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Mobile Guides: Taxonomy of Architectures, Context Awareness, Technologies and Applications

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Abstract—Portable devices are increasingly employed in a wide range of mobile guidance applications. Typical examples are guides in urban areas, museum guides, and exhibition space aids. The demand is for the delivery of context-specific services, wherein the context is typically identified by a combination of data related to location, time, user profile, device profile, network conditions and usage scenario. A context-aware mobile guide is intended to provide guidance services adjusted to the context of the received request. The adjustment may refer to tailoring the user interface to the perceived context, as well as delivering the right type of information to the right person at the right time and the right location. It may also refer to intermediary adaptation, as in the case of mobile multimedia transmission. This paper offers a taxonomy of mobile guides considering multiple criteria. The taxonomy considers several aspects of the mobile applications space, including context awareness, client architectures, mobile user interfaces, as well as offered functionalities, highlighting functional, architectural, technological, and implementation issues. Existing implementations are classified accordingly and a discussion of research issues and emerging trends is offered.

Keywords—context aware services, mobile computing, mobile guides, urban computing.

1. Introduction

In the mid 90's a number of 'e' applications, such as e-commerce, e-learning, internet-gaming, e-sensing and data acquisition, internet cultural and tourism guides and e-health, have emerged. They have steadily grown in maturity and have redefined the ICT business and applications landscape. A more recent trend has been marked by the advent of wireless technologies and mobile devices. Following suit from their 'e' predecessors, there is now a whole range of 'm-applications', including m-commerce [75], m-learning [73], m-gaming [10], m-guides [77], m-health [36], mobile worker applications [71] and so on. Such applications are already making headways to everyday practice [17] and the global mobile applications market was forecasted to reach $25bn by the end of 2015 [3].

The essential characteristics of mobile applications are largely defined by their functional and non-functional requirements. Functional requirements may vary significantly, as they are application-specific. On the other hand, key non-functional requirements are shared across the applications domain, to the extent that they are imposed by technology usage and its associated restrictions. Setting aside the specific end-user needs, common non-functional requirements are related to the mobile device characteristics (especially its small form factor), wireless technology usage (e.g. network protocol support), as well as security, privacy and interoperability considerations. Importantly, mobile applications are characterized by a range of common usage characteristics, which differ from desktop ones. For example, as the typical mobile application usage pattern is that of frequent, but short in duration, service requests, it is unacceptable to have a response time exceeding a couple of seconds or to have a long wait in initiating an application. Although the offerings of a mobile guide can be quite rich, a practical application must aid the user to focus on a specific task, rather than distract him too many options, as is the case on web applications designed for desktop usage. Therefore, although it appears natural to consider mobile applications as miniature versions of their desktop counterparts, the different usage pattern requires a different treatment in designing and implementing efficient mobile solutions [92].

Mobile applications offer benefits which cannot be matched by desktop ones. The key advantage is the combination of mobility with 24/7 multi-connectivity in order to deliver contextualized functionalities. Contextualization refers to the capability to offer the right information and services, tailoring them to the right device, to the right user, at the right time and location [103]. Although context-dependent delivery can be relevant to non-mobile applications too, the flexibility offered by the device and user mobility places mobile applications at the very heart of context-aware computing [38, 99]. Furthermore, as mobile devices and tools are being increasingly employed in collaborative settings, the prospect of true mobile collaboration is raising expectations for deeper business penetration of mobile guides. Such expectations are supported by the emerging characteristics of mobile applications, including active data management, enhanced web-based interactivity, ready access to knowledge and information, and usage of advanced communication networks [43].

Mobile guides provide context-dependent, multimedia-rich touring services for visitors. A typical simple scenario is that of a user operating a portable computing device, e.g. a Personal Digital Assistant (PDA) or a smartphone, in order to get interactive indoors or outdoors navigation aid. However, mobile guide functionalities offered today cover a much wider range of activities. These include navigation services (via location-awareness and map-based navigation) , access to additional services (bookmarking, collaboration, shopping, email, data processing), contextual information delivery with multimedia (video delivery, educational tools and games) and in some cases annotation options and user provided content, as well as advanced knowledge processing resulting in adaptive and context-dependent services. Knowledge deduced from user data can be exploited to tailor the offered services and content to the user profile and offer better recommendations for available tasks and services.

In this paper we provide an analysis and taxonomy of the mobile guides' literature by considering multiple criteria, to accommodate for the considerable complexity of the mobile guides application space. Previous surveys focused largely on context awareness [86, 98] or location estimation [12, 68]. In [50] an evaluation framework for mobile guides is developed and four representative mobile guides are evaluated. A requirement assessment of mobile tourism services is provided in [116], both from the tourists' and the service operators' perspectives. In [61] a survey is performed taking into account several technological axes (localization, networking, input/output systems and provided services) and examining a limited number of systems in detail. Our survey acknowledges the complexity of the mobile space [54] and therefore follows a review methodology that seeks to take it into account in a comprehensive manner.

This paper is structured as follows. In Section 2 we present our review analysis methodology, explaining the methodology for application selection, as well as the taxonomy axes selected.

Section 3 contextualizes our research by providing an overview of the mobile guide applications, highlighting the functionalities that mobile guides are offering. Before analyzing the mobile guide taxonomy and literature, Section 0 provides an analysis of the key concept of context and context aware services, along with an updated classification of context categories, to suit the mobile guide domain. Section 5 presents the detailed literature taxonomy, classifying and analyzing relevant literature accordingly. The paper closes with a discussion on the current trends, including a research outlook for future research & development in the area of mobile guides.

2. Review Analysis Methodology

Research methodology in mobile guides is severely constrained by the level of fragmentation and complexity of the 'mobile space' itself. In particular, the multiple factors contributing to this complexity include the variety of users, the different characteristics of the employed hardware devices, the nature of the software development and execution platforms, the diversity of the delivered content, the multitude of networking delivery means, along with associated delivery bandwidth, the increasing impact of context-awareness, as well as the actual functionality offered by mobile applications [54]. Thus, in contrast with previous surveys, this paper seeks to take into account all aforementioned issues related to the complexity of the mobile space, focusing on technical aspects of mobile guide development, offered functionalities and services availability and delivery, as well as considering networking and user interface issues, highlighting functional, architectural, technological, and implementation issues. We discuss, analyze and categorize the literature taking into account multiple such criteria, which differentiate the various implementations and constitute important aspects of design and system development. While past surveys focus on a limited set of such criteria, a more comprehensive treatment and taxonomy of mobile guidance literature has been missing. Therefore, our comprehensive literature classification, apart from reviewing the offered functionalities, it further analyzes implementations under the two broad taxonomy axes shown in Fig. 1.

A. System Technologies and Characteristics.

1. Localization techniques, i.e. how user location and/or orientation are inferred.
2. Environment type (e.g. indoors/outdoors).
3. Data retrieval (e.g. means of data delivery to the device).

4. Context aware implementations, according to a comprehensive context classification scheme and context support level.

B. Client-side devices and components, including:

1. The mobile guide device type.
2. The application type, i.e. native, browser-based or Virtual Machine-based applications.
3. The offered functionalities that enhance user experience, like navigation, bookmarking, games and support for content types (e.g. textual, multimedia, history, etc).
4. Mobile user interfaces to satisfy the special requirements of the small form-factor end-device, which significantly deviate from desktop computer requirements.

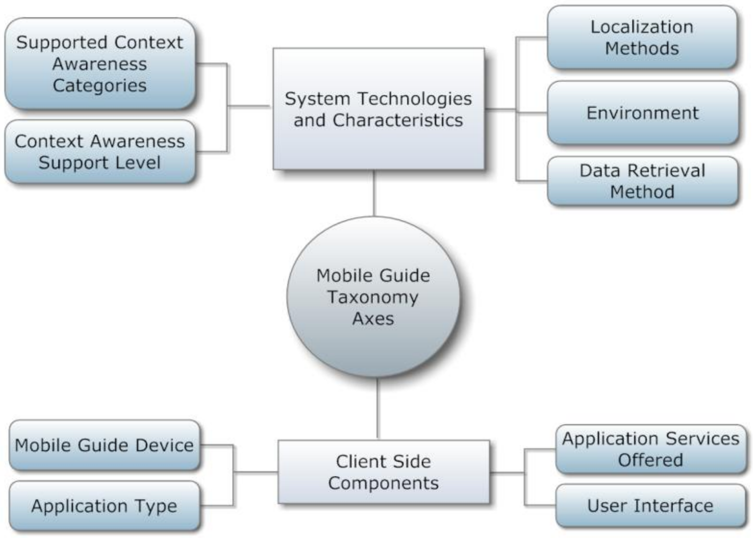

Fig. 1 Mobile Guide Taxonomy Axes

We consider a wide range of mobile guides, including indoors and outdoors, museum and city guides, looking at both research and commercial implementations. The cited references are not exhaustive but representative examples of the mobile guides' taxonomy. We opted to include systems that have been implemented and tested at least at an experimental level, rather than conceptual works, with limited or no implementations. Through the study of existing guides, we provide an interpretation of the employed practices and highlight emerging trends. We offer insight into current technology limitations, raise outstanding research issues and propose potential directions for further research. The next section contextualizes our survey, by considering the key mobile functionalities offered in typical mobile guidance applications.

3. Mobile Guide Functionality

Mobile guides aimed at supporting user indoors or outdoors navigation, extending the visit experience with access to additional relevant information and services. Most mobile guide applications until 2005 provided navigation support services considering the location, device type, user profile, and environment characteristics. The latest trend is to consider social awareness. The ability of interaction within the group (or even between different group members) can significantly enhance the visit experience. In mobile guides, nomadic users are supported by visit planning and tracking services, that offer prospective visitors the ability to plan their visit in advance and review their visit after they have left the site. Similar functionality can be offered on both desktop and mobile clients, but in mobile guidance, users are empowered to become mobile actors, greatly enhancing their physical interaction options. Alongside visit planning and tracking services, bookmarking and annotation options offer an enhanced user experience, enabling users to mark favorite exhibits and add comments or even pictures to exhibit descriptions. This user-generated information can be shared with other group members or even future mobile guide visitors, depending on the privacy policy of the mobile guide and the user's preferences.

Navigation services provide the users with suggested routes to their destinations, increasing the visit efficiency by removing the burden of path finding from the visitor. Those services often require some planning and optimization mechanisms to determine the optimal route, depending on user preferences, desired timeframe and other context-related factors. More challenging is the ability of the navigation service to adapt the route and navigation directions, according to dynamic context data. For example, a user might deviate from the original path to spend time at an exhibit or object not initially on the selected route. The service should detect this detour and recalculate a new path. Most navigation services offer a map view of the suggested route. It is also possible to include voice directions, making users less dependent on consulting the device screen during navigation.

Internet connectivity in mobile guides enables information access from external sources, for example, retrieving information on facilities and services that might not be included in the mobile guide. This feature is often met in city guides, to offer users access to information about local shops and services. Although many mobile guides offer network connectivity, only a few integrate access to third party services. However, apart from guidance, mobile guides are now gradually enriched to offer additional services, including games, educational and social applications. Educational applications and games can be user-engaging and effective means for knowledge conveyance. Users participate in a game (either as single players or as part of a group) aiming at specified goals. In Table 1 a categorization of the functionalities offered in mobile guides is presented. Commercial guides are largely employed as navigational aids, thus the focus is mostly on research application prototypes. The latter have placed some focus on delivering context-dependent services. Therefore, before analyzing the mobile guides' literature, the concept of context awareness and its relevance to mobile guides is first discussed.

Table 1. Literature Taxonomy By Functionalities Offered

Guide Type	Research	[78, 110]	[29]	[8, 42, 112]	[16, 108]	[31, 34, 95, 115]	[13, 32, 48, 69]	[26]	[39, 66, 79, 82, 84, 97, 100, 102]	[1, 14, 24, 30, 58, 85, 106]	[46, 72, 80, 104, 113, 117]	[23, 33, 35, 63, 101, 105, 107]	[9, 27, 70]
	Commercial											[2, 5, 6]	
Functionalities	Games								[39, 66, 82]	[1]	[46, 72, 113]	[105]	[27]
	Educational	[78]				[115]			[39, 66, 102]	[1, 58]	[72, 113]	[23, 63, 105]	[27]
	Messaging & Communication	[78]	[29]	[8]		[115]	[32, 69]		[66, 79]	[1, 24, 85]	[72, 113]	[107]	[27]
	Bookmarking	[78]	[29]	[42]	[108]	[115]	[32]		[82, 100, 102]	[1, 14, 24, 85]	[80]	[2, 5, 6, 107]	
	Navigation	[78]		[42, 112]	[108]	[31, 34, 95]	[32]	[26]	[39, 84, 97, 102]	[1, 14, 85]	[46, 72, 80, 104, 117]	[23, 33, 101, 105, 107]	[9, 27, 70]
	Visit Planning and Tracking	[78]		[42]	[108]	[95]			[100, 102]	[1, 24, 58, 85]	[72, 80, 104, 117]		[70]
	Access to External Services				[108]		[13]			[1, 24]		[35]	[27]
Year		1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011

4. Context Awareness

4.1. Context Definitions

The notion of context has been linked with computing for long, largely associated with computational linguistics. Since the mid 90's, increasing attention has been paid to the role that context might have in adaptive computing. Specifically, the interest focused on how computer applications can be adapted to match the requirements or needs of different situations and users.

With the prevalence of service-oriented computing, adaptation capacity has become synonymous to adapting the offered services and consequently a context-aware system is expected to tailor each service to the apparent usage context. Yet it is only following the deep penetration of mobile and wireless technology into everyday applications that context-adaptive computing has been placed at the centre of focus by a much wider computing community [38]. Mobile and wireless technologies radically change the role of computing devices. Portable computing devices, such as PDAs and smartphones, empower users to become mobile actors, operating in dynamic domains. Their dynamic nature typically implies that different actors employ different devices for different services, at different locations and at different times, in short the actors are using the devices in different situations. In mobile guides, the context has been largely associated with the delivery of location-based services. It has gradually expanded to encompass additional factors affecting services delivery adaptation, yet the growing complexity of the mobile applications space deserves a more comprehensive treatment of context.

The word context does not have a unique definition. In Merriam-Webster's Collegiate Dictionary, it is defined as *"the interrelated conditions in which something exists or occurs"*. In Wikipedia, it is defined as *"the surroundings, circumstances, environment, background, or settings which determine, specify, or clarify the meaning of an event"*. A system providing context-aware services must somehow take into account the conditions of the situation under consideration and this may justify the alternative term *"situated computing"* [59]. However, this definition does not provide sufficient basis for a rigorous treatment of context. Consequently, several different definitions have been proposed by researchers, resulting in rather fragmented context classification schemes. In the past, the literature has largely looked at context from three rather different viewpoints, namely "by example", "in terms of specific context synonyms" and "by categories" [38]. When assessing context by example, this is typically done by providing specific information about the user location and identity, the time of the service request, as well as various aspects of the user environment and its social state, [19, 45, 91, 94]. However, lower-level definitions of context are often needed, focusing more on technical implementation details, such as in [64], wherein, context is defined as a set of attributes and predetermined values, labeled in some meaningful way and associated with desirable semantics.

Definitions by example proved difficult to apply in practice, as they lacked the abstraction needed to capture the breadth of context. A popular approach has been to derive specific context synonyms for the range of the information that may influence services adaptation. A typical example is to consider the data needed to represent the state in an ambient environment [44, 59], an approach often taken in intelligent inhabited environments [52]. Thus, any information relevant to elements of the environment that can be obtained by the user's computer, such as location, adjacency to other objects, critical environment states, computer states, imaginary companions and time can be considered [18]. Context can be divided according to user surroundings, human or material, thus defining it to be the constantly changing execution environment [94]. Similarly, from a computer programming perspective, context can take into account whatever affects computation except explicit input and output [65].

The 'ambient' view of context is environment-centric. Yet, services adaptation needs to be driven by factors beyond the environment. To accommodate for such factors, context was classified into three categories, human factors, physical environment and time [96]. Human factors include user, social environment and tasks, while the physical environment includes conditions, infrastructure and location. Alternatively, enumeration of context categories can include physical, system, infrastructure, location and application context [88]. Similar classifications distinguish between physical, system, infrastructure and domain context, as well as between physical, internal and social context [40, 86]. Providing contextualized services to users must ultimately place the context focus on the user [81]. The environment, the given task, as well as the social, spatio-temporal and personal (user) context can all be considered as distinct categories [47]. In a similar setting, any information describing an entity can be classified in one of the following five categories: individuality (natural, human, artificial and group entity context); activity; location; time; and relations (social, functional and compositional relations) [119]. Personal context can be divided into physical or mental user state [47]. It can also be distinguished into identity (name, address, nationality) and mental context (mood, experience, interest) [57]. Depending on whether actionable context drives the application adaptation, mobile applications can be said to employ active or passive context [28]. Active context places the user at the centre of the adaptation strategy, either by presenting him the new or updated context or by making context persistent for later retrieval and use. It can be exploited by automatically linking actions to specified context (contextual adaptation), by discovering relevant resources (contextual resource discovery) or by providing situated augmentation (contextual augmentation) to offer relevant user aid [83].

Other classifications distinguish between physical and conceptual [56, 83] context. Physical is the practical perception of a state of interest, while conceptual refers to an abstract concept with no material implications. A similar categorization is between physical and logical coordinates. The former represents the user location and orientation while the latter represents the current level-of-detail explicitly requested by the user [89]. This categorisation is also termed as the operational vs. conceptual context [109]. The conceptual is user-centric, while the operational is environment-centric. A different viewpoint considers sensed, static, profiled, or derived context [55], while another considers state-based and event-based context. State-based context consists of a set of attributes relevant to the entity (environmental, location, network, device and user-related), while event-based context consists of a set of events (internal events for the application; user-related events) [49]. In all definitions context generally refers to the whole situation relevant to an application and its users. Table 2 summarizes the main context categories considered in previous context classifications. These are largely relevant to research prototypes, as commercial guides have yet to exploit the full context breadth.

Table 2. Context Categories in Context Classification works

Reference	by example	context synonyms	by categories	human factors	time	location	user	environment	social	task	conditions	domain	application	system	infrastructure
[38]	●	●	●		●	●	●	●	●						
[94]	●				●	●	●	●	●						
[91]	●				●	●	●	●	●						
[19]	●				●	●	●	●	●						
[45]	●				●	●	●	●	●						
[96]				●	●	●	●	●	●	●	●				●
[18]		●			●	●		●	●						
[88]						●		●				●	●	●	●
[86]								●	●						
[40]								●	●						
[47]					●	●	●	●	●	●					
[119]					●	●	●		●	●					
[49]						●	●	●						●	●

4.2. Context in Mobile Guides

As an application niche, mobile guides' usability can be significantly improved by context-based services adaptation. Although most of the context classification schemes are also relevant to mobile guides, they still treat context in a rather fragmented way, without considering the full complexity of the mobile guides' application space. Taking into account the different context definitions and examples we adopt a context classification scheme containing five abstract context categories (Fig. 2), in order to describe context in the mobile guides domain.

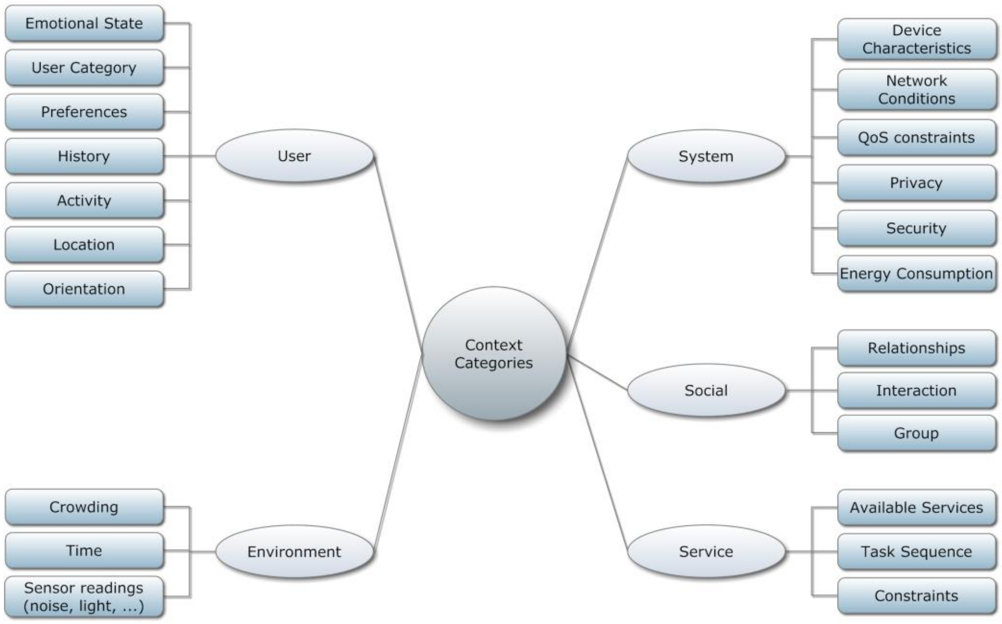

Fig. 2 Context taxonomy

These are (i) User; (ii) Environment; (iii) System; (iv) Social; and (v) Service. Each of the five categories has distinct characteristics in this domain. Users are at the centre of personalized services; system refers to non-functional context, mostly relevant to technological constraints; environment provides the ambient context setting; social context becomes increasingly important, especially in collaborative settings; and the service context is particularly relevant to the offered functionalities in mobile guides.

User-related context awareness is the basis upon which to adapt content and services according to the user's profile and preferences. Although preferences may concern any other context category, they do originate from and are set by the user. Therefore we chose to place them under the "User" context category. Many mobile guides contain an initial customization phase during which a pre-existing profile (for example child/adult) is selected, or a set of preferences can be configured to create a custom-made profile for the visit. Developing a guide with a number of preconfigured profiles is simpler than allowing for a larger set of profiles to arise from multiple combinations of system preferences. However, the context sensitivity in the second case is potentially better, as the choices are more finely grained. The user's emotional state may constitute an important factor to consider. For example, boredom or excitement detection can guide different recommended services or activities. User profiling (e.g. expert, inexperienced, learner, adult, child, etc) is central to achieving efficient mobile guide's content and services adaptation. The user category can either be manually entered or inferred through interpreting user interaction with the system. A more challenging approach is to employ smart visit monitoring and current activity tracking. The concept is for the system to monitor user activity during the visit and adapt the content according to the inferred user preferences. Usage history data can also be exploited as a post-guidance evaluation method. Activity-based adaptation offers a more user-friendly service, since the user doesn't have to configure the system manually; however, the learned preferences are error-prone. Finally, the current user's activity can also be used in contextualizing any mobile guide proposed actions while the user's location and orientation can indicate which objects the user may physically interact with.

Basic system context categories include the mobile device characteristics, especially relevant to mobile guides that support multiple device types, and the network conditions during usage. The device energy consumption is an essential parameter that affects quality of service (QoS). The latter also largely depends on network conditions, since most applications receive their data on the client side from a remote server. Applications with heavy bandwidth requirements need to take into account both the network speed available as well as prioritize traffic depending on the time-sensitivity of the information to be received. Privacy and security are important categories of system context as well, since contemporary mobile guides are network applications, often accessible through the Internet. User privacy protection is critical and needs to be enforced in both network transmission and mobile guide server database storage.

Environment context categories may involve parameters such as time, sensor readings or crowding estimation. Time may be an option (i.e. preferred visit time) or a constraint (visit within time constraints). Sensor readings, sometimes referred to as ambient information, are important in many ambient intelligence applications but have been less applicable to mobile guidance. Crowding is also an essential factor. While it can be considered a social factor, the perceived quality of service can be significantly different depending on the number of other nearby people (e.g. in video delivery it can significantly degrade performance), and therefore can more appropriately be considered as a constraint, belonging to the environment context. Indeed, data delivery and localization may be affected by network congestion caused by the presence of several mobile guide users within a limited space.

Social context also plays an important role in the guidance experience. Group visit-supporting systems may offer interaction services among the group visitors, as well as between the group leader and the group members, which enhance the experience and remove the sense of isolation that mobile guides can sometimes cause.

Finally, the service context includes the determination of which services are available at any moment and is usually supported in large-area guides, where notifications about services like bus arrivals and departures or gift shop operating hours are sent to the mobile users. The service context also includes the ability to define higher-level goals and be guided through the appropriate task sequence to achieve them, helping a user through a complex multi-step task. It may also take into consideration any further service constraints, such as service interdependencies, which might affect the possibility of achieving a given task.

Context-based adaptation can be of great value in enhancing users experience in practical situations. This can be highlighted by considering a hypothetic scenario of a museum visit, where *User*, *Environment*, *System*, *Social* and *Service* context adaptation can all contribute to making the visit more exciting. For example, in an implementation of user-context-adaptation, the *User* context category assigns the instance to a child visit and adapts content accordingly, e.g. by presenting text in story-telling mode. *Preferences* can be set to include some educational tests, to increase the educational impact of the visit, or distinguish between a specified or a random visit path. *Emotional state recognition* may detect boredom during the visit and bring up a game option to offer more excitement. Exploitation of *History* context can warn the child when returning to exhibits already visited, so as to direct the visit accordingly. In *Activity*-based adaptation the system may be programmed to detect whether a child prefers science or art exhibits and either direct the visit to such exhibits, or make available more relevant educational resources and games. *Orientation* context resolution may simply distinguish between two different exhibits of interest, based on the detected device orientation. In the same visit, the *Environment* context category can detect visitors *Crowding*, so as to re-plan the visit sequence to less crowded areas, take into account the *Time* to adjust the visit plan for a 2-hour visit or warn the child of imminent museum closure, as well as *Sense* the room light conditions to adjust the screen color layout and brightness according to whether the child is visiting a dark or brightly lit room. *System* context adaptation may refer to adjusting the offered user interface to the detected *Device* type, transmit a lower resolution or frames-per-second video to mitigate network congestion problems (*Network* *conditions*), offer a lower-resolution augmentation in mobile augmented reality navigation, as the localization element has much higher priority, compared to the superimposed image representation quality (*QoS context*), ensure non-sensitive data management and prevent other users from accessing the child's own smartphone device (P*rivacy/security*), adjust video quality, screen layout and data fetching mechanisms to reduce *Energy consumption* when a need for that is detected based on current battery levels. *Social* context can refer to a child opting to join or leave a *Group* visit with a guide, a parent instructing a child to follow the visit together (*Relationship*) or exchange messages between group members (*Interaction*), for example inviting another visitor to come to see a specific exhibit. *Service* context can implement a *Service-discovery* feature, for example a specific game is available when certain conditions are met (e.g. in large rooms, or in areas with science exhibits, etc.). Furthermore, *Task-sequence* dependence can be relevant in a treasure hunting game, where clues should be discovered in turn. Offered services can be affected by *Constraints,* e.g. in group mobile augmented reality navigation, some services are only offered if other visitors are in the same area of influence or interest. Although these are only some hypothetical examples, it is clear that in many mobile guidance practical application scenarios, context-based adaptation can greatly enhance user experience.

4.3. Context identification

The assignment of a situation or request to a specific context may be sound but still fail to reflect the actual context, when based on incomplete or wrong information, raising the issue of Quality of Context [21]. Context-aware systems which also consider the quality of the context need to address the issues of precision (the accuracy of the information in the context), correctness (whether the information represents reality or is borne of error), trust-worthiness (whether the supplier of the information is trustworthy), granularity (the data space to which the information refers) and aging (the degree to which the information is up-to-date). Therefore, it is important to make a distinction between *actual* and *perceived* context. For example, the environment is expected to be 'sensed' but readings may be inaccurate or may correspond to unknown situations.

When considering different user profiles, these can be a-priori defined or inferred, based on user behavior. Depending on the sources of uncertainty about the perceived context, it can be classified as sensed (susceptible to sensing errors), static (system or user provided, potentially wrong), profiled (based on user interaction, with uncertainty about the interaction correctness), or derived (employing context aggregation mechanisms, which may be imperfect) [55]. Simultaneously considering both user-centric (conceptual) and environment-centric (operational) context may reduce uncertainty [109].

As the likely combinations of context instances can grow fast, it becomes difficult to identify a context-outcome for each such combination. Instead, a context agent has to be built to fuse the context information and anchor the offered services and content to it. Although an application can acquire, process, and store context data, it is the ability to fuse this information in order to link states and events to actions, which truly characterizes a context-adaptive system. Such a system perceives and processes the context in order to provide flexible, adaptable, responsive and localized information and/or services to the users. To this end, more advanced context processing is needed, up to the level of context reasoning [15, 25, 35, 51].

A system designer has to determine which of the context categories can be supported, depending on the availability and the usefulness of relevant data. A first step would be to prune the context categories and only leave the ones whose context can be usefully employed to provide a better experience. For example, if the application data is stored on the device, the network conditions and QoS constraints need not be taken into consideration. The designer will also need to take into account the implementation feasibility of reasoning capabilities, taking into account both the hardware limitations and the accuracy of the perceived context data. If a specific source is known to be error-prone, for example, orientation data, then it may have to be excluded in order to both lighten the processing burden and not allow the decision making process to be misguided.

Having positioned the key concept of context in mobile guides, the next section provides an analysis and taxonomy of the mobile guide literature, including an assessment of how the different reported applications deal with context-awareness.

5. Mobile guides taxonomy analysis

Mobile guides deliver touring services to the visitor devices or to dedicated devices on-site. Museum guides are amongst the most common applications, with city guides also increasingly employed. Fig. 3. illustrates the typical high-level components of a mobile guide system.

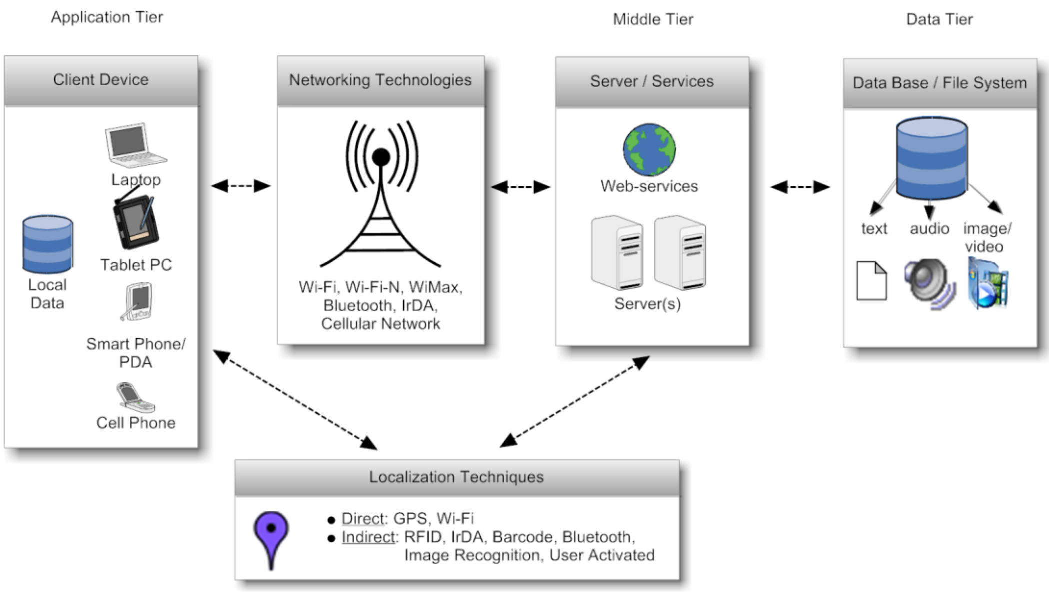

Fig. 3 Mobile Guide Components

It is typically structured as a three-tiered architecture. The data tier refers to the physical data storage and structure. In most cases, it resides in a remote server; however, it is also possible to be distributed across multiple servers. Mobile guide data may also be stored locally, at the client device. The middle tier offers middleware services, mostly related to the management and delivery of the data tier content. The middle tier also typically resides at the server-side, unless content data are stored locally. The third tier is the application-end of a mobile guide, typically comprising the software on the client device. A mobile guide system may deliver content to multiple client device types. The networking component interfaces the client and middleware tiers, ensuring content delivery. It can also be employed for data access by the middleware, when content resides at a location different from the middleware server, or when data resources are of distributed nature. The localization component is in most cases present at the client side, but has access and is linked to the middle tier, for services adaptation or data retrieval. It is the basis upon which to offer location-based services (LBS). Since the development of early mobile guide prototypes [7] the features of mobile guide systems have significantly advanced.

Early mobile guides usually involved user localization and a location-based content adaptation mechanism. Recently, mobile guides may offer context-based personalization, user collaboration and social interaction. Commercial implementations emerged, usually acting as the electronic equivalent of a printed guide, without offering any kind of context-based adaptation (e.g. www.mobiexplore.com, closereachservices.net/ctc/GTA0808, unlike.net, www.traveldodo.com/content/free_mobile_city_guide). Other commercial systems offer some form of location-based content and services adaptation (e.g. us.holland.com/iphone, www.blackbookmag.com/mobile, www.lonelyplanet.com/mobile/iphone-city-guides.cfm). The majority of commercial systems are city guides, offering navigation support and tourist information. In the remainder of this section, we examine each aspect of the mobile guides' literature in turn, according to the methodology described in Section 2.

5.1. Data Retrieval

In mobile guides, data can be locally stored in the device memory and/or can be wirelessly retrieved either from a central server or from multiple distributed servers. In Table 3 the mobile guide literature is categorized by the employed data retrieval method. The majority of systems and especially most of the recent ones use remote data retrieval. Commercial city guides often do not presuppose network connection availability and therefore offer their basic functionality locally. Updates and dynamic information (e.g. weather conditions; special offers) are in most cases optionally offered through the Internet.

Table 3. Literature Taxonomy by Data Retrieval Method

Data Retrieval Method		1997	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
	Remote distributed			[29]		[16]	[67]			[39, 102]	[24, 30, 85]	[80]	[6, 35, 105]	[9, 27]
	Remote central		[78, 110]		[42, 112]	[108]	[31, 115]	[22, 32, 48, 69]	[26]	[66, 79, 82]	[1, 14, 58, 106]	[72, 104, 113, 117]	[23, 33, 37, 41, 63, 90, 101, 107]	[9, 27, 70]
	Local	[7]			[8]		[34, 67, 95]	[13]		[82, 84, 93, 97, 100]		[20, 46, 60]	[2, 4, 5, 105]	
Year		1997	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011

5.2. Localization Techniques and Environment Type

Localization can be divided into two categories, depending on the way the user's location is determined: direct and indirect (i.e., by proxy). Direct localization methods produce an absolute coordinate tuple to identify visitor location. Such methods include GPS, Wi-Fi triangulation and mobile phone network triangulation. With indirect localization, localization is inferred via "active" or "passive" elements whose position is known to the system. When the user interacts with these elements the system can infer that the user is near the element's position in the environment. IrDA, RFID, Bluetooth, bar-coding as well as image recognition can be identified as indirect localization methods. It is also possible to avoid automated localization and rely on the user to indicate the location. This can be accomplished by tapping on a map, on an exhibit icon or even by simply typing in an exhibit code. Table 4 classifies the sampled literature in terms of localization technique used and the type of the environment (indoors/outdoors) of the application.

Table 4. Literature Taxonomy of Localization Method by Environment Type

Environment	Indoors	[7]	[78, 110]		[8, 42]	[16]	[31, 34, 67, 95, 115]	[13, 22, 32, 48, 69]		[39, 66, 79, 84, 93, 97, 100, 102]	[1, 30, 58, 106]	[20, 46, 80, 113]	[35, 63, 90, 105]	
	Outdoors	[7]		[29]	[112]	[108]	[67]		[26]	[79, 82]	[1, 14, 24, 85]	[60, 72, 80, 104, 117]	[2, 4-6, 23, 33, 35, 37, 41, 101, 107]	[9, 27]
Direct Localiz.	GPS	[7]			[112]	[108]	[67]		[26]	[79, 82]	[14, 85]	[72, 80, 104]	[2, 4-6, 33, 37, 41, 101, 107]	[9, 27]
	Wi-Fi			[29]			[95]		[26]	[66, 79, 84]				
	Cellular										[24]			
Indirect Localization	Image		[110]		[112]			[13]				[20]	[37, 41, 90]	
	RFID				[42]		[115]	[32, 69]		[79, 84, 93, 97, 102]	[1, 30, 58]	[46, 113]		[27]
	IrDA	[7]	[78]		[42]	[16]	[31, 34, 67]	[69]		[39]		[46, 113]		
	Barcode				[42]									
	Bluetooth							[13, 22, 48]			[106]	[20]	[63]	
	User	[7]		[29]	[8]		[34]		[26]	[100]	[24]		[105]	
Year		1997	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011

Amongst direct localization techniques, consumer-grade GPS is appropriate for outdoor environments, when accuracy of several meters is sufficient, and can be accelerated by A-GPS, which can offer assisted GPS functionality that exploits mobile network services to achieve faster and more precise localization. Wi-Fi triangulation can be used both indoors and outdoors but suffers from rather low accuracy and the need to deploy a dense network of access points to achieve even moderately accurate results. In addition, the need to weather-proof the network nodes increases installation costs. On the other hand, cellular positioning is practical for both indoors and outdoors, but without high precision. It works by measuring signal levels and patterns between the mobile device and the base stations. In urban areas where there is a denser network of antenna towers, positioning can be achieved with a 50m precision, while in rural areas precision can deteriorate. Cellular positioning does not require special equipment on both the user and the area of visit. Low localization accuracy has limited utilization in mobile guides.

Amongst indirect localization techniques, IrDA and Bluetooth implementations employ beacons which actively emit information, whereas RFID and bar-coding use low-cost tags which contain information (stored electronically or printed) to be read by the reader. IrDA beacons are highly directional, allowing greater pointing precision but hindering area-based positioning. Reversely, Bluetooth beacons can be used for area-based positioning but have low directionality and thus determining the direction in which the user is pointing becomes difficult. In both cases, providing one beacon per exhibit is not practical and has to be financially justified considering the scale of the application and the number of exhibits or points of interest. Bluetooth can be used as a direct localization method as well, in a similar manner to Wi-Fi triangulation but due to its limited range it has not found significant use. RFID localization is functionally similar to barcode-based localization. RFID costs are higher than bar-coding but this is may be justified by the ease of use as no alignment or correct positioning is required, though that advantage may be less significant with the advent of 2D (QR) barcodes, which can be can be produced cheaply and be used by standard camera-bearing client devices.

Image recognition follows a different approach by using a camera to allow a user to specify the location by taking a picture of an object whose location is known. By superimposing virtual features to the picture, together with localization and directional support from GPS and inertial sensors, image recognition becomes an essential feature of mobile augmented reality interfaces, discussed in section 5.5.

When building a mobile guide for wide areas [67, 79, 112], direct localization can be used for coarse localization (e.g. identifying area blocks or large city landmarks), while indirect (and more precise) ones can be used indoors to facilitate pointing at a specific object. Hybrid techniques can be employed indoors, too. For example it is possible to identify the room the user is in using Bluetooth or ZigBee beacons [63]. Recently, indoors/outdoors seamless positioning has been sought using multiple technologies [53, 87]. Alternatively, exhibit identification may be performed by image recognition [13, 20]. Although technically feasible, this approach places an additional burden on the application, requiring image processing and recognition software to be available.

Apart from user localization, sensing the user orientation is also useful. This is especially so when there are multiple points of interest nearby, especially in museums. In such cases, exhibits can be located closely together. IrDA can be used to determine the user's orientation, as direct line of sight is needed. The movement vector of the user or a digital compass can also be used to identify orientation. Accurate sensing of the user's movement direction is important for Augmented Reality (AR) Systems, where the layer of extra information should be correctly placed on top of the user's view.

The current trend is to gradually abandon some of the older localization technologies such as Wi-Fi, IrDA and manual user position input. The near ubiquity of GPS receivers in mobile devices makes this technology extremely popular. At the same time, indirect localization technologies, such as RFID and 2D barcodes, have become more commonplace due to better device support.

Amongst the surveyed literature, most applications support indoors localization, while commercial outdoor guides employ the device's own GPS localization. In some cases, mobile guides are designed for outdoor environments and wide area navigation, while others operate both indoors and outdoors, usually combining different localization methods.

5.3. Client-side device characteristics and software

Mobile guides can employ different portable device types, such as PDAs, mobile phones, smartphones and tablets. Based on the specific application requirements, the mobile guide system may also be designed to provide content to other devices, such as infokiosks and laptops. Systems that are intended to augment the user's senses may also employ an augmented reality (AR) visualization device, increasingly now integrated as standard feature in mobile augmented reality interfaces in smartphones.

The mobile device choice influences to a large extent the available options for the development of the client software. The most important parameter is the device's operating system (OS). In the reviewed literature, most PDA devices employed Microsoft operating systems, such as Windows CE and Windows Mobile. Others, mostly older ones, employ Palm OS. Tablet PCs in most cases carry Microsoft PC operating systems as well as most laptops. One work used a Linux-based laptop [20]. Commercial mobile guides now support multiple smartphone devices that come with Windows Mobile, Apple iOS, Symbian or Android. The aforementioned operating systems support different types of applications, namely Native applications, Virtual Machine-based and Web-based, with the latter becoming more common recently. VM-based applications on PDAs were implemented with either Java or Microsoft .NET CE. Table 5 summarizes these client-side device characteristics in the form of a timeline.

Table 5. Timeline of Client-side device characteristics and software

Application Type	Native										[58]	[72] [70]	[2, 4-6, 23, 33, 37, 41, 101]
	Web-based	[78]	[29]		[42, 112]	[108]	[31, 95]	[13, 48, 69]	[26]	[102]	[106]	[80, 117]	[35, 105, 107]
	Java				[112]	[16]		[22, 32]	[26]	[79, 100]	[30]	[60, 72, 80] [104]	[9]
	.NET	[78]	[29]		[42, 112]	[108]	[31, 95]	[13, 48, 69]	[26]	[102] [76]	[1, 106]		[63] [27]
Operating System	Multiple								[26]		[24]	[60, 80, 117] [70]	[4]
	MS PC OS	[78]			[112]					[84, 93]	[106]		[41, 105]
	MS PDA OS				[8, 42, 112]		[34, 67, 95]	[48, 69]		[39, 79, 82, 97, 102] [76]	[1, 14, 58, 85, 106]	[113]	[35, 63] [27]
	Linux							[22]			[106]		
	Symbian									[100]	[106]		[6, 23, 33, 35, 37] [9]
	Android											[72]	[6, 35, 107]
	Apple iOS											[72] [70]	[2, 4-6, 35, 101, 107]
	PalmOS					[16]	[31]				[106]		
Device Type	PDA	[110]			[8, 42, 112]	[16, 108]	[31, 34, 67, 95, 115]	[32, 48, 69]	[26]	[39, 66, 79, 82, 93, 97, 102] [76]	[1, 24, 58, 106]	[46, 60, 80, 113, 117]	[2, 5, 35, 63] [27]
	Cell phone					[16]			[26]		[24, 30]	[20, 60, 80] [104]	[35]
	Smart-phone									[100]	[14, 24, 85, 106]	[60, 72, 80, 117] [70]	[4, 6, 23, 33, 35, 37, 101, 107]
	laptop	[78]			[112]			[22]	[26]	[84]			
	tablet PC		[29]		[112]			[13]					[41, 105]
	Info-kiosk							[69]			[106]		
	AR				[112]					[84]			
Year		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010-11

5.4. Context Aware Implementations

Following the context categorization introduced in Section 4, Table 6 classifies systems according to the way context awareness is handled and supported. In general, location awareness is the most common feature. User profiling/categorization, activity history and preferences are also dealt with in some cases. Context-awareness is evidently rather poorly addressed in mobile guidance implementations. The still unexplored potential is further discussed in Section 6.

Table 6. Literature Taxonomy By Supported Context Awareness

	Year	1997	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
User	User Category		[78]		[112]	[16]		[32, 69]	[26]	[39, 66, 76, 79, 82, 97, 102]	[1, 24, 30, 85]	[46, 72, 80]	[105]	
User	Preferences		[78]				[95]	[22, 32, 69]	[26]	[76, 102]	[14, 30, 58, 85, 106]	[60, 80, 117]	[2, 4, 35, 107]	
User	History	[7]	[78]			[108]	[67, 95]	[32]	[26]	[79, 97, 100, 102]	[14, 58, 85]	[20, 46, 80]	[35, 107]	
User	Location		[78, 110]	[29]	[8, 42, 112]	[16, 108]	[31, 34, 67, 95, 115]	[13, 22, 32, 48, 69]	[26]	[39, 79, 82, 84, 93, 97, 102]	[1, 14, 24, 30, 85, 106]	[20, 46, 80, 113, 117]	[2, 4-6, 33, 35, 37, 41, 63, 101, 105, 107]	[9, 27]
User	Orientation				[112]		[67]			[84]			[6, 41]	
System	Device Characteristics		[78]		[112]	[16]		[69]	[26]	[39]	[30]			
System	Network Conditions		[78]	[29]							[24]			
System	Privacy							[32]						
Social	Relationships							[32]		[39, 66, 79, 100]	[24, 85]	[46, 80, 113]	[6]	
Social	Interaction				[8]		[115]						[33, 107]	
Social	Groups						[115]				[1, 58]		[33, 107]	
Service	Available Services						[67]	[32]			[14, 24, 85]	[80]	[2, 5, 6, 33]	
Service	Task Sequence												[33]	

5.5. Mobile User Interfaces

Mobile guides aim at aiding the visit, not substituting it with a virtual one. Therefore, the intention is to provide contextually relevant information and services to assist visitors in focusing on the real visit points of interest. To this end, some mobile guides offer spoken instructions and descriptions, so that the visitor's gaze remains on the real visit objects. At the same time, mobile devices are characterized by their small form factor, resulting in special user interface requirements. The limited screen resolution increases the need for smart user interface design. In general, the mobile user interface must be clear, intuitive and consistent, leaving some flexibility to the user to decide upon the type and amount of information to receive. The interface should not contain all available functions within a single screen. The most common functions should be directly visible to the user, whereas secondary functions can be indirectly available through the use of navigation options which enhance and expand the limited capacity of small mobile device screens and as a result the ease of use and acceptance prospects. Fig. 4 illustrates the typical mobile device interface design patterns [11].

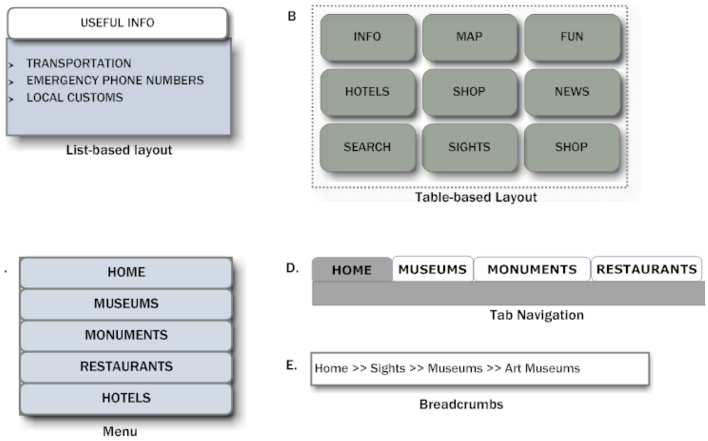

Fig. 4 Mobile user interfaces Design Patterns

Table 7 summarizes the main user interface features, commonly met in mobile guides. The command bar was a frequent feature, while the undo/back button still is, allowing a user to cancel the last action and go back to the previous screen, while the rest of the features are less common. Only a few systems offer the ability to change the system options (e.g. preferences for color and contrast) while using the guide. Many guides contain an initialization phase, where the user can configure the guide and these settings remains unchanged throughout the navigation session.

Table 7. Literature Taxonomy By Mobile User Interface Features

Command bar	[7]	[78]	[29]		[108]	[31, 34, 67, 95, 115]	[48]	[26]	[39, 66, 82, 93]	[14, 24, 30, 85]	[46, 80, 113]	[2, 4-6, 105, 107]	
List		[78]				[95]			[39, 93, 100]	[14]	[72, 117]	[2, 4-6, 23, 35, 101, 107]	[9]
Menus			[29]	[112]	[108]	[95]	[69]	[26]	[84]	[24]	[46, 60, 80, 117]	[33]	[9, 70]
Tab navigation				[112]	[16]	[67]	[69]			[1, 14, 24, 58]	[72]	[101]	[9]
Breadcrumbs		[78]						[26]				[2, 5]	
Interactive map				[8]		[67, 95]			[39, 93]	[1, 85, 106]	[46, 72, 80, 117]	[6, 33, 101, 105, 107]	[9]
Hyperlinks			[29]	[42]	[108]				[102]	[1, 14, 24, 85, 106]	[46, 60, 72, 117]	[2, 4, 23, 35, 107]	[9]
Undo/Back button	[7]		[29]		[16, 108]	[31, 34, 115]	[48]	[26]	[39, 66, 93]	[1, 24, 58]	[60, 113, 117]	[4, 23, 33, 107]	
System Options			[29]	[8, 112]					[39]	[14, 24]		[23, 33]	
Virtual 3D Guide									[84]				[9]
Wearable device									[84]				
Voice Recognition					[108]				[84]	[1]			
Year	1997	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011

Amongst the different interface patterns, the list-based layout is more suitable for desktop applications, than for a mobile guide. List usage is now uncommon in higher-level mobile user interfaces but is reserved for lower level user options. It is useful to provide "Next", "Previous" and "Done" commands, to allow for easier navigation to the next and previous item of the list, as well as to return back to the list. Common options are also soft keys and buttons that provide easy access to frequently used actions and remain always visible to the user. Soft keys and buttons were employed to provide consistent functionality for each screen or even for each item of the application. Scroll-and-select functionality was supported to extend beyond the typical screen size but is now replaced by full-screen scrolling. Tables were often used for the design of the main screen of an application, especially now that touch-based devices are extensively used, allowing quick access to different functions and applications. Menus offer a list of commands, suitable for scroll-and-select devices with button input. If the number of commands is large (usually more than ten), they can be broken down to submenus, according to the frequency of their use. It is standard practice now that lists, tables and menus are implemented as a grid of clearly identifiable icons.

Applications employ tabs to offer rich selection options. It works the same way as desktop tab navigation, only restricted by the number of tabs that can fit on screen. They are often used in touch-based devices, but can also be used for scroll-and-select ones, provided that left and right navigation through the tabs is possible. Breadcrumbs were a common mechanism, usually employed in web pages, but are less appropriate for modern portable devices. An alternative breadcrumb style includes a drop-down list offering similar functionality. Application navigation for mobile applications is mostly designed to be split into more than one screen, due to the small screen form size.

Map-based navigation is increasingly popular but still poses difficulties. Empirical studies have shown that people acquire a better understanding of space using paper rather than mobile maps [114], but this could be due to familiarity with paper maps and their larger size. Space in real life is conceived as quantifiable and bounded, thus communicating spatial information through a mobile device is harder. Yet interactive maps are a key feature of mobile guides.

Touch-based interfaces have now become the norm in mobile devices. They are intuitive and fast to use and can also substitute a physical keyboard. Efforts continue to pursue designs that enable the user to make maximal use of the device and application options with as little physical interaction as possible with the device touchscreen and buttons. An increasing trend is the exploitation of multi-touch interfaces, enabling more complex HCI interaction with the mobile device. Some examples are shown in Fig. 5 (www.gestureworks.com).

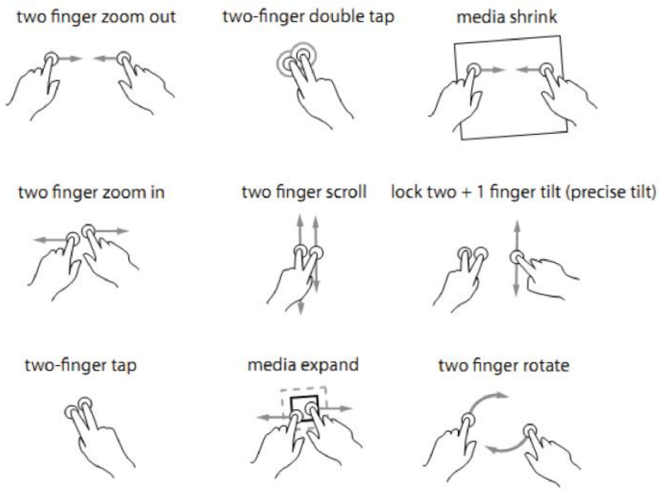

Fig. 5 Multi-touch interface gestures

Voice interfaces make it possible to include a natural interfacing modality, allowing the mobile guide user to interact with the mobile guide, without physically touching the device, a feature which is highly desirable. Voice recognition in crowded or noisy environments require more robust features to be built in with increased noise immunity, tolerance in voice variations and some, but as little as possible, training for initialization. Beyond application control, voice synthesis can be exploited to move away from pre-recorded static messages to dynamically generated content, without the need to pre-record messages. Whether for static or dynamic content, the user-to-device interface remains more demanding compared to the device-to-user one, as it has to account for user voice and environment noise variability.

More advanced features, such as image recognition utilizing the device camera, or mobile augmented reality-aided interfaces (MAR) are increasingly pursued [62]. MAR can be marker-based (ie based on visual cues or tags) and markerless, with the latter employing GPS or other localization capabilities, together with Augmented Reality (AR) browsers to display information in a fused manner, which makes the interaction with the system much more intuitive and natural. MAR takes advantage of GPS, compass and accelerometer data to constantly sync the user position and orientation and adapt the user interface accordingly. MAR interfaces have already made it to the mass market (e.g. Wikitude: www.wikitude.org, Layar: www.layar.com, Junaio: www.junaio.com, Sekai Camera: www.sekaicamera.com, TagWhat: www.tagwhat.com, Acrossair: www.acrossair.com, Google Goggles:

http://www.google.com/mobile/goggles/#landmark). For example, layar combines GPS localization with user-selected information layers to augment the device real camera or the map view with information about points of interest or even social networking entries availability, such as nearby Facebook affiliates. On the other hand, solutions such as Junaio may also function indoors via marker-based navigation. Nonetheless, development efforts applicability is limited by the fact that such MAR-based solutions often need an AR browser, while is most cases rely on the availability of a backend infrastructure. An alternative user interface option is the use of a virtual 3D Guide, a digital substitute to the human guide, offering an intuitive interface. Wearable input devices can substitute on-screen mobile user interfaces.

Context-adaptive mobile user interfaces are still a largely unexplored option. Benefitting from a growing maturity in context-based adaptation, they are expected to become more prevalent, tailoring the offered interface options to the mobile device usage context.

6. Challenges and Trends

Significant progress has been achieved in designing and developing mobile guides in a range of applications, such as urban, museum and exhibition spaces. The growing maturity of the employed hardware and software components and platforms, as well as the advances in handling and exploiting context have enabled a transition from the early guides, often equivalent to electronic versions of guide books, to more sophisticated systems. In this paper, we reviewed the mobile guidance literature and classified it according to multiple criteria in order to encompass the significant complexity embedded in the space of mobile guidance applications. Rather than attempting an exhaustive listing of works, we focused on technical aspects of mobile guide development, applications availability and services delivery, while also considering networking, middleware and user interface issues, highlighting functional, architectural, and implementation issues. During this process, a number of open research issues and emerging trends were identified and are discussed in the following paragraphs.

6.1. Technology Evolution

Fig. 6 illustrates the evolution of some technological features in mobile guidance applications. A gradual change from older to newer technologies can be seen. IrDA-based localization was followed by RFID and Bluetooth-based localization. GPS has been used as an outdoors localization method. Fig. 6 also shows the emergence of some interesting trends: the first web-based mobile guide reviewed here appeared as early as 1997, while socially-aware guides took another 5 years to appear. In 2007 there was a significant spike in the usage of smartphones as client devices for mobile guides, and that was followed by the appearance of iPhone and Android mobile guides two years later, as the smartphone platform became the de-facto standard.

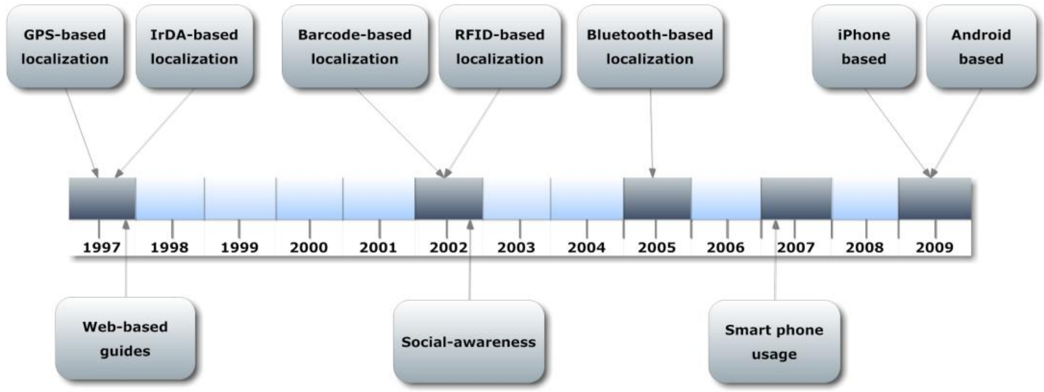

Fig. 6 First usage of Technologies and Trends in Mobile Guides

6.2. Hardware Devices

6.2.1. Device characteristics

The vast majority of works employed a PDA device. Mobile phones were also used, but in many cases they were supported as alternatives to PDAs. Mobile phones cost less and are already familiar to users. Although they offer almost universal connectivity, they are diverse and therefore extra design effort is required to achieve consistent interfaces across platforms. Smartphones are becoming increasingly popular and they offer the advantages of both device types. A few systems employed tablet PCs, with much larger screen than PDAs or cell phones, but these are bulkier to carry and have reduced battery life. As a part of multiple device-type support, some systems also used Infokiosks and stationary touchscreen PCs, while some lab prototypes also employed laptops. In the past a larger variety of device types were used in the literature, possibly in the process of trying to find the optimal mobile device for end-uses. Since 2008, consumer PDAs largely gave way to smartphones. Additionally, recent years have seen the introduction of more successful versions of the Tablet PC form. While there have been attempts at products with this form factor in the past, they were not commercially successful, mainly due to hardware limitations. With devices such as the Apple iPad (1&2) based on the iOS platform and Android-based devices such as the

Samsung Galaxy Tab and the Motorola Xoom we now see a transition of a portion of the mobile guide applications to include these devices as well, particularly for meeting higher-end user application requirements. Such devices provide much improved usability due to larger displays and user interfacing options, as well as higher performance and battery capacity. Furthermore, the software development tools used are the same as the ones used for the respective smartphone devices making the porting process extremely easy.

6.2.2. Performance and features

Cellular and PDA devices continue to converge in the form of smartphones. The demand is for devices that offer cross-protocol connectivity, enhanced CPU power and memory capacity, screens of higher resolution, brightness and rigidity. Advanced characteristics like more powerful and improved graphics and multimedia handling capabilities, improved user interfaces and better support for Web2.0 technologies, are gradually becoming common in new smartphone devices.

6.2.3. Power efficiency and operating autonomy

Energy consumption and consequently battery life is expected to remain a concern. The increasing usage of advanced mobile application features and the need for constant connectivity will fuel the demand for enhanced energy efficiency and higher battery capacity. A power-aware operation, that makes rational power usage, is likely to remain a design concern for developers. As wireless networking operations are energy-costly, smart handling of network transmissions is also an issue to be taken into account at the device level. Additionally, applications are expected to make increased use of multimedia, 3D rendering, compression / decompression, as well as parsing and rendering complex web pages, all of which cause high power consumption. Thus, network communications and CPU management need to become increasingly energy efficient. The device display is usually the highest power consumer. Screens with improved energy efficiency are likely to emerge, following continuing efforts in this direction. Their power management could be pursued by shutting off the display back-light, but this is rarely practical during the usage of the mobile guide. Careful design of the application interface, making it easily viewable even with low levels of back-light, may be a suitable compromise.

Optimizing the power consumption of wireless transmission, CPU and screen usage is a complex multi-criteria optimization issue as these resources are interlinked. For example, reducing the power draw of the wireless component, by using data compression, inadvertently increases processor usage to perform the decompression and therefore may not yield the expected results. The need for efficient power management becomes more prevalent in wide area guides, used for longer time periods in outdoors settings, without recharging options. As these guides are often accessed through the users' personal device, power capacity and management differ amongst devices. Extensive testing is therefore needed, along with monitoring and exploiting advances in hardware, software and networking-related solutions for lowering power consumption.

6.3. Software

6.3.1. Context-Aware Implementations and Reasoning

The analysis of the surveyed works indicates that location awareness is the most common feature (see Fig. 7) but most other types of context are still rather unexploited. Most of the guides today are able to directly or indirectly locate the user and adapt the presentation of the content accordingly. On location change, content may be automatically retrieved and displayed. Alternatively, some kind of user input to trigger content presentation may be required. A simple location awareness method is to detect the room or area the user is in, providing a set of available exhibits and expecting the user to select which particular exhibit to display. Only a few mobile guides are able to detect the user's orientation, maximizing the accuracy of the presented content.

The implementation of context-based adaptation in mobile guides is still very much open to research. The set of possible input combinations that need to be taken into account in defining the context can grow exponentially. Rather than defining an 'input-output' correspondence, wherein input is the perceived context and output is the system response, more efficient and intelligent ways of reasoning about context, producing actionable context identification, and determining a context-based services adaptation mechanism is needed. Thus, research into developing efficient context aggregation and reasoning mechanisms is highly sought and may have substantial impact on making mobile guides more practical to use in different applications [25, 35, 111, 118].

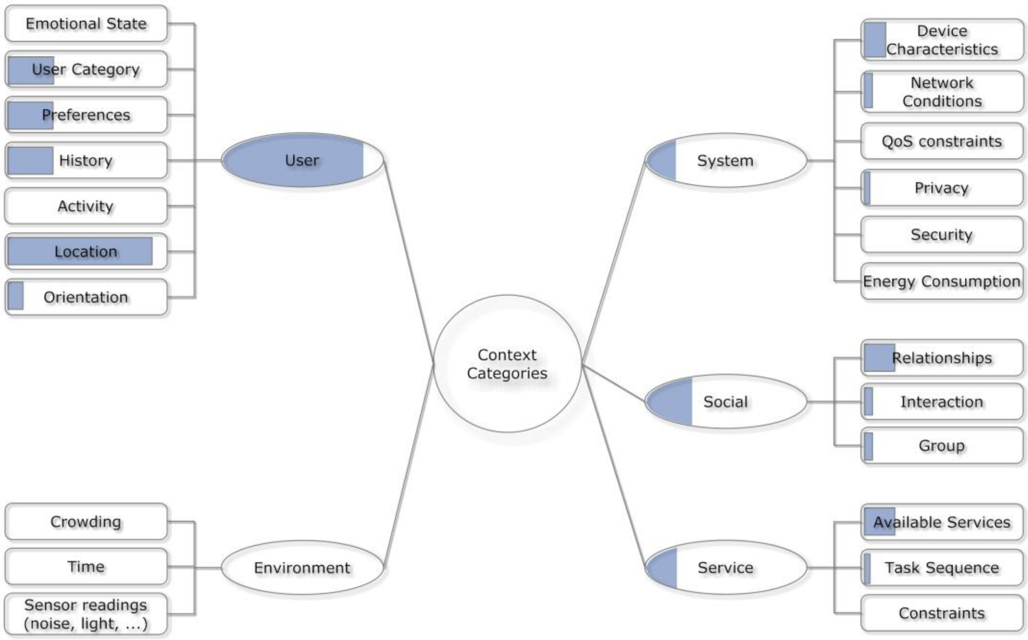

Fig. 7 Qualitative context awareness support in surveyed works

6.3.2. Data mining – exploiting visit data

The usage pattern of a mobile guide application may also offer valuable input to a services-adaptation mechanism. Data mining and knowledge processing of usage history data are features that have only recently started to be incorporated. Research should focus on methods for extracting knowledge out of usage patterns, as well as on exploiting this knowledge to offer more advanced, intuitive and personalized services. Many mobile guide applications, especially indoor museum guides, provide a set of predefined descriptions of the exhibits, offering little or no adaptation to the user profile. Supporting multiple user profiles, predefined or inferred from user behavior, demands smart design, user profiling capabilities and the development and customization of appropriate content. Information derived from mobile guide users can also be utilized to predict user behavior and offer recommendations that closely match user expectations or interests.

6.3.3. Incorporation of social context

Although social interaction has the potential to significantly enhance user experience, it is not a common part of current mobile guides. Incorporating social context and features introduces additional functional and non-functional requirements to be addressed. For example, real-time communication makes networking quality of service even more important. Beyond non-functional constraints, designers must carefully analyze the application scenario and developers need to come up with solutions so that social interaction does not distract the user, but rather enhances the visit experience. Alternatively, social context can be interactively resolved by means of augmented interfaces, such as in Mobile Augmented Reality (MAR) implementations. For example, in Layar (www.layar.com), different layers of social networking entities can be superimposed on a map-based or camera-view-based interface, allowing the user to select the context of interest.

6.3.4. Content aggregation from heterogeneous sources

An increasing trend is to offer wide area (urban/rural spaces) mobile guide services, but also public transport mobile services. Such mobile guide applications need to rely less on a central repository of content but act more as content aggregators from a multitude of distributed and heterogeneous resources and services. Considerable research effort will need to be devoted on how to build applications which can act at a higher abstraction layer and yet are able to harvest and process data from such disparate resources. This new generation of applications will require greater focus on Web 2.0 and beyond, enabling seamless information sharing, supporting data interoperability and facilitating user collaboration at a much larger scale. Enabling the generation, processing and exploitation of user-generated content will emerge as a key research challenge for the next generation of mobile guides.

The development of proactive and efficient data quality assurance mechanisms will become a key design issue, as user generated content cannot easily follow specified formalisms. However, the inclusion of the users themselves in the data quality assurance process may facilitate producing emergent, rather than centrally controlled quality assurance mechanisms. The integration of touring options with augmented navigation interfaces, such as those offered by MAR applications, can facilitate the inclusion of disparate content sources, by means of third-party developed layers of information, often with user-generated content. Apart from exploiting user-generated content, mobile guides will be expected to aggregate third-party services, acting as mediators for accessing services offered by a larger vendor and user community. Additional services are expected to emerge within this framework, such as e-shopping and online booking, thus expanding the range of services available to mobile users. The inclusion of such services may become a key contributor to the financial viability of mobile guide services.

6.3.5. Privacy and security

User and user-generated data will increasingly be placed at the centre of mobile guide applications. This will lead to increased demand for a more rigorous treatment of privacy preservation and security. Mobile guides to date do not actively protect user privacy and system security. Special care should be taken to ensure the application's security and frequent updates should be applied to deal with new security issues. Data mining can be exploited to offer advanced personalization services. Usage patterns can provide important information about user interests and behavior but should be prevented from being revealed (intentionally or unintentionally) and used for other purposes. Care should be taken that only the necessary information for the knowledge processing is collected and processed and that no *personal identifiable information* (PII, i.e. information that can identify the person, such as their name, address or telephone number) are collected. Bearing in mind that a set of non-PII can also contain sufficient information to identify a person, privacy protection during knowledge processing can be sought by processing aggregated instead of raw data. This means that data derived from the users' behavior is processed in groups, so that no individual record can be revealed. Another privacy preserving method of acquiring and processing user information is to collect obscured user data. This can be achieved, for example, by not collecting user birth date, but instead use the age group of users.

6.4. Past and Future

While mobile guide prototypes have flourished over the last several years, boosted by the evolution in hardware and software and the maturing competition in the smartphone and tablet segments, more drastic advancements are to be expected in the near future. A number of limitations have impeded progress in the past, turning the lifecycle of mobile guidance applications into a vicious circle, as illustrated in Fig. 8. The reasons for this are attributed to both hardware and the software aspects of mobile computing. As far as the hardware is concerned, limited device capabilities, such as slow CPU, limited RAM and storage capacity, small display size and few or no embedded sensors such as GPS, accelerometers and digital compasses, but critically also significant differences in device characteristics, resulted in higher cost development efforts and rather expensive market offerings. On the software development front, the high variability between devices and the severely limited hardware made mobile application development hard, with considerable compatibility problems across the different devices and platforms. Moreover, development was quite specialized and for that reason insufficiently served by a relatively small community of skilled but unaffordable developers. The immediate result was that the end-user of mobile guides experienced applications of insufficient usability on limited capabilities devices and thus formed a negative bias for such technologies. The high costs and the lack of cheap universal network availability further compounded the issue. Therefore, there was only limited consumer demand for such applications, closing the vicious circle loop and making hard for vendors to justify further investment.

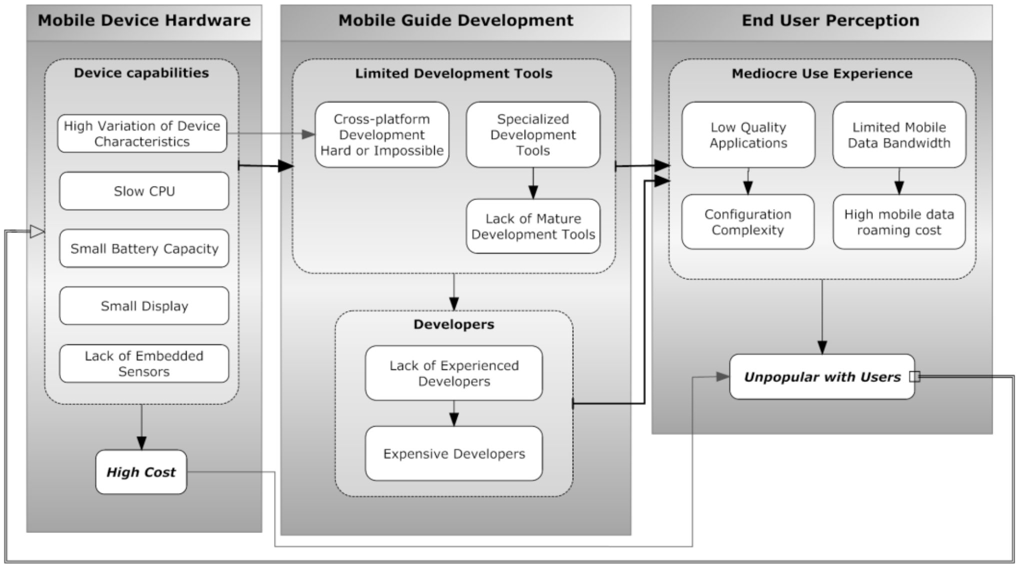

Fig. 8 Mobile Guide Applications in the past: Causes for vicious cycle of impediments

With relatively cheap, powerful, highly connected and easier to develop software devices becoming increasingly available, the vicious circle was gradually broken. The initial breakthrough came with Apple's iPhone. This offered a rather expensive but impressive and highly usable platform, which dramatically increased user demand for mobile devices and applications. Since then, a significant competitor, Google Android, has started to provide the means to easily create mobile applications. Device processing and storage capabilities have increased rapidly and at the same time costs have gone down. Developers today can use common development tools, versatile emulators and rich documentation to aid them. As application development became easier and cheaper, sufficient incentives were provided to larger communities of developers to be drawn to these platforms, simultaneously making their skills increasingly available and affordable.

It is reasonable to expect that users will increasingly employ their own devices for mobile guidance applications, with networking optionally being provided by the visited venue where 3/4G network coverage is weak. With the increasing ubiquity of social networking applications, it is also expected that users will find it natural to combine mobile guidance usage with their commonly employed social tools and mobile guide solutions vendors will seek to exploit this trend by providing a tighter integration with social tools. The Web development model fits the need to support multiple devices and social networking services integration and is likely to be further strengthened with the latest set of technologies, such as HTML5 and Ajax. This in turn will make context awareness easier to implement, as context data integration into a single application will become easier, in a platform-neutral way, supported by some form of context-processing application engine. Thus, applications and devices usability will be further enhanced.

Such developments are likely to have a clear impact on the business model fuelling further development in order to provide mobile guidance services. Mobile guides have been deployed in varying forms in both non-commercial and commercial settings. The most common case for non-commercial mobile guides consists of public authorities-sponsored deployment to enhance the services provided in an area or venue and in turn increase its attractiveness. A commercial mobile guide can also be offered for free, but a sustainable revenue stream is still needed. One way is through displaying in-application advertisements from an advertisement server, such as Google AdSense. Another way is by requiring that beneficiaries of the service (e.g. participating businesses in a city guide) contribute on a subscription or a per-customer-received basis. A subscription or per-use payment may be alternatively required from the mobile guide user but this tends to alienate visitors, especially if they cannot tell whether the guide will cover their needs before paying. As an example of such guides, mobile museum guides are often offered as an add-on to the visit. They can be optional and paid-for-use or free with the extra cost included in the visit price. Finally, revenues can be drawn through the 3G/4G operator, as delivery of mobile guidance content can become a mainstream service offered to smartphone users.

6.5. Conclusion

This paper provided an updated review and analysis of the mobile guides' literature. Our research methodology focused specifically on different aspects of the mobile applications space complexity. As the survey focus is on mobile guidance applications, research is contextualized by considering the different functionalities offered by such systems. A discussion on the different types of context relevant to mobile guide applications was included and a generic context classification definition scheme was adopted, more aligned with the mobile guides' application space compared to previous classifications. We have reviewed the set of technological and functional features of mobile guide applications and discussed their various tradeoffs. In the light of this analysis, a novel, comprehensive mobile guide literature taxonomy was offered, including a discussion on emerging trends and research prospects. There is arguably considerable potential for placing the user well-inside the mobile guidance experience. Thus, any future wider adoption of mobile guides largely depends on the level to which mass-personalization and the social nature of humans when performing a visit are exploited by further research, as well as commercial development efforts. Currently, there is a clear lack of user-centered assessment of mobile guidance user experience and this line of research, currently actively pursued in personalization and recommendation systems [74], should invite more systematic active research in the field.

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