limitations of Bluetooth beacons have been used as a game mechanic to offer a game experience [60]. Personalized guides that provide the user with a tailored visit through context-aware technologies have been developed [35, 61], with some aiming to extend the visiting experience by suggesting a subsequent destination for future visits [8] and others trying to implement learning via mobile systems [7]. However, a limited number of studies have investigated the design and testing of a smartphone guide with content preference. Additionally, investigations of users' attitudes toward using mobile guides in situations that require self-guidance are even more scarce; thus, insights into smartphone use in this situation are highly limited. Consequently, many questions about mobile self-guided guidance remain unanswered. We argue that the following research question is a critical part of the challenge of designing mobile guides for self-guided exhibitions: *How can digital mediation add sufficient value to promote use, and what criteria for exhibition content are preferred by guests in self-guided contexts?* To guide the exploration of these two intersecting problems, we propose the following two hypotheses:

1. The communicated content must, first and foremost, provide the visitor with a more functional dimension to support their visit (e.g., wayfinding, guidance, practical information, and discounts) if self-guidance use is expected.
2. User experiences differ depending on the media modalities of the content (e.g., long text, short text, audio book, and video snippet).

The remainder of the paper will detail how these two hypotheses are qualified through design and user testing of the mobile guiding platform "Aratag," which will be used to explore the content preferences needed to encourage use and provide value to digitally mediated self-guidance.

2 Designing "Aratag"

In 2018, the authors began a collaboration with the company Pangea Rocks to create a shared application platform for cultural heritage and zoological sites. A range of Danish exhibitions participated as "beta clients" in a series of co-design sprints and acted as field testing contexts for the development of the mobile platform [62]. The authors were actively involved throughout the process, from the first ideation workshops and the design sprints, to the first live user testing at one of the participating exhibitions. The initial workshops functioned as a discussion session with the participating organizations, the goal being to identify the requirements for the application. In particular, two potential solutions were discussed; separate applications for each organization and one application for all organizations with dedicated pages. The major disadvantage with the separate

applications was the financial burden entailed in developing, updating, and sustaining an application and its content over time. Furthermore, the organizations expressed limitations in their ability to update the content continuously, which particularly underscored our research interest of examining different content preferences among visitors. In contrast, a single-platform solution offered the possibility for the organizations to focus on providing flexibility in updating their content continuously and added practical value for their visitors by enabling features such as wayfinding and the provision of practical information. In general, the single-platform solution offered the potential to leverage economies of scale by increasing the degree of onboarding across organizations.

2.1 The Aratag Application

The Aratag application is a mobile application for iOS and Android with a web-based content management system platform to create, edit, and distribute content across multiple content formats. It also provides location-aware features in exhibition contexts through both Bluetooth beacons and the global positioning system (GPS). The application is created as a multi-attraction platform, where different institutions can create their own individual "shell" to present themselves on the application's start screen.

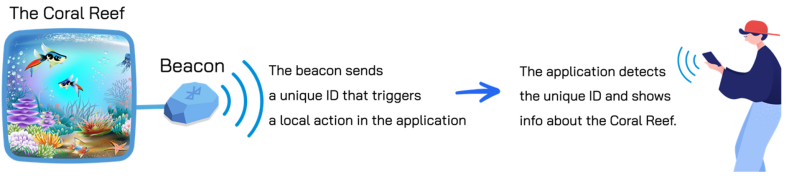

Fig. 1. Typical user interaction scenario with Aratag in the context of an exhibition.

Aratag is a location-based application that utilizes GPS and Beacon technology to provide location-specific content to users (Fig. 1). In detail, GPS is used to position the device outdoors and trigger location-specific content in the application, while beacon technology triggers location-specific content in indoor areas. Specifically, a beacon emits a unique identification (ID) number at a given distance. This ID number is captured by a smartphone via Bluetooth and can trigger a local action in the application. While GPS technology may be limited in indoor areas, Beacon technology can be used in outdoor areas as well as indoor. Beacons are inexpensive, and battery life typically ranges from 1 to 5 years, making the technology cost-efficient and sustainable.

The Aratag application consists of a main screen presenting the different attractions the user can chose to explore (Fig. 2). Clicking on an institution provides different information to the user. The *Introduction* screen presents "Events," directing the user to select the events they want to attend. "Experiences near you" shows nearby points of interest (POI) along with an approximate distance to the location. The "Explore" tab at the bottom shows all the available experiences. "Near You" brings the users to the "Experiences near you" tab. "Map" contains a map of the location, showing the venues of the experiences in the form of POIs. The users can click on any POI on the map and see the information for that specific location. After reaching a selected POI, the user

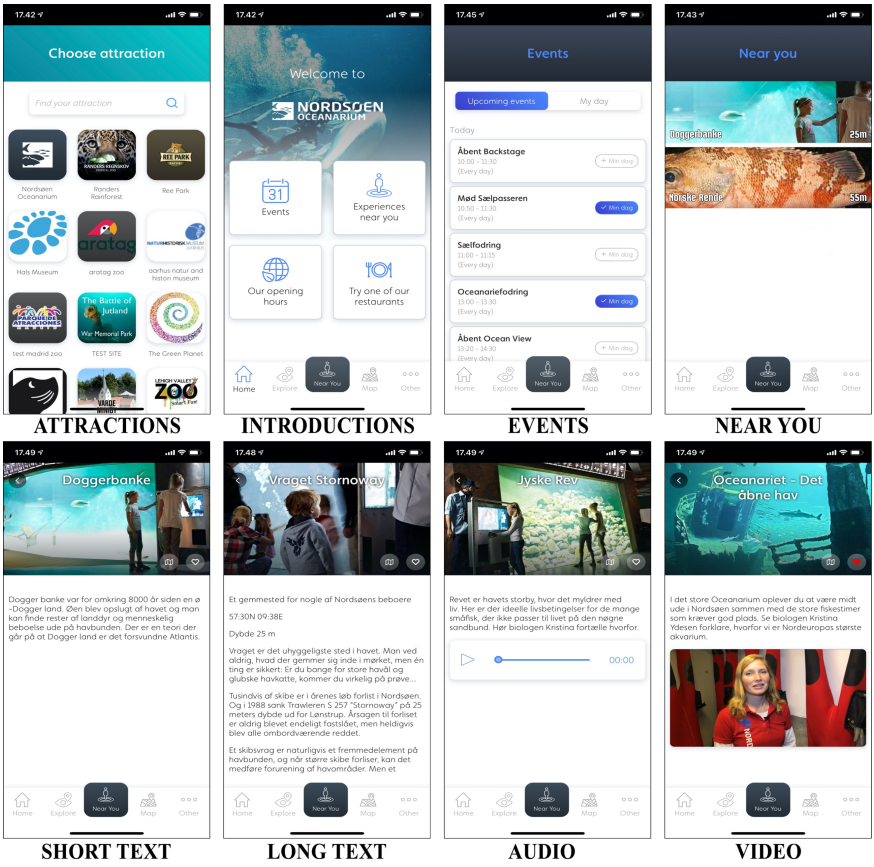

Fig. 2. Designed interfaces for wayfinding and point-of-interest (POI) discovery applications (top panel) and different tested content formats (bottom panel).

can be presented with different content, namely short text, long text, audio, and video (bottom panel in Fig. 2).

Bluetooth beacon technology is used to inform the application about the user's location. When the user approaches a specific beacon location, the distance to that specific POI decreases, and the updated distance is shown under the tab "Near You."

3 Research Design of Aratag in the Wild

The challenge of onboarding users, namely facilitating "the first use" of downloading an application and getting the users to understand and engage with it sufficiently to continue using rather than abandoning it, is an important consideration when designing mobile applications for exhibitions (e.g., [43, 63, 64]). The platform design of Aratag, namely the shell that multiple cultural institutions can share, includes the service design dimension of being usable across a multitude of different sites and attractions, with the

same user interface standards, interaction modalities, and conventions for all users. This element potentially overcomes one of the oft-repeated onboarding challenges of self-guided use: persuading the user to download a mobile application on their own phone. While we do not focus on this aspect in this study, we argue the platform-oriented design of the application has potentially affected the outcome of this work, since all of the researched user groups were aware of the other attractions available on the platform and also remarked upon the potential effects this availability on their desire to use their phone during visits to attractions. As such, we do not study the onboarding experience of self-guided mobile applications in this work; rather, we leverage the platform characteristics when assessing certain aspects, such as how the platform might affect users' evaluations of their experiences with the application.

We posit that this pre-facilitated onboarding creates a bias when assessing the user's behavior with the application in the self-guided context of this study, since "self-guidance" becomes restricted to the outcomes after the application onboarding has taken place. However, we seek to account for this aspect when assessing how the evaluation was conducted by limiting our areas of concern to the following questions:

- Which content types engaged the visitor the most during their visit?
- What were the content preferences for fact-based information when using the mobile application?
- How did the visitor experience the use of the mobile app during their visit (e.g., in terms of extension, disturbance, tool, personal vs. shared device etc.)?
- How did the visitor's user experience reflect their requirements with regard to the self-guided digital exhibition design?

As such, the research design focuses on addressing the content preferences and assesses the use of mobile applications as a guiding tool for visitors when no personnel or other facilitators are present.

3.1 Applied Methods and Frameworks

The study on users' application of Aratag was conducted as a field experiment [65] at an authentic exhibition. The goal of this work was to reveal unforeseen consequences of users being allowed only a digital device to support their experience during a visit, and to observe their actual behavior, how they use the content provided, and if and when breakdowns in user experience occur. The application uses four formats to communicate information; short facts, longer text, audio, and video.

In preparation for the user studies, we created a specific experimental setup of different content types (varying text lengths, audio logs, and video presentations) and paired them with different physical locations spread around the exhibition area of the North Sea Oceanarium, one of the participating beta clients in the Aratag project. Each content page was connected to a Bluetooth beacon, prompting the user when they were near the exhibition as well as providing an approximate measure of how far they were from nearby POIs. The beacon points of interest were spread throughout the entire exhibition area to enable assessment of whether the mobile application and the location-dependent

content could facilitate the visitors to move around and experience the entire exhibition area (both indoors and outdoors) without any human facilitation or guidance.

Using inputs from the curators of the North Sea Oceanarium, we enlisted seven families to participate in the field test. The enlisted families were a mix of frequent visitors (those who visited the exhibition multiple times each year), infrequent visitors (those who visited the exhibition approximately once a year), and newcomers (first-time visitors to the exhibition). The families consisted of two parents and children of varying ages, but all of them belonged to the age range of the specified target audience for the North Sea Oceanarium (Table 1).

Table 1. Details of the families that participated in the field test.

Family	Adults	Children (age)	Total number of members per family
Family 01	2	2 (6 and 8)	4
Family 02	2	2 (3 and 8)	4
Family 03	2	2 (5 and 7)	4
Family 04	2	2 (3 and 11)	4
Family 05	2	2 (10 and 12)	4
Family 06	2	2 (10 and 13)	4
Family 07	2	1 (3)	3

The families were invited to arrive at the exhibition at different times in the morning. The authors provided them with a brief introduction to the context of the exhibition and a mobile device with the Aratag application installed. The families were invited at a specified time in the afternoon to rejoin the authors for a debriefing focus group interview. Besides the short introduction, none of the families were provided with further information or a detailed walkthrough of the application. This was necessary to facilitate the use of the application and allow the families to devise their own specific strategies for pursuing location-aware content.

When each of the seven families had been briefed and started their respective journeys through the exhibition, two other authors, who were not present at the introduction, conducted contextual shadowing observations [66] by blending in among the visitors and taking field notes about important interactions, behaviors, or conversations concerning the families' interactions with the application in the exhibition. Some of these field notes were based on actual quotes made by visitors, indicating, for instance, frustration or wonder over some aspect of using Aratag. Other instances, however, involved the authors interpreting non-verbal interactions with the application as well as the social interactions of the families being observed.

The debriefing focus group interviews were conducted with four setups, one with only one family of four participating, and the remaining three with two families participating in each discussion. The focus group interviews were based on a semi-structured interview guide, following the funneling principles of Morgan [67]. Initially, open questions were asked to the family about its journey through the exhibition, before honing the discussion

to clarify its opinions about specific POIs, content types, and interactions between the application, the family, and the physical exhibition. The initial broad queries were based on the four general research questions mentioned above, which were paraphrased into the interview questions [68]. The interview questions asked in the latter part of the focus group interviews were based on the more specific behaviors and social situations observed during the contextual shadowing, and thus were not part of the interview guide; rather, they were based on the merged field notes of the two authors, which were used to probe the families further about specific details of what they did, said, or omitted from the observations.

3.2 Analytical Approaches and Limitations

The observations and focus group interviews from the user study resulted in 2 h and 15 min worth of empirical material for analysis. The material was transcribed with annotated time codes and labels so that the participants could be identified in their respective family's groupings. They were otherwise anonymized to ensure privacy. The data were further codified into themes within broad categories based on their relation to each other as well as the research questions. Each of the overarching themes were codified into subtopics, which presented more specific instances, such as those pertaining to content preferences or wayfinding guidance through the application. Each instance was counted and visually categorized in an affinity diagram, clustering them into the analytical topics presented covered in Sect. 4.

3.3 Presentation of Data

The topics most relevant to designing the mobile guide are content type and technology use. We identified several themes from our analysis, which were grouped and subsequently "dot-voted" to be either included or excluded in relation to the areas of concern, depending on the functional value that the technologically driven digital mediation could provide and the users' content preferences. These areas were used as "filters" to identify the relevant themes from the focus group interviews to be included in the analysis (Table 2).

Table 2. Ordering of the information that emerged from the focus group interviews into content- and technology-specific themes and further specification into subthemes and topics based on thematic analysis.

THEMES	SUBTHEMES	TOPICS	INSTANCES		
CONTENT	PRACTICAL INFO	Practical problem first, dissemination secondary	18	45	153
		Overview and Planning	17		
		Checklist	20		
	MEDIATION	Apps are not attractions	04	77	
		Content value	11		
		Text	14		
		Audio	20		
		Video	19		
		Mixed content	09		
	EXPERIENCE	Experience over enlightenment	01	14	
		Experience can be enlightenment	04		
		Coherent content over the same communicator	05		
		More experience content	04		
	AMBIGUOUS	Enlightenment vs Experience	07	17	
		Discovery through wayfinding	10		
TECHNOLOGY	MOBILE DEVICE	Self-facilitation	07	96	169
		Social vs Individual	08		
		Disturbance vs Amplification	23		
		Bring your own Device	14		
		Up and Down	27		
		Mostly for Adults – disseminates to children	17		
	WAYFINDING	Usability	06	28	
		Usability enabler	03		
		When does wayfinding give meaning?	19		
	TECHNICAL EVALUATION	Push & Pull messages	16	45	
		Feature Request	10		
		UX & Usability Inhibitor	06		
		More vs less content	13		

4 Analysis and Findings

This section is structured into the two main themes: content and technology. The findings are described through quotations from the focus group interviews and analyzed in relation to the relevant subthemes and topics.

4.1 Content

An exhibition visit starts at the entrance, where pamphlets providing practical information, such as opening times, special event times, and a map of the place showing the POIs, toilets, ice-cream stores, lunch cafes, and playgrounds, can be found. This service is often provided to help visitors access the most essential information. It was evident that the families expected all of this practical information to be provided by the application so

that they could dispense with the need to use the pamphlets, visit the exhibition website during the visit, and/or find a tour guide to help them. Thus, the practical information provided by the application was considered valuable by the families, more so because it was provided in one application. However, the families did request additional practical information, such as a calendar with special activities and special deals to help plan their visit accordingly. The importance of planning was also expressed by how the visitors used the "Experience" tab. Consider the example below.

> *"I especially like the 'Experience' tab where you can plan the day's trip, because you cannot remember all those feeding times, so it is better to plan what you want to see." (Man, Family 2)*

Some families marked the locations they wanted to see as "Favorites" in advance, thus making the application experience more personalized for themselves. Others used the same feature to check if they had visited all the places (Fig. 3). Another set of families visited the POIs one by one and never reached the second floor, as none of the POIs were situated there.

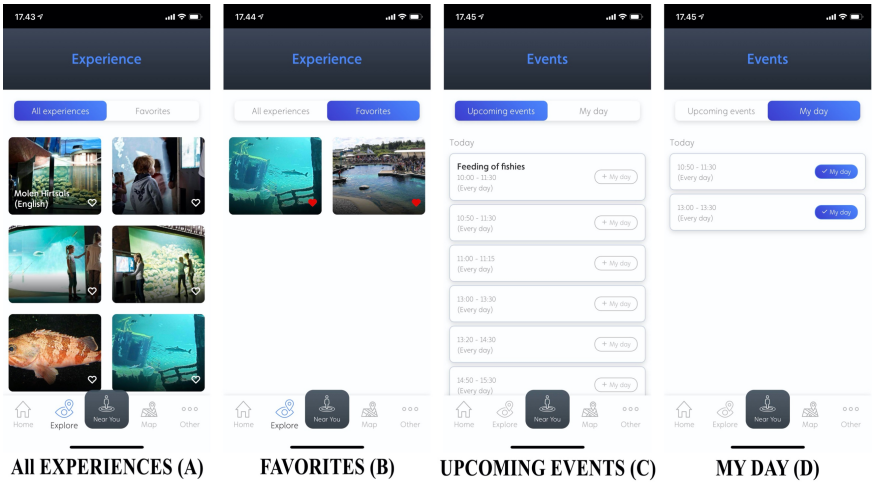

Fig. 3. Images of the application pages showing (A) a listing of available experiences, (B) favorite experiences, (C) upcoming events, and (D) selected events in the "My Day" tab.

> *"I would probably say that if I went to another attraction in Denmark, where we have not been for a long time, I think we will take it one by one, so we do not miss anything." (Woman, Family 3)*

These families trusted the application to navigate them through the entire exhibition. This finding underscores an important and practical use of such applications from the users' viewpoint and the need to consider the same in the design process. In addition to planning, a notification system was requested by the users to substantiate the planned

journey. The families expressed that it would be convenient if they were notified when they were approaching a POI or a location that required their attention. However, they also observed that such information should be provided in reasonable amounts and the feature should be optional. The value of a notification system lies in the extent of support it provides visitors with regard to allocating their time for different activities in the exhibition.

Typically, the families remarked that all of their practical needs should have been met before they were motivated to explore other mediated content. This finding supports the hypothesis that the communicated content must, first and foremost, provide the visitor with more functional dimensions that support their visit.

A set of factors should be considered when selecting the formats to mediate content through a smartphone application in an exhibition context. The Oceanarium is a family-oriented exhibition, and therefore, its primary target group comprises families with children. In this situation, children play a major role in how families interact with a smartphone application during an exhibition visit. With regard to the text format, the families primarily preferred short facts, as longer text was time-consuming to read and already widely available at the exhibition in the form of signages and pamphlets. Moreover, the parents were also increasingly occupied with looking after their children, who were not interested in longer texts (see also the screenshots showing the short and long texts in Fig. 2). If the parents spent too much time reading long texts, they would probably lose track of their children. For instance, one participant remarked,

> *"No, I will never be able to make time for long texts when I have the kids. But it's fine with the short texts. So you can read more if you want to know more." (Woman, Family 6).*

However, some of the visitors did mention that the longer texts were more detailed and therefore preferable for those who wanted to know more. Short texts, which provided the families the most essential facts, were considered important, as some families did not have the time and interest to delve deep into the given information. Longer texts are also probably more appealing to enthusiasts, who have a deep interest and want to know more than just the availability of information at the exhibition. The audio format, which functioned as an audio guide, was appreciated by some parents who visited the aquarium.

> *"The one that made the best impression on me was the sound file; I stood and looked at the little sharks while she [the voice-over in the audio] talked about them. This gives a really good understanding of what you are looking at." (Man, Family 1)*

As expected, the children did not express much interest in listening to the audio descriptions. However, in such situations, the parents could hear the audio while also looking after their children. Most often, if the parents had heard something interesting, they passed on the information to their children. Even though such an experience cannot be described as "shared listening," the passing on of the knowledge from parent to child makes it a shared learning experience. The audio format suffered from one constraint; a less noisy area was preferable when listening to the audio. The families suggested

using headphones to solve this problem and also prevent disturbing the other visitors. However, the headphones might limit shared family experiences.

The video format was the most preferable for the families. Notably, the short length of 1–2 min appealed to both the parents and their children. The videos were often watched together, which created a dialogue between the family members about the topics at the exhibition. The parents explained that their children were normally not receptive to signages at exhibitions because they tend to be too long, unappealing, or difficult to follow. For example, one of the participants stated that,

> *"I also think in the long term that not many children bother to stand and read long texts. But to see a small video would appeal more to them, so they can get something more than just looking at a skeleton and only know what it looked like." (Woman, Family 7)*

Compared to information posters, children are typically distracted by attractive elements that catch their attention. In contrast, the videos were much more enriching for the children than the usual posters and signages. The families also suggested limiting the videos to approximately 30 s, with the added option of seeing a longer video depending on the user's interest. However, the video format also suffers from the same constraint as the audio format, namely loud areas. The families suggested adding subtitles to the videos to resolve this issue.

> *"It would be good if there were subtitles. Because if you have text and you miss some bits of the narration because of the surrounding sounds, you can still easily follow the video. Subtitles could be the best option to help videos work optimally." (Woman, Family 3)*

This idea somehow contradicts some participants' attitudes about longer texts. However, when the longer texts are facilitated through a video format, the families tended to be much more receptive to the information being provided. It can be argued that, by itself, longer text can be characterized as education rather than entertainment, whereas when it is encapsulated in a video substantiating the footage, it offers a balance between education and entertainment, providing optimal circumstances for information enrichment.

Regarding the authors' questions about coherent experiences, the families revealed that they perceived having the same guide in the video and audio as an element of cohesiveness. The guide in the video functioned as a tour guide, taking the families around the exhibition. Continuing with the same person adds a feeling of reliability and coherence to the overall experience, but could also become quite monotonous. For example, one of the participants observed that,

> *"Well, I can see the coherence with having the same person communicate all the information, but it can also be monotonous...so I do not think it necessarily needs to be the same person. But the content must be coherent." (Woman, Family 2)*

Therefore, the users typically preferred maintaining cohesiveness throughout the content, in form of its theme, difficulty, and length. According to the majority of the visitors, a human guide still adds a unique value to the exhibition experience, but the

participants in this study did not find themselves requiring critical assistance from a guide during their visit on the day of the experiment. For example, one of the participants noted that,

> *"A guide gives great value during special events, such as when the backstage is opened, because this is a real person who stands in front of you and communicates with you, making the visit memorable. But it is not something you will miss." (Man, Family 2)*

Even when the families noticed the guides at the exhibition, they did not feel the need to ask them about anything. As such, there was no immediate need for the visitors to seek information from a guide. They may only approach a guide if they require information.

In general, the participants were satisfied about the amount and difficulty level of content as well as the manner in which the guide mediated the content. The families expressed that the content was well communicated and easy to understand. It was neither too complex nor too simple; rather, it added value for the parents as well as their children. The families who had visited the Oceanarium before also appreciated the fact that previously inaccessible knowledge about the exhibition was communicated through the application:

> *"It is always better with more info because we can know more. We have been here many times, and this time, we got to know more than we usually do. So, we have learned new things today." (Man, Family 5)*

Thus, the participants expressed delight in having learned something new. As such, not only did the families in this research express increased interest toward more POIs throughout the exhibition, but they also reported appreciating the seasonal updates that support revisits. However, they noted that regular updates alone would not encourage them to revisit. This clearly shows that the smartphone application served as an element that supported their experience rather than becoming the experience itself.

In summary, a smartphone application must fulfil the practical needs of the visitors for them to consider using it. The different media formats on a smartphone application in this exhibition context are characterized by different strengths and weaknesses. Short texts provide easily acceptable information for both parents and children, and are easily usable in loud areas. The audio format works best in less noisy areas, while videos can include subtitles, facilitating their use in both quiet and loud areas. These findings support the second hypothesis, namely that differences exist with regard to user experience with different media modalities for information provision, especially in the context of family-oriented exhibitions. In general, the families expressed their interest in being able to choose the content format, length, and difficulty level according to their needs:

> *"It could be very cool if there were different kinds of content. Because I think some would rather read and others would rather watch a video and vice versa. If you have two children with you, or if there is a lot of noise around you, then it may not be easy to hear, so it will be nice to be able to read it." (Woman, Family 2)*

This idea about choosing format options arose through their previous experiences with audio guides; these guides were initially interesting for them, but became boring and redundant over time as the visit progressed. As such, different visitors have different needs, and therefore, the possibility of customizing the content format, length, and level of difficulty was preferred.

4.2 Technology

All of the visitors were familiar with using different technologies during a visit to an exhibition and had also explored different smartphone applications that supported specific exhibition activities. The visitors also presented good insights about the possibilities of improving the smartphone application, given their everyday use of their own devices. As such the technology-related feedback from the visitors originated from these previously acquired experiences.

Given these experiences, it is evident that the visitors also have certain practical information-related expectations that need to be fulfilled by such technologies. One of their major practical expectations involved navigation support with the application. Almost all smartphone users today are accustomed with navigational applications, such as Google and Apple Maps. Thus, the navigational feature is a critical element when considering smartphone applications for exhibitions. Thus, it was not surprising to find that the map in the application was criticized as not supporting either orientation or navigation:

> *"The smartphone knows where you are, but you just miss the dot on the map in the application. The outdoors are fine; there are paths you can follow, but inside it is just a square and you do not know where you are and what level you are on in that square." (Man, Family 3)*

The map in the application showed the outlines of the halls in the exhibition, but it did not provide any indication of where and which floor the families were on. To compensate for the limited navigational option, some families tried to use the rangefinder in "Near You" as a navigational tool to find POIs. However, they became demotivated by the inaccurate distance provided by the application and the lack of a direction to follow. In contrast, one of the families that had visited the exhibition before conveyed that they had discovered new areas and exhibits they had not seen during their previous visits through the "Rangefinder" feature. For example:

> *"That big screen you have, I only discovered it because of the 'Near You' feature. I thought it was a narrative about that location in the aquarium, but I found it was located behind the aquarium because of the 'Near You' feature. It was not there the last time we were here." (Man, Family 1)*

However, all the families insisted that it is crucial to know one's location on a virtual map or at least be able to orientate their location during the visit. While the "Rangefinder" was praised as a good feature for exploration, the families felt that it could be more valuable with an orientation feature. All of these observations elaborate the importance of wayfinding in exhibitions, which the visitors expect the application

to support through smartphone technologies. This understanding also supports the first hypothesis, namely that the communicated content must, first and foremost, provide the visitor with a more functional dimension to support their visit.

In general, the families reported having prior experience in using applications in the exhibition context. Therefore, the use of Aratag was not perceived as disruptive by the families during their visit. Even though the visitors had tried similar products at certain other locations, they noted that the functionalities of the Aratag application were the most numerous of all the applications they had tried so far. The advantage of this application lay in its ability to communicate through different formats, which was particularly useful in an exhibition. They especially preferred the video and audio formats over information-heavy signages typically seen at exhibitions. Some visitors did not feel particularly interested in exploring aquariums and fishes, but they expressed that the application motivated them to learn more about these locations, as they were very interested in using the new technology. However, the attention that visitors would need to pay while gleaning the information provided by the application could cause them to lose track of their children, and thus, this was viewed as a disadvantage of Aratag. The Oceanarium was also very noisy, which prevented the visitors from hearing all of the content. The instability of some of the features and the few POIs were also demotivating factors for most of the visitors:

> *"If you want people to have the application open all the time, you have to provide something all the time. Well...otherwise you will be lost in this zapper generation." (Woman, Family 4)*

The visitors also expressed that in a normal-use scenario, they would have put away their mobile devices due to these disadvantages. Thus, it was important that the technology be stable and flawless. Moreover, the technology should provide a consistent flow of content throughout the exhibition instead of limiting this information for certain areas. Thus, it is clear that users want the freedom to choose the type of content as well as not be restricted by limited information.

In general, exhibitions tend to provide visitors with technologies to support visitor experiences. However, the families preferred using their own devices rather than borrowing one for several reasons. First, users are more familiar with their own devices. Second, when using ones' own device, visitors need not be concerned about data privacy (e.g., sensitive personal photos taken by their children). However, the families also expressed their concern about conflicting interests if everyone in the family were to use the application simultaneously. This shows that the parents prioritize a shared family experience over individual experiences. Typically, the visitors would like to shun using mobile devices on family tours, but when they require to use an application for a specific purpose, they are motivated to use it and do not feel that it diverts them from their focus. In contrast, they revealed that the application amplified their accessibility to information, as they did not need to queue or wait for other visitors to move away from the signages or info-screens in the exhibition. As such, the content provided by the application was the primary reason for the families to continuously use the mobile device during their visit. Encouragingly, they expressed that they would likely use the application for the entire duration of a first-time visit to explore the exhibition:

"We went through the exhibition with the application open all the time, to see what appeared. I did not put it away but kept it open to look for something new. It was more about exploring the exciting things it [the application] could tell me about that I was not bothered to read up on." (Man, Family 1)

Notably, one family did mention that the intense use of the application might be attributed to its participation in this experiment; on a normal visit, they might have used it to a lesser extent. Currently, the application interface is mainly designed for adults. The families concurred that the application should appeal to all age groups, with different interface designs for different age groups.

In summary, these results prove the importance of practical functionality for smartphone applications and the possibility of identifying their requirements in the context of exhibitions. People are accustomed to using mobile devices and applications, which has created a set of predefined requirements; thus, users expect a well-designed application using these technologies.

5 Discussion

The Aratag project followed previous studies with regard to the design and implementation path to create a mobile guide for exhibitions. It also extended previous work by investigating users' content preferences for a location-based, context-aware application for self-guided exhibitions. Content preparation for museum visitor guides is a time-consuming and laborious task [1, 69], but the Aratag prototype resulted in a robust method for configuring mixed media modalities. The platform offers a unique tool for exhibitions to share experiences and provides users a more streamlined application across multiple exhibitions. This study was guided by the following two hypotheses:

1. The communicated content must, first and foremost, provide the visitor with a more functional dimension to support their visit (e.g., wayfinding, guidance, practical information, and discounts) if self-guidance use is expected.
2. User experiences differ depending on the media modalities of the content (e.g., long text, short text, audio book, and video snippet).

The first hypothesis was related to the functional dimension (e.g., wayfinding, guidance, practical information, and discounts) in order for the user to initially perceive the value of the system. Our experiment showed that first-time as well as returning visitors found the access provided by the application to be useful because of the different levels of information. This result hinted that multi-level content is favorable, as the user is able to glimpse important information or immerse themselves into more detailed content that captures their individual interests. This finding aligns with research that emphasizes user modeling in design to personalize the visitor's experience and sustain individual user interest [70, 71].

The backbone of the system lies in its "Wayfinding" feature, which provides the user with precise information about locations to support their navigation within the exhibition. For example, the map in the application shows the outlines of the halls in

the exhibition. However, at this time, it does not provide any indications of where and which floor the families are located on. This shortcoming was pointed out several times by the participants. As many people use smartphones for daily activities and tasks, they are well aware of the map function provided by the Apple/Google Map apps, and when Aratag failed to deliver the same functionalities, the users expressed frustration with the application. This shortcoming impacted user experience negatively. Examples of desired interactions with the application map include rotating and scaling functions, which were unavailable at the time of the experiment. However, this shortcoming is more usability-specific and has been tackled in an updated version that was tested recently.

The second hypothesis was related to how different media modalities affect user experience. In self-guided exhibitions, the smartphone application assumes the role of the guide. In such cases, several modalities may be used to mediate content. The different media formats presented various strengths and weaknesses. Short texts were preferred by both parents and children, and were more helpful in loud areas in particular. The audio format worked best in less noisy areas, whereas the video format was the most preferable of all. The inclusion of subtitles was suggested to add value to the video format in both quiet and loud areas. These findings supported the second hypothesis. In generally, the families expressed their interest in being able to choose the content format, length, and difficulty level according to their needs. Typically, the visitors would like to avoid using mobile devices on family tours, but if they are offered an application customized for the purpose, they are more receptive to using mobile devices. This is because the application amplifies accessibility to information and/or provides additional content that is inaccessible at the exhibition. Therefore, it is very likely that mobile guides will not be rejected by visitors to exhibitions in favor of other tools, such as smart cards and smart objects; in fact, users prefer bringing their own devices to exhibitions as they are readily accessible. This point aligns with recent studies that focused on different types of interaction frames (i.e., ways in which users can interact with digital media technologies at exhibitions) and showed that user preferences are highly dependent on the content [20]. The users' content preferences revealed a predilection toward shorter texts and more video, but these findings do not imply that the institutions should "dumb down" on information; in fact, they should make information accessible, but at the user's request and not by adding to their cognitive load as is typically the case with the content displayed in the physical space at exhibitions. In this regard, a notification system could alleviate the cognitive load by pinging for the user's attention, in relation to the user's interests and location in the exhibition.

Our findings align with those of existing studies as well as extend our knowledge with design insights that are central to the development of interactive mobile systems for self-guided situations in exhibitions. The first finding of this work points to the importance of content personalization through **multi-level content formats** to accommodate an individual user's interest. Moreover, the information should be scaffolded such that the user may have varied types of access, from glimpsing the content to immersing themselves within a particular subject should they wish to. This design insight should be investigated further in order to understand how a user's curiosity can be triggered (e.g., by prioritizing knowledge acquisition). The second design insight provided by this work concerns the pragmatic features that are key to creating reliable, robust, and precise

mobile guides capable of **real-time location tracking.** The implementation of location tracking was inadequate in the current study, and the participant's feedback points to a clear desire for this functionality in the application. In other words, this feature is critical for users to want to use mobile guides for self-guided exhibitions.

6 Conclusion

Smartphones with context-aware applications can potentially support exhibition experiences, particularly since visitors are more likely to be accustomed users of these devices. The rapid technological development in this field and the lessons learnt with context-aware applications in exhibitions will expand practitioners' knowledge about creating self-guided smartphone applications. As the technology matures along with its users, research in this field continues to expand; the potential and implications of self-guided exhibition experiences with smartphones must be explored continuously.

In line with the two hypotheses discussed in the previous section, this study was guided by the following research question: *How can digital mediation add sufficient value to promote use, and what criteria for exhibition content is preferred by guests in self-guided contexts?* We found that users' attitudes were positive toward the use of smartphones at exhibitions, and on several occasions, they voiced that they would indeed have preferred to use the application on their own devices. Thus, the users signaled their openness toward institutions implementing the BYOD strategy. Users' content preferences varied, but in general, they agreed that the entry-level content should be just sufficient for them to sample whether or not the information interests them. If it does, they should be offered additional in-depth information on specific content. We see this outcome as an indication of users' desire to be able to explore more content of their own volition instead of having it thrust upon them by the institution. Removing unnecessary signage and labels will allow the exhibition to benefit as well, as it would lower the cognitive load on the user and possibly create more explorative and immersive environments.

Our experimental results also show that the video format was preferred from among all content types, because it could engage with both the children and the adults, thus enabling situations where the operator of the mobile guide could share information with the other members of the family. These insights relate back to the desirability and utility dimensions. We did not investigate the latter in this study, but our results did provide some insights about the use of beacons. Bluetooth beacons (which were not under scrutiny in this study) were chosen based on market reports and trending consumer technologies. This specific type of technology is highly unreliable at this time, as signal strength between different types of smartphones is inconsistent.

Our findings point to the need to study the extent of content and its types on the mobile guide so as to calibrate these aspects for actual implementation of the application. Conversely, the physical space at the exhibition must be designed to avoid overloading users' cognition with a plethora of information. A balance will provide the user with the freedom they need to experience the exhibition as they see fit, while still being enticed to explore the site. The proposed technology can alleviate the cognitive load experienced by the user by facilitating content selection by them. Thus, future work

should aim to better balance the content, user, and physical signage of the exhibition with the mobile exploration system. This is a very challenging topic, however, and the results of this research will assist to this end. Thus, we recommend conducting a comprehensive quantitative study as a follow-up on this qualitative study. This future work should include tracking people's activity on the smartphone and triangulating the data with user preferences to reinforce and explore the possibilities and widen the area of application. Future work should be scaled up by using a mix methods approach and increasing the number of participating families and exhibitions. It will also be possible to explore the potential and challenges of using one application for multiple exhibitions. It would be interesting to understand how exhibitions can collaborate to promote each other and create a coherent experience across different event spaces. Furthermore, the advent of new location-aware technologies and improvements in existing ones will help developers improve user experience with such applications. Thus, a more focused study on location-aware technologies will provide a comprehensive picture for designing context-aware mobile systems for self-guided exhibitions.

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