Pers Ubiquit Comput (2011) 15:97–111
DOI 10.1007/s00779-010-0295-7

ORIGINAL ARTICLE

Electronic mobile guides: a survey

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Received: 29 September 2009 / Accepted: 2 March 2010 / Published online: 8 April 2010

Abstract Mobile tourist guides have been in the spot light for the past decade and are becoming increasingly available in various forms to tourists visiting places. The majority of these mobile tourist guides are to be used via a constant network connection and some as proprietary standalone mobile applications installed on-device. Some are solely navigational assistants using positioning technologies for large cities offering exploratory services and others are used indoors, for example as museum guides. This research paper attempts to categorize these mobile guides using a detailed set of evaluation criteria in order to extract design principles which can be used by application designers and developers.

1 Introduction

The convergence of information technology, the Internet and telecommunication industry has generated massive changes in the tourism industry field. Those changes were a result of the evolution of technologies used to spread information amongst tourists and the industry. Amongst other activities, tourists use information technology to search for destination information regarding prospective places to visit and the industry makes use of such technologies to offer information to tourists. In addition, due to the increase of Web 2.0 technologies such as social networks, blogs, wiki's, etc., tourists seek out information from their tourist peers. There are numerous Websites on hand which offer this sort of personal information space to tourists such as tourist blogs, tourist diary notes and communication technologies to connect with family and friends and with others.

In parallel, an increase in mobile phone usages for services other than voice calls and text messaging has been also observed. This is owed to the mobile phone transcending from a traditional voice communication device to an instrument facilitating an interaction of the three major sectors noted above [1]. The mobile phone sector is showing a large increase in mobile phones with personal navigational systems along with an increase in the usage of the mobile Web platform. However, by nature, mobile phones will always have differences in comparison with the desktop computer; let it be screen size, input methods, or just capabilities. Also, there has been some advancement in mobile Web technologies, gone are the days of WAP-based Web pages which have been replaced by dynamic XHTML pages and partial scripting compliance, making the mobile phone a strong predecessor of traditional Web technologies (i.e. mobile blogs, mobile Webmail, mobile sites, etc.). However, the mobile phone is still evolving, which brings about problems in the making of standards. This has heightened the need for solutions which can compensate on constraints of mobile browser capabilities and the lack of device standards compliance (some attempts have been made with mobile Ajax). Current trends indicate an increase in the need of mixed mode Web applications running both on the static and on the mobile Web (i.e. gmail, google maps, facebook, youtube, etc.). One of the most popular solutions of using the mobile Web in conjunction to the static Web is the use of robust stand

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alone applications running on the mobile phone which compensates on constraints of the mobile Web browser. Due to the large number of mobile devices available amongst users each having unique features, raises issues of factoring to fragmented mobile phone types readily available. Most mobile application developers build separate applications for each of the mobile devices; the software companies want to target resulting in large development overheads and the expense of many man hours. This in turn has raised issues of development platforms and different variations in porting to mobile phone devices. The question lies in what standards will prevail to facilitate tourists mixed mode usage of the Web in a static home/office situation and what for the dynamic mobile situation in regards to mobile navigational tourist guide applications; what standards do developers have to build tourist Web applications running on the Web and what for the mobile phone sector.

This paper focuses on the evaluation of research and commercial applications used by tourists to retrieve information, navigation and guidance using some form of mobile devices. For this evaluation, a large number of relevant projects have been investigated addressing a number of different issues. Yet, in order to extract design principles for such a mixed mode platform area, a set of design criteria were extracted. Focus has been given to mobile tourist guides systems running on any hardware architecture with or without a network connection medium.

The remainder of this paper is organized as follows: Sect. 2 analyses the design criteria sought out to complete this research. Section 3 evaluates the projects with respect to the issues stated in Sect. 2. Section 4 comprises a summary of research findings and includes some tables of summarizing data. Section 5 discusses the extracted design principles and concludes the paper.

2 Design criteria

In the scope of mobile tourist guides, the research carried out over the past decade falls into two main categories [32]: application-led research and technology-led research. Application-led being research led by a domain problem which is evaluated by deploying a solution and quantifying the benefits of this solution and technology-based research is motivated by the benefits of the solution, yet challenging technologically wise. Thus, these two categories of research are basically brought about from usability designers and by device technology designers [21].

Until today, evaluation research of mobile guides has mostly been presented by scope of issue [3, 17, 23]. Kray et al. [17] studied map-based navigational guides evaluating guides based upon five basic issues: features offered, situational factors, adaptation capabilities, user interaction and architecture. Others like Chen and Kotz [3] took into consideration the issue of context awareness to evaluate mobile guides. As such, our evaluation attempts to address two main questions; what design principles can be used by application designers for the design of mobile tourist guides; what technological choices do developers have while embarking on this specific domain area. During the evaluation, these two fundamental questions brought forward a new sub-set of evaluation criteria which took into consideration our vision for the creation of a nomadic[1] tourist information platform running on readily available mobile technology.

The accumulated findings of the design criteria from the angle of both application designers and technology developers brought out our main evaluation criteria which are summarized below in the form of questions:

- In regards to application designers:
  - What *information models* were developed for mobile guides; do they make use of personal profiling and/or collaborative filtering techniques to offer personalized information and services; could the information model be updated easily; could it support different languages?
  - What types of *input/output modalities* were used? Did the projects offer various types of information using multimodality technologies such as 3D graphics or speech?
  - What *unique services* were designed and how were they implemented (e.g. using web agents, web services, etc.); were these services well accepted by tourists? Did the projects integrate any existing standards-based frameworks or initiatives to support tourist users or were all services proprietary?
- In respect to technology developers:
  - What *architecture* was used; which technology platform was chosen to implement the applications in stake; could these be used in today's mass mobile technology devices?
  - What type of *network infrastructure* was required to support the project at hand; what network infrastructure was used (e.g. WiFi, BT and 3G); could the application adapt to changing networking environments? What was usage cost of such systems for the end-users?
  - What type of *positioning technologies* and *map technologies* was used to support indoor and outdoor use; were maps used to support the user;

[1] Nomadic Tourist Information platform being access to tourist information and to personal space anytime anywhere [9].

could they be used to support route finding, dynamic itinerary support to users? What types of location-based and context-aware services were offered? How did navigational technology support the user context with respect to information published to them?

In enhancing the above-stated questions, five issues where extracted and summarized in Fig. 1 below. All the projects reviewed in section three are reviewed in respect to the aforementioned issues.

3 The evaluation

The field of mobile tourism has only been around the past decade or so, yet includes a large number of research and commercial applications database. The majority of related projects addressed are in the form of Websites, Web applications and mobile guide applications all addressing ubiquitous mobile tourism solutions. The projects investigated were classified into four groups: mobile guides, navigational assistants, web-to-mobile applications and mobile web-based (Fig. 2).

Mobile guide applications are projects that use mobile devices as the key user platform offering tourist information and the use of services in various forms. The majority of the overall projects that were evaluated were thick applications running as a stand-alone application or on a networked centralized application mode. Due to the incompatibility of mobile devices, many different development platforms were used [8]. One of the original milestone mobile guide projects was Cyberguide [1]. The main goal of the Cyberguide project (see Fig. 3) was to support rapid prototyping

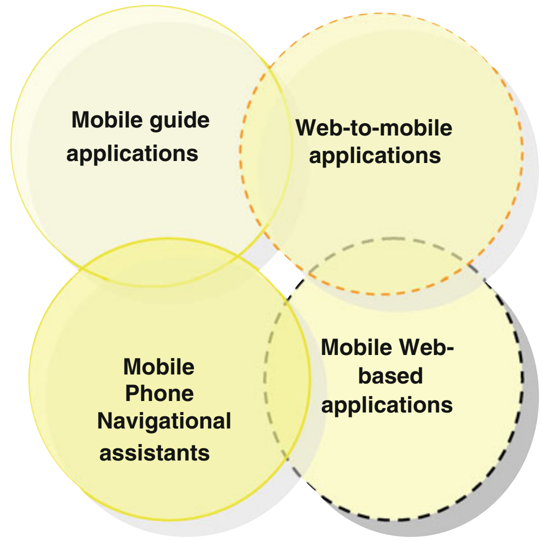
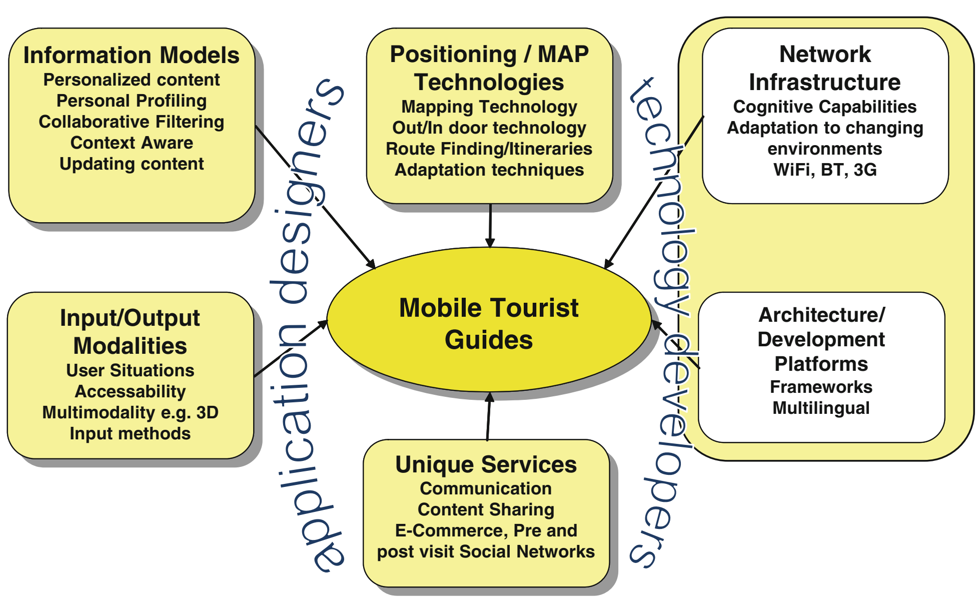


Fig. 2 Projects were classified into four main groups

[20] resulting into many separate systems prototyped for outdoor and indoor use. The guide system [5] was a mobile tourist guide project implemented for the city of Lancaster. The project was designed to be flexible, to enable visitors to explore and learn about the city without the need to follow guided tours (see Fig. 3b). The Local Location Assistant (LoL@) [38] was a research project which investigated location-based multimedia Universal Mobile Telecommunications System (UMTS) applications (See Fig. 3c). The main idea behind the usage scenario of LoL@ was being able to access tourist information via tourist mobile phones without renting a project-specific device. HIPS (Hyper Interaction within Physical spaces) [27, 28] was a hypermedia-based guide application (see Fig. 3d) designed to offer support in the multiple stages of a museum visit:

Fig. 1 Evaluation criteria used to review mobile guide projects



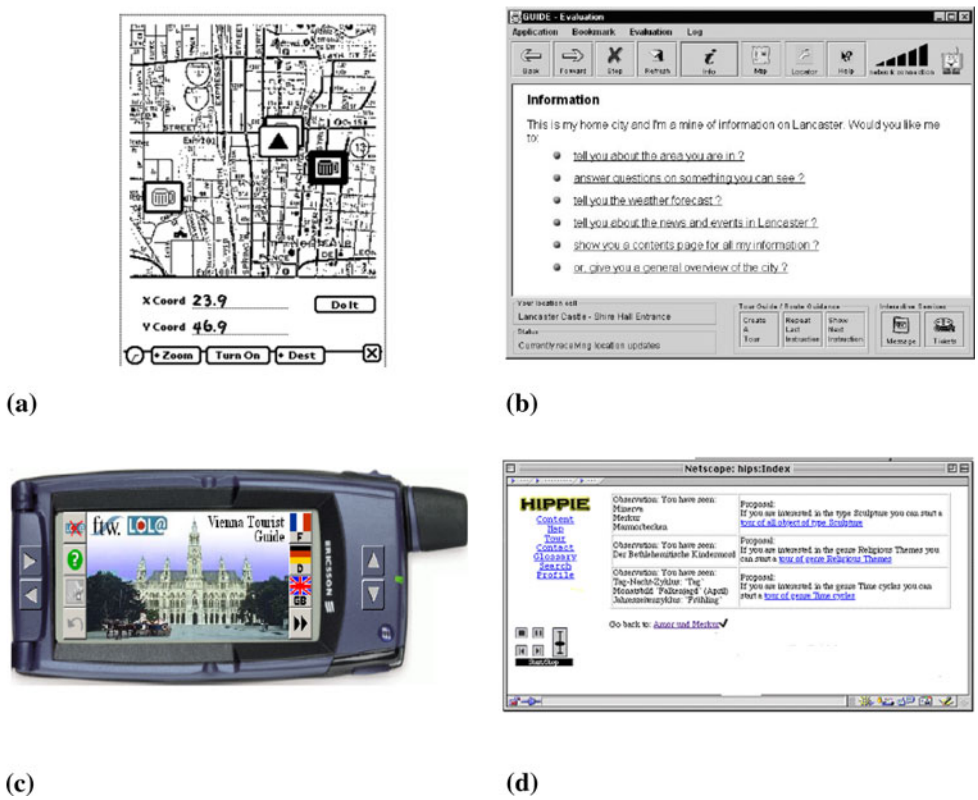


Fig. 3 Various screenshots of the mobile guide projects. **a** Cyberguide: Screenshot of the mapping service. **b** Guide: Custom built browser using WLAN for LBS. **c** LoL@ guide running on a UMTS mobile phone. **d** Hippie browser–based user interface

Preparation at home (pre-visit), execution on site (on-site) and evaluation process (post-visit).

TellMaris, a Nokia Research centre prototype [18, 33], was one of the first mobile systems to use OpenGL-based 3D maps prototype in combination with 2D maps (see Fig. 4a) for the city of Tonsberg in Norway targeting boating tourists in the Baltic Sea area. The project presented 2D and 3D maps on mobile devices in a way in which to provide easier orientation for tourist [31]. The DeepMap project [22] was a research framework conducted by the European Media Lab and several cooperating institutions that envisioned the future of tourist guidance systems that worked as mobile guides and as a web-based planning tool (see Fig. 4b). The CRUMPET project [29, 34] implemented, validated and tested tourism related value-added services for nomadic users across mobile and fixed networks (see Fig. 4c). SmartKom [40] was a multimodal dialog project which combined speech, gesture and facial expressions for both input and output (see Fig. 4d). REAL [2] was a hybrid (combination of client–server with application-based architecture) pedestrian navigation system, which helped the user to find information by generating a graphical route description. The REAL project developed a pedestrian navigation system that combined active and passive location sensitivity in such a way that the changeover between both adaptation paradigms was barely noticeable for the user.

The web-to-mobile projects are projects that use the web to offer tourist information and services to tourists by deploying a mobile application to the user's device. In general, there are quite a few projects that use the web to deploy mobile applications to their users. A popular web-to-mobile application is the Google maps [11] application, due to incompatibility of mobile web browsers, when a user opens the Google maps website via a mobile phone, instead of opening the map in the users' browser; it redirects them to a webpage where the user can download the Google map Java ME [24] application. This is the case for gmail and for youtube.com, when a user accesses these pages instead of prompting them to download a thick mobile application the mobile sites state the benefits of their mobile applications in respect to the mobile websites, allowing for users to decide to download the mobile application or to use the web application as a limited mobile web application. In the scope of tourism web applications, there are not that many web-to-mobile projects that allow mobile applications to be customized online then built and downloaded to the mobile phone. The Mycitymate [26] is a web-to-mobile project (see Fig. 5a) providing information namely of city locations like venues, café, pubs, bars, accommodation etc., but also offering personalized social features like where are my friends, make new friends etc. The system has a Web interface for the pre-visit stage where users select content and then can

Fig. 4 Screenshots of PDA-based mobile guides. **a** TellMaris used 2D maps and 3D representation. **b** DeepMap PDA–based mobile guide. **c** Crumpet PDA browser–based mobile application. **d** SmartKom used mapping technologies

build their customized mobile phone guide application for download and install the application on a mobile phone. Also, in this category, the Mytilene guide (see Fig. 5b) project is an electronic guide for the city of Mytilene, Greece [16]. One of the outstanding features of this project was the initiative of giving tourists multimedia information for designated tourist locations of the Municipal Council, running both online via a PC and offline via a mobile device.

As for navigational assistants, these are classified as mobile applications using a map as the basic user interface, offering routing and guidance services to tourists through the use of Points of Interest (POI) displaying specific tourist information. A large number of off-the-shelf commercial navigational applications were investigated but because these applications were not solely targeting tourist users not having tourist guides as an option, only the Nokia Maps application [9] was incorporated. Nokia Maps is a navigational mobile application found on most new Nokia phones or is readily available to download from the Nokia website. This application comprised of mapping and navigation services which require either built-in GPS or external Bluetooth GPS receivers, yet it works in simulation mode for those who do not have a GPS unit. It was stated as having maps for more than 150 countries, and with 15 million points of interest (POI) pre-loaded as such offering navigational and route-planning features [35]. This application gives the tourist the ability to enhance the Navigational assistant via the Nokia Map application (see Fig. 6) electronic guides from traditional tourist guide companies like Berlitz™, Insight Guides™, Lonely Planet™ etc., offering photos, video, audio commentary and informed coverage on places of interest to tourists [10].

The mobile web-based applications refer to mobile tourist (XHTML Mobile or WAP-based) portals which offer tourist information to mobile device browsers through a client–server HTTP interaction (e.g. [6, 7, 25] etc.). Practically, these applications do not differentiate from traditional 'desktop' web applications, as they treat mobile devices like thin (web) clients; hence, they are not thoroughly reviewed in this article.

The three out of the four groups of projects were included in this research resulting in an overall evaluation of mobile tourist guides whereby design principles extracted are summarized. Following is the summarized evaluation ordered by design criteria.

3.1 Information models

The information models used varied from project to project. Table 1 summarizes all information models stated in this section. Some used a centralized hypermedia model

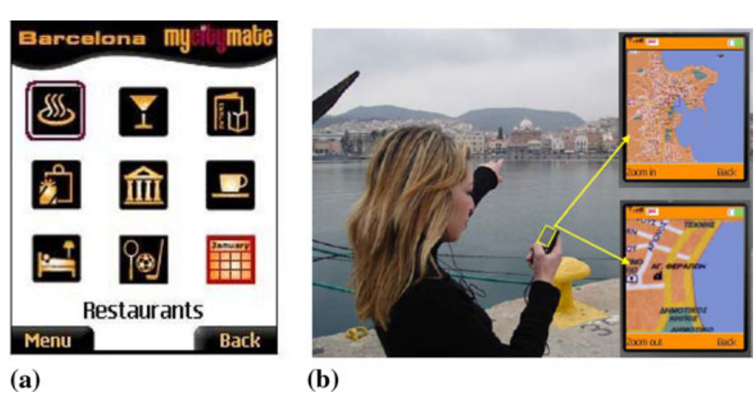


Fig. 5 Screenshots of mobile phone guides. **a** MyCityMate main user interface. **b** Mytilene Guide usability study using map-based services

Fig. 6 Screen shot of a mobile navigational mapping application (Nokia Maps mobile phone–based navigational tourist guide)

wherein a browser-based application is used to browse through hypermedia content. Others used distributed dynamic information models where the network would push information to the users' application upon entering the network vicinity. While other projects used a decentralized on-device storage facility system allowing for users to have unlimited connectivity to the information, yet not allowing for the easy updating of content. Notably, the majority of projects used a centralized approach, i.e. a connection of some sort to feed information to networked mobile devices, which meant costly wireless metropolitan installations or cost incurred for tourists using such connections directly from a mobile phone device. Apart from the information models, this section also references projects that make use of personal profile and context-aware systems and discusses the support of multiple languages.

The Cyberguide project used a centralized hypermedia information model basing information on maps. The system was conceptually divided into four independent components: the Cartographer offered users knowledge of their physical surroundings through maps, the Librarian provided access to sights information, the Navigator provided navigational information and the Messenger offered communication services for tourists to communicate with sight staff and for the system to communicate with visitors or groups of visitors. The GUIDE project provided multilingual information and was based upon a distributed and dynamic information model [5]. It extended traditional hypermedia models [4] offering information based on personal context. The project named it 'dynamic information serving', informing users of sudden change of sight operating times, if sights are closed, the status of ticket queues etc. The personal context involved the use of a personal profile, in which the system explicitly prompted the visitors to complete an entry-level survey of their personal information, getting information based upon age, technical background and the preferred language and also involved the use of environment context, e.g. the time of day, the opening times of the attractions, etc. The content was adaptable with respect to, what the visitors had already seen, e.g. welcomed back visitors if re-visited a site.

The LOL@ project used a hierarchical approach to model information enabling a centralized browser metaphor of hypertext links, linking to text and multimedia information [30]. The content was based on XML/XSL using flexible templates, and the multimedia data were accessed using the browser's functionality. The Hippie project also used a centralized information model and was based on context sensitive models which apart from location, positioning and direction also used an adaptable personal profile, determined explicitly and implicitly logging the users' preferences which resulted to a context-

Table 1 Summary of information models

	On device storage	Centralized hypermedia model	Propriety application model	Personal profile	Context-aware
Cyberguide	✔				✔
GUIDE		✔		✔	
LoL@		✔			
Hippie/HIPS		✔		✔	✔
TellMaris			✔		
Deep map			✔		✔
CRUMPET		✔		✔	✔
SmartKom		✔			
REAL			✔	✔	✔
MyCityMate	✔		✔		
TIP					
Nokia maps	✔		✔		

aware system. The HIPS project was based on an adaptive hypermedia information model which provided information about the exhibits through a hierarchical method using dynamically created Web pages having additional knowledge of the user model and interests, e.g. each time an object was visited was marked by the system so as to adapt information provision. The user model was one of the key strengths of this project: by evaluating user interactions and physical navigation, recommended tours of exhibits to visit were offered. The TellMaris project was based on a centralized client/server application model, which meant all data was downloaded upon request via a wireless communications network connection. In the mobile version, the system displayed both 2D and 3D maps.

The core of DeepMap was the centralized geographical information system (GIS) and other databases. The GIS database stored spatial data while there was a database to store temporal data (i.e. historical information of sights) and a separate database to store topological information such as user information and general information about places (i.e. restaurants, cafes, shops). The information model was quite complex as it was connected to the spatial and the other databases. The CRUMPET project also integrated GIS as a means to integrate large volumes of geographical data. This meant that the project offered information on topics such as personal tours, navigational assistance and route finding. Map adaptation examples include culture-specific map colouring, map generalization, user-orientation-dependent maps, focus maps and personalization. As of personalized services, this project argued that the solution to the problems associated to mobile devices (such as restricted screen size, input methods, network capacity) could lie within the adaptation of personalized information and services for nomadic users i.e. view the same information on any device. In CRUMPET, the adaptation of such services resided on the notion of filtering based on a user profile which was gathered by getting information of interests, abilities and characteristics of the user.

The MyCityMate mobile system used a decentralized hierarchical information model based on XML documents and user menus. The MyCityMate system was one of the first systems using the web-to-mobile dynamic application generation technology to mass deploy applications to users mobile phones. The MyCityMate system used the web platform to attract users to choose tourist content of personal interest or automatically generate selection using an explicit personal profile system. The system would then deploy an application to be downloaded to the users' mobile phone to run on an adaptable standalone mode or connected mode. The Mytilene guide used a similar propriety XML information model but also used maps to show location of a specific sight and incorporated multimedia tours in the mobile application.

3.2 Position and map technologies

The use of maps and positioning technologies prevailed in most of the projects reviewed. Table 2 summarizes all position and map technologies stated in this section. Some systems were somewhat simplistic using raster image maps whereas a number of systems used GIS running a client/server functionality model. This meant that all GIS data were stored on a central server and when needed were rendered to be viewed on the mobile device. This method surely needs a network connection to run, but allows for heavy calculations to be carried out on the server side and not on mobile devices. In the same way, a mobile network connection is needed to extract routing information. Some projects used sophisticated routing systems to map navigational paths for users whereas other used the map just to show an area of interest. The use of positioning technologies varied by indoor outdoor use, yet most projects used

Table 2 Summary of positioning and mapping technologies

	Map	Outdoor positioning	Indoor positioning	User adaptable positioning
Cyberguide	✔	GPS	IRDA	
GUIDE	✔	WLAN		
LoL@	✔	GPS/CELLID		✔
Hippie/HIPS			Electronic compass/IRDA	
TellMaris	✔	GPS		
Deep Map	✔			✔
CRUMPET	✔			
SmartKom	✔	GPS		✔
REAL	✔	GPS	IRDA	
MyCityMate	✔	✔		
TIP				
Nokia Maps	✔	✔		✔

GPS systems outdoors and IrDA/RFID/Bluetooth technologies indoors. Some projects offered user position adaptation which allowed for users to manually calibrate their position on the map.

The Cyberguide project used image maps for indoor situations using IrDA positioning technologies and vector maps stored and run on device using GPS positioning technology outdoors. The Cyberguide project also used a logging system to track user sight visits. The GUIDE system incorporated maps to allow visitors to use in specific situations, but did not use them as a means of route finding or did not use the installed WLAN technology for showing positioning on the map, yet showed position by using the identity of the wireless hotspot. The LOL@ used maps as guidance and proposed an adaptable user positioning system using GPS but also using mobile networks cell id positioning system. The system also offered route finding functionality and used a manual logging system as a means for the user to capture the sights visited as a means to create a user diary log. The Hippie/HIPS project offered guidance not using maps but using IrDA positioning sensors at room level and at object level and also incorporated an electronic compass to proactively notify users of upcoming exhibits. When a user visited a sight, this was automatically logged; and when revisited, different information was provided.

The TellMaris project used both 2D and 3D maps as a navigational aid for the city of Tonsberg, Norway. The use of such technology allowing for routing functionality used a client/server infrastructure as well as GPS positioning in order to generate on the server side the geospatial representation and to portray this information on the mobile device. The DeepMap and SmartKom projects also used GIS server side technology to generate the 2D maps including user adaptable GPS positioning as well as route-finding features. The CRUMPET project took the Deepmap project one step further incorporating GIS maps as guidance and route finding features using personal profile and an agent-based recommendation system also. The Mycitymate used a Google maps mash up application to show POI's and used GPS for location tracking. The Mytilene city guide used raster map to show the specific POI on the map. No route finding or positioning technologies were stated as being used. The NOKIA map application used maps stored on the device. The user could track POI on the device using GPS positioning. No means of adaptation was available in the Nokia maps application. The route finding is calculated via the server and later returned and showed on the device map.

3.3 Architecture/network infrastructure

The architecture and network infrastructure of the projects also varied from project to project. Table 3 shows a summary of all architecture and network infrastructure stated in this section. As such, a trend to use generic mobile applications and customized user interfaces was seen as enhancing user experience. These mobile applications needed a specific hardware platform to run, incurring fragmentation problems which arose to newly available devices with new operating systems. The projects basically could be split up to four main platform groups: the personal computer platform, the Personal Digital Assistant (PDA) platform, the Java mobile platform and the browser technology–based platform. Only applications which used native browser technology could claim platform independence. The network technology used mirrored available infrastructure of the projects and to the availability of such network infrastructure. Emphasis was given to projects

Table 3 Summary of architecture/network infrastructure used in stated projects

	Application programming environment	Offline use	WLAN	GPRS, UMTS, GSM HSDPA	Resource adaptive
Cyberguide	Visual basic runtime		✔		
GUIDE	Java portable PC	✔	✔		
LoL@	Java Applet			✔	
Hippie/HIPS	Microsoft.net		✔		
TellMaris	Windows CE PDA				
	Nokia s60		✔	✔	
Deep map	Standards compliant open source agent		✔	✔	
CRUMPET	Standards compliant open source agent		✔	✔	✔
SmartKom	Agent architecture			✔	
REAL	PalmOS/Pocket PC;		✔	✔	✔
MyCityMate	Java ME application based system	✔	✔	✔	
TIP			✔	✔	
Nokia maps	Symbian S60 3rd edition platform	✔	✔	✔	

which were cognitive resource adaptable i.e. the software adapts seamlessly to a change in the network environment.

Cyberguide used the Microsoft Visual Basic runtime system running on portable device technology. The portable devices used a WLAN infrastructure installed on the campus university test site. No cognitive resource adaptation was mentioned for this project. The technological infrastructure varied because of the different prototype projects implemented. The system used a commercial PDA; yet, at some stage, the project stated to use the Apple MessagePad 100 with Newton 1.3. This indoor version of the system was tested using IrDA sensors for location tracking. The prototype was also tested on the Dauphin DTR-1 palmtop. The GUIDE system used specific mobile devices, namely Fujitsu TeamPad 7600 portable PC empowered by custom Java applications. The Java application included a Hot Java browser [36] and also included gauges to show signal strength, an indication to which WLAN hotspot the user was connected and another indication when the mobile guide was downloading information. This project did not have a system of cognitive resource adaptation due to the fact it could only run using the WLAN as it was also its means for user position finding. Yet, the project was adaptable to failing connections where a caching system would download and store content on device at earlier stages allowing for the device to gracefully degrade.

The LoL@ system was based on conventional Internet software technology and user interface paradigms, extended by concepts to improve usability for the mobile domain. This application targeted high-end mobile phones and smart phones with Java Applet enabled fully fledged Web browsers and used touch screens as input. The mobile terminal used applet technologies, while Java Servlets technology was employed on the server side. A network-centric 3-tier application architecture was chosen for this implementation enhanced with telecommunication-specific constant network connection using UMTS (3G) or GPRS network via a mobile phone. The fact that the LoL@ project required constant network connectivity where all content data were stored on a server database and prepared on demand resulted to data intensive costs for the user which was observed as a disadvantage during user tests, visitors were reluctant to use the system considering the high roaming fees [38]. No adaptation capabilities were designed for failing network shortages. The clients of the HIPS system were PDAs which used a thin client (Web browser) application with client–server architecture requiring a stable network connection to operate. The PDA devices were called HIPPIES and were connected via a wireless LAN (WLAN) infrastructure. Apart from the use of PDA devices, the project stated the use of notebooks or PCs to access web content. The TellMaris project was based on a client/server model, which meant all data were downloaded upon request via a wireless communications network connection. The OpenGL system was developed on Linux, Windows and Windows CE platforms; however, the system also ran on the Nokia communicator 92XX. In the mobile version, the system displayed both 2D and 3D maps simultaneously; however, the user could choose the desired type of map. No reference was found for support of cognitive network resource adaptation. These databases were accessed using four main agents: The database agent to retrieve non-spatial information; the geo-spatial database to retrieve spatial information and to calculate geo-spatial information (i.e. place with regards to user location); the route agent used to compute and manage routes; the map agent which generated at first raster maps as a picture case and later as vector maps used to display features on the maps. The architecture of the Deep map system was based on the agent-oriented software paradigm which allowed reusability of various system components. The prototype was implemented using two technologies; one of a belt worn Xybernaut mobile assistant IV having a visual output on a flat touch screen mounted on the arm and the other a laptop PC placed in the user's backpack.

The CRUMPET implementation was based on a standards-compliant open source agent framework, extended to support nomadic applications, devices and networks. The system was built using a 3-tier structure; with mobile clients and user services on the two ends and the use of multi-agent systems in between both. At the stage of usability testing, a PDA was used as the client device using GPS as positioning technology. Yet, it was argued that any mobile device able to display rendered maps and simple HTML pages could be used. The system could use all types of networks that a tourist might be exposed to, i.e. WLAN, GSM, GPRS, UMTS. The REAL project developed a pedestrian navigation system that combined active and passive location sensitivity in such a way that the changeover between both adaptation paradigms was barely noticeable for the user. The REAL project uses both PalmOS and Pocket PC platform for indoor and uses a SONY VAIO notebook outdoor for computational power but for graphical and textual presentations; a special clip-on for glasses from MicroOptical was used in conjunction with a customized Garmin GPS unit as a pointing device. For both indoor and outdoor systems, the 2D- and 3D-graphics are generated via the embedded Cortona VRML1-browser. The SmartKom uses distributed component architecture using an agent-based multi-blackboard system. The integration platform is called MULTIPLATFORM (Multiple Language Target Integration Platform for Modules), built on top of open-source software, making it open, flexible and scalable able to integrate heterogeneous software modules implemented in diverse programming languages and running on different operating systems. SmartKom modules were coded in C, C++, Java and Prolog. SmartKom supported dynamic multi-lingual interaction by introducing a semantic layer that encoded interactions in a language-independent way.

The MyCitymate and the Mytilene guide systems included a mobile application developed on the top of the Java ME Platform [24], essentially comprising a certified collection of Java APIs for the development of software for small, resource-constrained devices such as cell phones and PDAs etc. These two projects are purposely custom built 'stand alone' applications not needing a network connection to operate. 'Tourists' incorporate people visiting international locations where roaming charges apply and not needing a network connection to operate could be critical in choosing a mobile tourist application. However, just like the Nokia navigational assistant if needed, many features are available if users want to use a network connection. Features such as 'where are my friends' in the MyCitymate project or the 'download more information' in the Mytilene guide project.

The Nokia Navigational project has been developed using Nokia Symbian platform supporting all s60 3rd edition phones and other Nokia platforms. The Nokia maps also has a free pc-based application where users upon installation to their pc can download extra maps and voice navigation files instead of downloading them straight to the user's phone.

3.4 Input/output modalities

At a first glance, the use of input/output technologies in mobile devices seems trivial. Table 4 shows a summary of input/output modalities stated in this section. Yet, in the context of this in depth review, it was considered as separate criteria for all projects reviewed. In this section, the projects are reviewed with respect to input technologies used by the users of the mobile devices also as to output technologies. In addition, the projects are evaluated in regards to accessibility and their ability to seamlessly internationalize the specifically targeted tourist applications.

The mobile device used in Cyberguide was a standard PDA using a pen input and a standard PDA screen as an output. In its documentation, there was no reference to multi lingual support or use of any other modality technology to support other forms of output. The GUIDE project employed devices with larger input area for use with an input pen and a transreflective screen for use in direct sunlight. The GUIDE project stated multilingual support in its documentation but that was not referenced extensively. The LOL@ project used speech as a form of input. Tourist used speech to input control to the hierarchical interface gaining access to menu items. This project allowed speech access in three different languages English, German, French using not only one-word commands but also natural language input phrases to control the menu. This system did not use natural language processing other than menu control for input purposes. The system used a VoIP solution based on the Session Initiation Protocol (SIP) [39] and the GSM voice codec [14].

The Hippie/HIPS system was a pen input-based system not offering multilingual support to its users. Standard pen input and PDA screen output were also used in the TellMaris project, along with 3D representation on 2D maps in an augmented reality environment to depict buildings of historic nature (including buildings that did not exist anymore). The DeepMap project integrated natural language processing to mobile devices. The Deepmap user could gain access to information by

Table 4 Summary of input/output modalities

	Keypad	Pen/screen input	Multilingual support	Voice/speech input/output	3D Modelling output
Cyberguide	✔	✔			
GUIDE	✔	✔	✔		
LoL@	✔	✔	✔(3)		
Hippie/HIPS	✔	✔			
TellMaris	✔	✔		✔	✔
Deep Map	✔	✔	✔	✔	✔
CRUMPET		✔	✔		
SmartKom	✔	✔	✔	✔	
REAL				✔(input)	✔
MyCityMate	✔	✔	✔		
TIP					
Nokia Maps	✔	✔	✔	✔(output)	

queering the system using natural language. The system upon queering, the database used text-to-speech to output the information findings. The project could also be used as a translator to interact with locals in their local language. Again, VoIP technology was used to transfer the voice to a server for further processing and speech recognition system to translate the spoken text to a query towards the database. Also, GIS maps in conjunction to 3D representation were used to create an augmented environment. The CRUMPET project supported multilingual content and used a PDA browser application, having a pen/screen modality. The SmartKom project was a multimodal dialog system which provided for full symmetric multimodality in which all input methods were also available for output. The SmartKon system captured speech, gesture and facial expressions using sensor technology trying to capture a natural experience for the user in the form of daily human-to-human communication, by allowing both the user and the system to interact. The Mycitymate, Mytilene and Nokia maps make use of the current mobile telephony devices available using keypad and joystick as input. No reference is given for pen input support. The Mytilene guide project offers video or audio guide as output information of sights while Nokia Maps offers speech output as navigation support. All the three above-stated projects offer multilingual support. The REAL system used speech input to accept a request for a route description. This request was then transformed into a user-specific request, taking into account limited cognitive and network resources. The request was then passed to the route-finding module which determined and forwarded the optimal route to the presentation planning module. This module optimized the presentation of the route not only according to the resolution, screen size and colour capabilities of the output device, but also to the quality of the given sensor information (i.e. precision of location, orientation and speed of the user).

3.5 Unique services

Many unique services where highlighted in the aforementioned reviewed projects. Table 5 summarizes unique services stated in this section. The services basically fall into three main categories: communication amongst users, tour generator and a log system. These projects felt that communication amongst tourist users was important. It was interesting to see that most projects tied the user's personal profile with the tour generator offering tours that reflect the users' personal interests. The log system was found in various forms, but as a fundamental system was used to allow users to keep track of visited sights and in some cases included a commenting system which was used to input comments about sights visited.

Cyberguide using rapid prototyping design methods implemented a number of applications. One such implementation had a messaging service whereby users could contact each other and also contact members of university stuff. For the messaging service, a wireless access system was designed to cater for communication between tourist users and the system. The system could document a user's visits which at a later stage could be sent via email to the visitor. The GUIDE project developed an intelligent tour guide builder which calculated customized tour guides based on time constraints and dynamic changes to the user's environment (stopped, for coffee, slow walker). The users could override the guided tour to change the next location giving them freedom of choice. The guide system also offered support for interactive services; a communication tool for visitors to contact the local Tourist Information Center, messaging tool amongst visitors. It also had

Table 5 Summary of unique services

	Added agent based services	Exploratory	Messaging/group communication services	Pre visit website	Post-visit web	Friend position finding	Ticket eservices	Guided tours
Cyberguide		✔	✔		✔			✔
GUIDE		✔	✔				✔	✔
LoL@		✔		✔	✔			
Hippie/HIPS		✔	✔	✔	✔			
TellMaris	✔	✔						
Deep Map	✔	✔						
CRUMPET		✔	✔					✔
SmartKom		✔	✔					
REAL		✔						
MyCityMate		✔				✔	✔	
TIP								
Nokia Maps		✔						✔

a built-in ticketing service where visitors could book accommodation and buy tickets avoiding queues.

In the LOL@ project, a tourist diary service was offered to users upon confirmation of arrival to a sight and/or by accessing the *My Data* menu item to enter information. The visitor could enter comments in the form of text via a predefined screen including title, text and a link to a photo or a video taken from the tourist mobile device. This was later uploaded to the server and offered to the user for viewing as a log of visited sights. The log file was not integrated in existing Web technologies but was implemented on a propriety-based Web platform in the form of Web pages. Similarly to the Cyberguide project, the Hippie guide also allowed for interpersonal communication and general public communication of ideas through message sending. The mobile system also allowed for personal annotation added to the user's personal space to be accessed at the post-visit stage. Other prototypes of the HIPS project implemented dynamic generation of presentations depending on the distance the user has to the object and how long they stood in front of the object. The TellMaris project quoted a number of services which could be implemented to be offered for both portable PC systems and for mobile systems. For portable PC services like weather forecasts, hotel reservation and navigational guidance services were thought of and for mobile devices users would be able to request information about various sights or restaurants, find closest facilities or to buy specific products. The CRUMPET system implemented guided tours and a group messaging service.

4 Evaluation results

In this section, we discuss the results stated from the five (5) evaluation tables listed above. Clearly, with respect to the information model, most systems used a decentralized web-based approach, yet others implemented proprietary-based applications using some sort of an adaptable information model offering personalized information to its users via a hierarchical menu system.

Most systems used a map as a central feature which in turn offered navigational and routing services. With only a few exceptions, GPS has been the standard choice as outdoor positioning technology. Certainly, this can also be confirmed by today's increasing tendency of mobile phones incorporating GPS units and not the use of say, telecommunication cell-id positioning (used in the LoL@ system). Apart from navigational and route-finding capabilities, only the GUIDE and the CRUMPET system offered basic itinerary planning for its users based on a personal profile. This feature was noted as being popular amongst tourist users visiting the city for the first time.

As of network capabilities, all systems used a HTTP IP connection which could be used in all cases of network connectivity being WLAN, GPRS, UMTS. However, only a few systems had the ability to adapt to network fluctuations offering on device cached content to the user. Also, systems such as the CRUMPET and the REAL system were stated as being cognitive resource adaptable. This is the ability to sense changes in network connectivity and being able to change the network connection without interrupting content flow.

Coming to situational factors, only some systems enabled alternative input and output modalities. The systems implementing speech modalities for input or output were said to be resource constrained acquiring constant large bandwidth network connection to function properly and efficiently due to the fact that all speech processing was completed on the server side.

As of architecture, only systems using agent-based architecture (CRUMPET, SmartKom) were said to be standards based and could be easily extended offering other services and integrating other sources of repository, other than proprietary based. Notably, only a few systems used thin clients of some sort to visualize hypermodel; most systems employed the use of thick client applications to offer a richer customizable interface.

Finally, as of services offered to tourists, it could be seen that these were split into three different stages of a tourism lifecycle: the pre-visit stage, the visit stage and the post-visit stage. The pre-visit stage was implemented by some systems offering the use of information for the places to visit and the ability of explicitly collecting personal information to build a personal profile. During the visit stage, services offered were mostly combined communication—friend finder tools and diary-commenting systems were also implemented. The post-visit stage stressed the need of documenting the visit offering it to tourists as a means of logging their visit to be retrieved via the internet at a later stage.

5 Design principles versus current trends

This paper focused on the evaluation of a large number of research and commercial applications used by tourists to retrieve information, navigation and guidance using some form of mobile device in the scope of application designers and technology developers. In order to evaluate these projects, a number of design criteria were extracted targeting both designers and developers. These projects were grouped into four groups: mobile guide applications, web-to-mobile guides, mobile phone navigational assistants (with built in tourist guides) and mobile web-based applications (the latter have not been extensively evaluated due to their resemblance with their web counterparts). A number of milestone projects were incorporated which according to the considered bibliography offered unique experimental features and so was a number of commercial projects offering unique services.

After analysing the above-evaluated findings (see Sect. 3), an application designer should keep in mind at least three principles: the Information model to be used, the Unique Services to be provided and the input/output modalities to be incorporated in the overall project. As of information models, there are basically three main choices:

- Decentralized information model
- Centralized information model
- Distributed dynamic information model

The decentralized approach is an on-device solution where the information content is stored on the device. A number of solutions used this approach where some projects used memory cards to store and encrypt the content. This approach though brought about content update issues and is mostly used in solutions that do not need the content to be updated, i.e. static tourist guides. The distributed dynamic information model was used to push specific content to a user entering the vicinity of the network node. This approach works in environments wherein a network installation exists or in scenarios where the system can use the mobile network cell ID to push information to the users. The centralized approach in most cases was used in conjunction to hypermedia content models. This was the case for the majority of projects evaluated and certainly there are a number of advantages of using the centralized hypermedia model (easy updating of content, access on a number of different mobile devices, etc.); the problems that arise in this case are normally due to compatibility problems in mobile browsers which normally lead to project developers implementing a custom browser–based application and also in some case where the cost of connection is incurred by the user, roaming charges are very high making. The use of a personal profiling system could increase the usability of the system in issue. Using a personal profiling system means the information model must be dynamically generated in regards to the explicit profile of the user and the implicit usage history. In conjunction with a personal profile and knowing the users whereabouts (using context awareness methods) as stated in the relevant projects (see Sect. 3) increase the usability of such systems.

An application designer should design a tourist mobile guide system keeping in mind the multilingualism; a case of easily bringing more languages to the tourist guide should be designed at the start of the system design. Also, the application designer should cater for users that do not have easy access to keyboard input and screen output implementing alternative input/output modalities, like speech input and output. This solution is network dependant and might increase the cost of fast network connection.

Finally, the case of unique services which should be incorporated comes down to the scope of each application designer's project. Below is a potential list of 'common denominator' services:

- guided tours,
- communication amongst users and the system,
- e-services (e.g. diary service, currency conversion, etc.)
- group meeting scheduler,
- registering position to friends,
- pre-visit and post-visit services support,
- rating/commenting service.

Indeed, a technology developer should surely keep in mind the three above-mentioned design choices which an application designer has to choose from but also choose from a range of architecture, development platforms, network infrastructure, positioning technologies and map technologies.

The architecture chosen by the evaluated projects' developers reflected the devices which they had to choose from. There was no real drift to particular devices or development platforms due to the large fragmentation problem which mobile developers face. Most of the systems implemented used the client–server architecture and some used propriety-based architecture, while a few used agent-based systems. The agent-based ones were noted as being standards compliant, which meant that they were being able to add more services to the existing infrastructure without major changes. As of development platforms, Visual basic.NET was popular for PDA-based projects while Java-based systems where popular for every other mobile device stated. All available network platforms were used (i.e. WLAN, GPRS, UMTS and GSM); notably, WLAN is an expensive solution and GPRS, GSM was a slow solution as was the UMTS a costly solution which the users of the systems incurred.

Most systems used some sort of maps in the mobile guides, some of which were raster-based maps and others which were GIS-based vector maps. Surely, in situations where routing and guidance was necessary, a GIS map server is useful; yet, raster maps better suited systems where maps were solely used as a means of displaying the location of POIs, when comparing the network usages and technology requirements. As of positioning in outdoor situations, GPS represents a reliable technology, while for indoor positioning, IrDA and RFID tags are better suited.

As such, our evaluation revealed open research issues and some specific areas of mobile tourist guides research that need to be systematically investigated tying them to current trends of the Web. Specifically, more work could be carried out on social networking for tourist users especially in the eye of recent advent of mobile social networks [19]. The Mycitymate attempts to add such functionalities in the form of 'locate your friends' services and via commenting of POIs service but no attempt to connect content to current social networks (i.e. Facebook, twitter, etc.) has been carried out. Even though much work has been already carried out on personal profiling systems, no research has been noted on server-side clustering of users or collaborative filtering techniques of tourist content used in many popular sites (e.g. Amazon) [13]. This server side attempt would decrease device system resources (heavy algorithm calculations would be done on the server), while clustering of user profiles would enable proper assignment of users to group of tourists with similar interests, thereby providing space for the development of innovative personalized features.

Lastly, this evaluation identified a few projects stated the use of dynamic tour generation which the system apart from proposing specific POIs' to visit would also consider the user's profile in dynamically choosing the tour before generating it. Yet, there was no claim of dynamic itinerary generation, wherein users would state the time and days they have available for visiting tourist sights and the system depending on external parameters (i.e. opening times, weather conditions, peers choices and ratings) could generate a *n*-day itinerary for the specific user keeping in mind the 'must see' sites and the user's profile. Recent works proposing algorithmic solutions for optimizing personalized tourist itineraries [12, 37] have revealed the potential of such services but remain to be implemented and evaluated through field trials.

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