DESIGNING AN INDOOR MOBILE MUSEUM APPLICATION

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This work presents the design issues faced while introducing hand-held devices in a museum environment. After outlining the general setting by studying the goals and the actions of a visitor, we analyze the actions that technology imposes to the user. We move on in exposing the rationale behind major decisions, which formed the final design. Decisions were based on thorough evaluation of available alternatives and careful inspection of technological means. We revealed metaphors which describe the interaction between visitors and exhibits. This process was fundamentally beneficial for selecting the most suitable technological solutions and ensuring a transparent interaction model.

INTRODUCTION

There is an increased interest in designing and developing systems that support navigational, informational and educational needs of the visitors inside various types of museums and generally in rich cultural/informational spaces, catalyzed by the technological boost known by the field of mobile devices. (Raptis et al. 2005, Exploratorium 2005)

The purpose of this paper is to describe the spiral design process of an indoor, mobile application that supports the learning process in a cultural-historical museum. Museums represent ‘living organisms’ that project, in a visible and tangible form the various facets of human civilization. Their main purpose is to assist the visitors in discovering and acquiring knowledge. We can characterize a museum as an ecology, (Gay and Hebrooke 2004), that is constituted by two main entities, the exhibits and the visitors, populating the same physical and virtual space. These ingredients of the ecology play a specific role. Cultural elements are exhibited to visitors, who react by discovering them in a way that is, at a large extent, influenced by the surrounding space, either physical or virtual.

The Museum Visit – A Learning Activity

Independently from using or not technology, when a visitor goes to a museum she/he has as a primary goal to learn. Visitors study the exhibits as physical objects, they get multilevel details about each exhibit, which can be artistic, historical, cultural, social etc, they correlate the exhibits among them and with previous knowledge and finally they seek answers to new questions created during the learning process. Additionally, a museum visit is not, in most cases, a lonely process. Groups of people such as families, tourists or pupils are going together to museums as a team. Therefore, we can allege that the learning goal is distributed among the members of a group and as a result all the actions related to this goal are flowing from the group. Another dimension of a museum visit is related with the emotions created to the visitor. The museum visit must be engaging and motivating, resulting in a meaningful and memorable experience (Falk and Dierking 1992).

The Notion of Space – Physical, Mental and Virtual Dimensions

An important issue in clarifying the parameters that affect the interaction between the visitors and the exhibits is the notion of space. Space can be primarily perceived by the term of *physical space*. *Physical space* is referring to the physical existence of the museum and contains all the existing physical objects. The visitors are interacting with the exhibits through the *physical space*. The effect of this interaction forms a mental representation of the exhibits in the visitor's mind, perceived by the term *mental space*. Because of this mental representation, we state that there is a direct relation between *mental* and *physical space*.
The involvement of mobile technology in the museum ecology gives birth to a new dimension, the *virtual space* (Figure 1). The *virtual space* refers to digital representations of the exhibits. These representations increase the interactivity with the *physical space* creating new affordances for the visitors to shape their *mental space*. Therefore we can point out that there is a direct relation between *virtual space* and *mental space*.

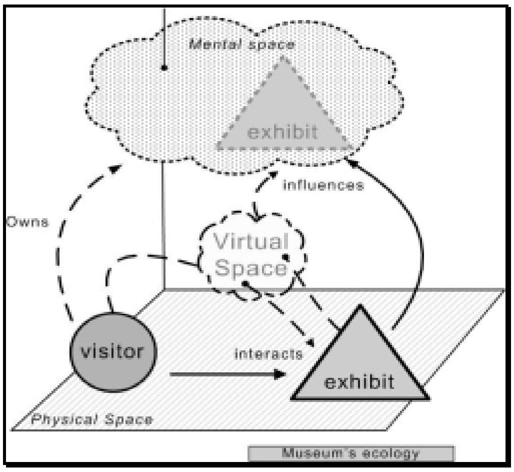


Figure 1: Dimensions of space

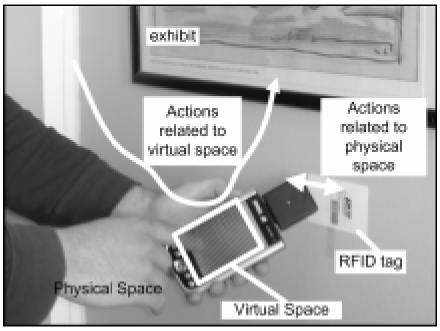


Figure 2: Actions imposed by technology

People visiting a museum usually belong to groups or sometimes form groups during the visit. Therefore, space can be shared with different degrees according to these dimensions. Certainly all the people that are physically located inside the museum share the same *physical space*. Social interaction between group members leads to some degree of shared *mental space*. Finally the existence of a shared *virtual space* is bound to the design decisions regarding the possibilities offered by the system.

The next step in investigating the impact that mobile technology can have in the ecology is to understand the unforeseen actions that inserts to the visitors. We can be certain that these actions are influenced both by *physical* and *virtual space* (Figure 2):

- *Actions related to virtual space*. These actions are formed by the possibilities offered by technology (e.g. browsing for more details about an exhibit).
- *Actions related to physical space*. These are the actions related to the affordances that technology inserts in the interaction (e.g. scanning an exhibit tag/label).

The actions related to the *virtual space* can certainly enhance the museum visit if they are supported by a good design. Regarding the actions related to *physical space* an extensive study of the affordances of each type of technology is needed in order to ensure a seamless interaction.

DESIGN PROCESS AND REQUIREMENTS

Our design team was comprised by researchers and experts with different backgrounds covering computer science, education science, mobile devices, computer-mediated educational activities, information foraging and HCI. We aimed at forming a team with diverse background that combined with the collaboration with museum experts to allow approaching the subject from different perspectives.

The design process followed a spiral model (Figure 3). According to this model every aspect of the system have been investigated by considering the available options, next creating a prototype that was tested and evaluated and finally studying the effects of our decisions on the rest of the system. We point out that we were forced to use such an approach during the design mainly because we were dealing with a system that uses technology which is relatively new and constantly evolving. The system is constituted by a lot of parts (i.e. mobile devices, technology to communicate with the exhibits etc.). For every technological part of system we had to examine all the alternatives and to check for any compatibility issues that might appear by combining them. This situation prevents us from having a somehow formulated system from the initial design phases and to constantly improve it through extensive evaluations.

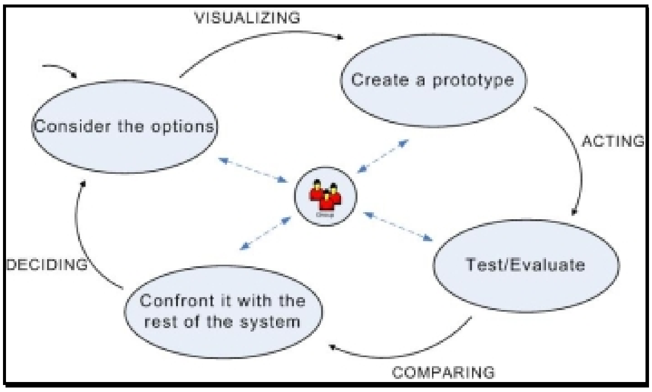


Figure 3: The Design Model

We have documented and digitized the museum collection and stored it in a CIDOC (Crofts et al. 2003) compatible database. We also designed a portal that allows visitors to prepare and plan their museum visit as well as to relive it afterwards.

The design decisions related to the options offered to the visitors lead to three usage types: 1) the use of the PDA both as a navigation tool and as an information harvesting device (Bridges 2002), 2) the use as a tool for educational activities and 3) the use of PDA as a notebook for leaving private or shared notes in the exhibits. These possibilities define the *virtual space* that our system inserts in the interaction.
In addition this design model gave us a set of requirements for the three possibilities mentioned above. These requirements are going to be presented under the prism of the new actions that technology inserts. Most of the requirements are products of an extensive study of previous installed mobile systems (Raptis et al. 2005), evaluations of the prototypes and brainstorming among the members of the team.
An important requirement associated to actions related to *virtual space* is the transparency of the system. Visitors want to live the experience and not exclusively use the technology (Schwarzer 2001). In our case the system can, only, be characterized as transparent when these actions have the minimum possible negative

impact in the interaction and the tasks of the visitor. In the case of actions related to *physical space*, transparency is associated to the affordances that technology inserts.

The issue of content provided by the system has a significant impact in the actions related to *virtual space*. Without an attractive content, technology will degrade in being an obstacle rather than an enabling factor. Having in mind, also, the same question, we opted for a design that had the need for engaging and constructive educational activities, suitable for different types of users, as a central issue. Therefore, we included in our design as an obligation, the design of a set of educational activities suitable for small groups (i.e. parents with children) and scenario based activities suitable for large groups (i.e. pupils and student groups).

Affined to the actions related to *physical space*, in combination with the learning goal in a museum, is the fact that visitors follow four different patterns during the actual visit (Levasseur and Veron 1983). These patterns must be taken into account while designing the system. Finally, there are aspects that comprise requirements and are essential in designing every system. Designers need to look forward for a flexible solution that can be easily maintained, updated, extended and upgraded. And, in real applications, the budget usually limits the design and forces designers to find a balance between a good and an affordable solution.

FULFILLING THE REQUIREMENTS

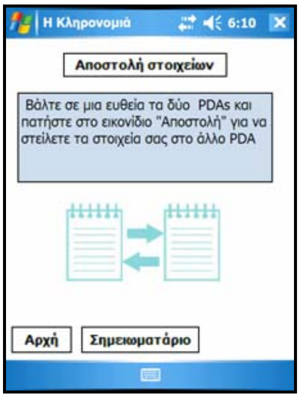
Dealing with Actions Related to *Virtual Space*

Great value concerning these actions is offered by the content. Independently from the form that the content is going to be provided, a careful choice has to be made regarding what is important to be presented to visitors. From the beginning of the design phase we decided, for obvious reasons that all scripts must be written by people with deep understanding for the museum’s collection and not by our research team. Our role was limited in providing requirements about the suitable size of text for the PDAs and the portal, and mainly technological issues. The docents of the museum and people with an academic approach to the collection were responsible for producing all the content. Museum experts created multidimensional, multidisciplinary information about exhibits establishing relations among them and assigning them to categories. This informational structure enabled us to design a basic level of personalization based on the age group the user is belonging to, combined with the user ability to adapt the information type according to her interests. Apart from the personalization regarding the content, our system must comprise support for the patterns of museum visit (Levasseur and Veron 1983). To include this in our design we considered a one hour predefined visit covering the most of the exhibits for the *ant* visitor. The *butterfly* visitor is assisted by a fifteen minute predefined visit, covering a selection of exhibits. For the *grasshopper* visitors the system offers the opportunity to prepare their visit in advance, from the museum’s Web portal. Finally, the *fish* visitor can freely interact with the exhibits and use the system voluntarily.

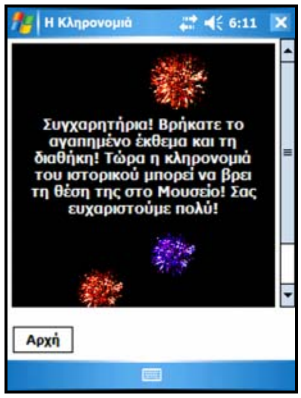
The most significant role in making these actions truly assisting the users tasks, perform the educational activities inside the museum. They constitute the core of the system. It is a known issue that wireless mobile devices can have a positive impact in learning (Roschelle 2003) and, combined with collaboration (Dillenbourg 1999), can alter the museum experience. The main issue in designing educational activities is their learning value. Therefore, a careful design was made for the content, the structure and the nature of these activities.

In collaboration with the docents of the museum we designed two different sets of educational activities. The first set is suitable for small groups (up to 3 PDAs). One example of a learning activity is a puzzle game where parts of pictures or verses distributed among the PDAs and the participants are trying to recreate the pictures/poem by collaboratively exchanging pieces (Cabrera et al. 2005, Stoica et al. 2005). A more simple individual game concerns answering questions related to one exhibit. The system, depending on the user's answers, gives more details and assists her continuously during the activity. Such activities are appropriate for small groups, like families, and can be started and stopped at any time during the visit.

description browsing



clue exchange



successful end

Figure 4: Inheritance scenario prototype screenshots

The other approach is related with big groups of people, basically classroom visits. We are designing scenario-based activities, where ten PDAs can participate simultaneously. Their scope is to create a sense of team spirit among the participants and drive them into collaboration. Through this process, the teams navigate through the museum, interact with the exhibits and generally acquire knowledge by game playing. Such scenarios can be altered or redesigned by the docents or adapted by the educators through the Web portal. An example of scenario is about a famous and wealthy historian that loved the museum. He dies and he hides his heritage in the museum to protect it from the greedy heirs. Children must use the PDAs to pick clues from the descriptions of the exhibits to share them among team members and collaboratively find the historian's favourite exhibit that has the proofs that will save the heritage. Through this process we believe that the kids are having a fun experience and unconsciously learn more than by following a typical tour. At the moment we have created a prototype to support these activities and we have plans to evaluate it with real classrooms inside the museum (Figure 4).

<u>Dealing with Actions Related to *Physical Space*</u>

After defining the possibilities that our system will offer and formulating the design decisions related to the imposed *virtual space,* we focused on technological aspects.

Selection of the Interaction Model

In an initial step, trying to achieve the maximum level of transparency in our system, having in mind the actions related to *physical space*, we revealed metaphors that can describe the interaction mediated by a mobile device between a visitor and an exhibit, with use of the different technologies in combination with PDAs. We came up with three metaphors:

- The *autopilot* metaphor. The visitor doesn't have to select an exhibit, but the system responds autonomously depending on her location.
- The *remote* control metaphor. The visitor uses the PDA in a way similar to the use of a television remote control.
- The *scanner* metaphor. The visitor uses the PDA as a scanner device. She selects an exhibit by scanning the label that each exhibit or a set of exhibits has.

We point out that although the last two metaphors seem to have no differences, because the visitor has to select on her own an exhibit, with a second look it becomes evident that the affordances are different. In the remote control metaphor, she can select the exhibit from distance, while in the scanner metaphor she must select the exhibit by almost having contact. In the next subsections we will present various technologies that we studied, which can be described by these three metaphors. Some of these technologies were tested in laboratory settings and others were rejected, for various reasons, early in the design phase. We have used PDAs and a WiFi infrastructure to deliver content in all tested cases.

The autopilot metaphor - By the term *autopilot* metaphor we are referring to systems that autonomously respond to the user, changing the content and in some cases the interface, based on the user's location. The location of the user triggers automatically information delivery on the mobile device. In order to have a successful implementation of this interaction model we have first of all to ensure that the position of the visitor is sensed with enough accuracy. Because of the stiffly placed exhibits in the museum, we needed an accuracy level of at least 30 cm in order to have acceptable results. WiFi based positioning systems were one of the options but they have been rejected due to the accuracy levels of 1-3 meters - not adequate for our interaction model. Other technologies that were taken into account were Ultra Wide Band (UWB) technology and the Cricket Indoor Location System from MIT, (Nissanka 2005) that uses a combination of RF and ultrasound technology. These two technologies provide satisfactory accuracy of 15cm respectively 10cm but they require high costs for setup and wall/ceiling mounted cells. Additionally the tracked persons need to carry a tag or device. Other indoor location systems, (Hightower and Borriello 2001), where rejected after a minimal research on their capabilities and limitations. While the WiFi positioning was rejected due to its accuracy, the UWB solution was disqualified due to its disproportionately high costs. The need for excessive modification to the museum's appearance in order to install the Cricket system was not an acceptable option. Other than that, in terms of user interaction the Cricket system was the most satisfactory since position estimation is accompanied by orientation information.

The remote control metaphor - The *remote control* metaphor implies the use of a PDA similar to a common remote control and can be fully simulated with the use of infrared technology. Infrared beacons are needed for each exhibit or set of exhibits as well as an infrared reader, which in most cases is a built-in feature of a PDA. Infrared beacons, costing a few euros each, are a quite expensive solution for covering 2.000 exhibits. They also are quite large and require a power source to operate (cables, batteries or solar cells). The required power source poses the same problem as was the case with indoor location beacons regarding the aesthetics of the museum environment. Powering the beacons with batteries was not an option either since they would have to be regularly checked and replaced, causing economic and environmental concerns. Our laboratory tests revealed also other issues like interferences, signal reflection or selection of an unwanted exhibit. While some of these issues can be solved by fine tuning the ranges and the angles of the beacons they have the trade-off in freedom of the user and subsequently breaching the remote control metaphor. Finally, we point out that the main advantages of this technology are: a) the user can quickly be accustomed with the system, and b) infrared support is widespread for most hand-held devices.

The scanner metaphor - In the scanner metaphor the PDA is used as a scanner of information. We concluded that the most suitable solution regarding the scanner metaphor is the use of RFID tags in combination with RFID readers on the PDAs. Bar codes can be viewed as a technology suitable for the scanner metaphor, but we considered RFID's properties as more desirable and thus bar codes were rejected. As was the case with the infrared beacons we used a prototype to evaluate the use of RFID tags in the laboratory, simulating the setting of the museum. The user must almost touch the RFID tag with the PDA. This can be very annoying because she has to do it every time she wants to select an exhibit. It is sometimes difficult to select an exhibit especially when it is placed very high or very low on the wall. Putting the RFID tag somewhere in the middle can be sometimes confusing and the user isn't 100% sure that she is selecting the correct exhibit. There were cases where we observed inability to read the tag for certain reader angle. In such a situation the system seems unreliable to the user. Finally, the main advantage is resilience imposed by the RFID technology. We can be certain that the system will present the correct information unless there are failures in other components.

Results Concerning the Interaction Model

After inspecting the available options and evaluating them, we concluded that the most suitable scenario is the scanner metaphor, using RFID technology. We state that concerning the actions related to *physical space* the RFID solution was not our top priority, because it requires from the visitor to come near every exhibit and scan the RFID tag. Issues like cost and reliability impelled us to adopt this solution. Concerning the interaction it can be described as a consistent model which is easy to understand by the user. The following table shows at a glance the results concerning each metaphor/technology combination we examined.

Metaphor	Technology	Cost	Comments
Autopilot	WiFi positioning (Ekahau 2006)	~1.500 € to track 7 devices	Low accuracy
	UWB positioning (Ubisense 2006)	~9.000 € per 60-100 m2	Excellent accuracy, high costs
	Ultrasound positioning (Cricket 2006)	~10.000 € per 100 m2	Excellent accuracy, high costs, immature
Remote control	Infrared beacons	~5 € per piece	Unreliable, powering issues interference
Scanner	RFID	~1 € per tag ~300 € per reader	Reliable, very acceptable costs, short distance

Table 1: Summarizing the results

Selecting an Ideal Mobile Device

The selection of a suitable PDA to assist the RFID technology evolved as an important issue that we couldn't imagine during the early stages of the design. We confronted a lot of problems because of the variety of characteristics that PDAs have. This variety refers to both hardware and software issues. We were obliged to select the most suitable hand-held device regarding three perspectives: the user's side, the developer's side and the 'device's' side. These perspectives comprise different views of the same issue and impose different and sometimes contradictory requirements.

The user's perspective - We studied the characteristics of the PDA that might affect the user interface and the user's interaction with the mobile application. The rationale of the system is that the user will be facing information presented in form of text, sound, image and video. As a result, a device with good screen and good sound capabilities is required. First we tested our prototype on devices with quarter VGA screen and we found out that it was rather difficult to distinguish sufficient level of detail in the videos presented. Additionally, the screens weren't big enough to display an adequate amount of text. Therefore we opted for PDAs with VGA screen. We have also tested in the museum (i.e. deployment environment) the screen readability (Hill 1997) through an experiment aiming to discover the most suitable background and foreground colours, font sizes and typefaces to be used. The use of sans serif, black letters on white background and selectable size was the most suitable solution.

Based on Exploratorium (2005) work, we decided that one way of simplifying the interaction is to provide the user with the minimum text possible. The default behaviour of the system will be the use of sound, and the text/image and video will be provided upon user selection. Having the sound as the main source of providing information we allow the user to make a complete navigation in the museum without looking at the screen (in order to select an exhibit by 'scanning' the RFID tag the user can press a physical button). In Woodruff et al. (2001) it is stated that users preferred the PDA's speakers to the headsets. The users liked to hear the other PDAs' narrations which sometimes contained something interesting and they were subsequently driven to search on their own. Therefore we initially decided not to use any headsets and to rely on the device's built-in speakers. To back up this hypothesis, we conducted a small experiment inside the museum where two or three PDAs were simultaneously playing various narrations with male and female voices. Because of the small rooms of the museum and the echo created, we found it impossible for even two PDAs to play concurrently in the same room. So we decided that users must be given the option of choosing between one-ear headsets (default option) and speakers.

At this point we must note that in most cases museum visits are conducted by groups of people who observe and discuss about the exhibits. According to our design, one such small group will usually get only one PDA. Consequently, in order to fully support small groups, we included two parameters in our design regarding the use of sound: a) users cannot have large headsets that cover both their ears because they are isolated from the other members of the group and b) each one of the members of a group must have a one-ear headset. This way it can be ensured that all members will share the same *virtual space* and can freely discuss among themselves about the exhibits.

The developer's perspective - The challenges developers faced were rather focused on grave compatibility issues. One example is that the use of RFID scanners with SDIO interface resulted in unexpected compatibility problems. The operating system SDIO support varied extensively even for slightly different firmware versions making impossible to determine if an RFID reader would be compatible with a specific device by just observing the device's specifications. We encountered such problems almost every time we tried to test different technologies. Another issue was the choice of the programming environment. We finally chose Microsoft .NET framework as the best environment, capable to ensure a good operation of our applications in future releases.

The ‘device’s’ perspective - With the term ‘device’s perspective’ we refer mainly to the industrial design of the device. This factor can play a significant role in selecting a mobile device and is much more important than in the case of a desktop system. Manufacturers compete in adding features (generally more cool and marketable than useful) and pay less attention to the usefulness of the arrangement of the interfaces (Figure 5). This way there are devices that simply holding them will block the infrared port or adding an extension card will impair the ability to use earphones. We feel that PDA developing companies must provide designers with the ability that desktop systems have, which is the ability to define the needed characteristics of a device, with the extent to place them in specific positions.

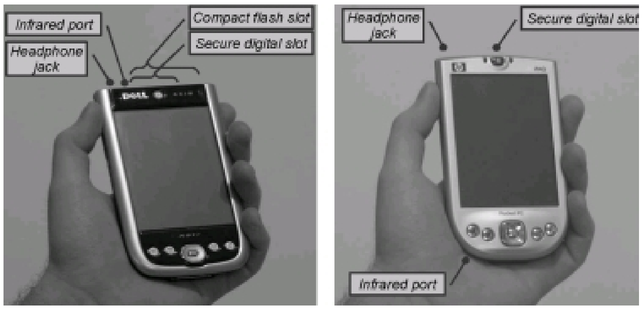


Figure 5: Two PDAs with interfaces in different positions

CONCLUSIONS AND FUTURE WORK

In this paper we presented real situations that anyone can confront during the design phase of such a system. In the initial phase of design, we tried to see what exactly is a museum visit from the visitor’s point of view (goals and tasks). We discovered that there are three inter-correlated dimensions of the space and that technology imposes actions which can be categorized as related to *physical* and *virtual space*. We followed a spiral design model which gave us a set of requirements like ensuring the transparency of the system, selecting a non-intrusive technology, choosing a suitable mobile device in terms of software, creating appropriate educational activities, and, of course, respecting the needs and the goals of visitors. We still have open issues regarding the legal aspects concerning content manipulation and user data (SWAMI 2006) that we plan to deal with at the final stages of development collaborating with the museum's administration.

We are planning to improve, as a first priority, the capabilities of mobile devices in relation to context. We want mobile systems that can sense various dimensions of context and adapt to it, according to user’s needs (Dey 2001, Dourish 2004). Main issue in this area is to set up a theoretical framework that can describe accurately the connections-relations among a device, a user and *virtual/physical space*. Another direction is to flexibly allow a variety of devices (e.g. smart-phones, etc) dynamically set up during the visit. Issues like compatibility, presentation of information, structure of information and software migration are important. Last but not least is an extensive evaluation of the learning value of the designed educational activities.

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