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X Ciclo

DESIGNING USABLE MOBILE INTERFACES FOR SPATIAL DATA

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- *Luca Paolino non avesse speso tanto tempo a:*
  - *a) trasmettermi la sua esperienza*
  - *b) dare consigli accademici e di vita*
  - *c) dire "te vuo' movere"*
- *Vincenzo Del Fatto e Davide De Chiara non avessero condiviso:*
  - *a) idee*
  - *b) conoscenza*
  - *c) caffè*
- *Pasquale Di Giovanni non fosse stato*
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  - *b) compagno di confronti accademici*
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Chapter 1 - Designing Usable Mobile Interfaces for Spatial Data

1 - Area of interest

This dissertation deals mainly with the discipline of Human-Computer Interaction (HCI), with particular attention on the role that it plays in the domain of modern mobile devices.

HCI concerns with the design and the evaluation of interactive systems. The keyword is “interface”, that is a means of interaction between human and computer. Both human and computer sides of this interaction are object of the study of this discipline. This is why this research field is considered as a multidisciplinary field. Indeed it involves computer science as traditionally conceived, for the design and development of interfaces and applications; psychology, sociology and anthropology for the study of users' behaviors and their interactions with the technology and the real world.

Several disciplines of computer science and human science are involved in the study of the communication between men and machines. On the computer side they range from computer graphics to operating systems and programming languages. On the human side, they range over social sciences and psychology.

The area of interest in the information technologies field (IT) which is nowadays growing more than any other is the Ubiquitous Computing (UC), which is a branch of the HCI. In the last years the main goal of ubiquitous computing has been to support users during their daily activities without being invasive [45]. In his early vision, Weiser, who coined the term, predicted that a great number of different devices would be available as a support for users [122].This is exactly the case of our present society, wherein laptops, netbooks, tablets and mobile phones are extensively widespread.

2 - Broader context

Mobile devices today offer a crucial support to a plethora of daily activities for nearly everyone. Ranging from checking business mails while traveling, to accessing social networks while in a mall, to carrying out business transactions while out of office, to using all kinds of online public services, mobile devices play the important role to connect people while physically apart. Modern mobile interfaces are therefore expected to improve the user's interaction experience with the surrounding environment and offer different adaptive views of the real world.

Designers should strive for usable mobile applications for two main reasons.

The first motivation is that mobile phones are spreading faster than any other information technology. Currently there are 800 million PCs vs approximately 4.5 billion mobile phones so that Weiser's visionary prediction on *ubiquitous computing* [122] has come true:

"... [the age] when technology recedes into the background of our lives"

Indeed, many people possess more than one mobile device (tablet, Pda, smart phone). Some people from Western countries own a mobile device but not a PC. A large number of people in developing countries own mobile devices only whilst they have never seen a PC, so that local governments encourage the diffusion of mobile devices as a means of bringing education to masses. Indeed Jain, in "Middle Of the Pyramid" [65], states that mobile phones can bridge the digital divide of the people in developing countries allowing them to reach part of the remaining world population. So the usability of the mobile interfaces is paramount in order to allow people of any cultural level to be involved in this process.

The second motivation is the advanced technological configuration of such devices. Single devices encompass different hardware and software technologies such as camera, GPS receiver, movement sensors, 3D graphics, permanent internet connection, Java, Adobe Flash, etc... Their integration of these technologies allows to design advanced mobile applications such as Geo-Social networks, augmented reality, life tracking, bank trading and office automation. So that new applications bring forward new challenges, in particular to usability engineers.

In the book "Designing software for the mobile context" [37], the authors describe the design of usable mobile applications as a real challenging task. Indeed, designers have the difficult problem of dealing with a continuously changing technology that always offers new sets of challenges. As a matter of fact, in the last quarter of century user interfaces have evolved from very simple text interfaces to graphical user interfaces (GUI) both for desktop oriented applications and for the vast world of the Web.

Nowadays mobile interfaces present new challenges and opportunities in the field of the Human-Computer interaction (HCI). Many issues are directly linked to the hardware.

First of all, the limited screen size, which causes a lack of room for displaying data is a constraint related to mobile interfaces. To overcome this problem, the Apple HCI lab has proposed a set of generic guidelines to develop user mobile interfaces [7]. These guidelines suggest to simplify the mobile user interfaces, compared to the traditional desktop user interfaces. For example, users should interact with one application at a time, on screen user help should be minimal and the application should have just a single window.

New interaction design challenges are also brought about by the diffusion on mobile devices of the touch-screen technologies. These technologies can detect the presence and location of a touch on the screen and allow users to directly interact with on-screen objects and controls by performing gestures. Thanks to the gestures, elements on the screen are perceived by users as physical objects which can be handled in realistic ways. For this reason, designers who develop gesture based interfaces should always try to use natural or discoverable behaviors closely related to the gestures.

Touch-screen technologies also introduce issues related to other fields, among which the issues related to visually impaired users are particularly important. Although visually impaired people constitute a large part of the users, they are seldom considered during the design of mobile interfaces. Touch-screens may be a hardware limit for this class of users, because of the lack of tactile controls, but they may also be an opportunity, thanks to the introduction of gesture-based interfaces coupled to multimodal feedback.

Another issue is related to the text entry areas. A text input device can turn the information provided by users into data that can be understood by the system. Today hardware text input devices are being replaced by alternative methods based on software interfaces.

The goal of this thesis is to enhance the usability of mobile interfaces for spatial data. Spatial data are particular data in which the spatial component plays an important role in clarifying the meaning of the data themselves. Nowadays, this kind of data is totally widespread in mobile applications. Spatial data are present in games, map applications, mobile community applications and office automations. In order to enhance the usability of spatial data interfaces, my research investigates on three main points:

1. enhancing the visualization of spatial data on small screens
2. making the interface accessible to visually impaired users
3. enhancing the text-input methods

There are several suggestions and guidelines about how the design of GUI features for mobile devices should be carried out. A different issue is how spatial data should be displayed to the user. No matter you think of a WEB page of a on-line newspaper or any document with a great amount of text and images, users should navigate the document following several directions in order to read the text and visualize all the images. Many user mobile interfaces offer an automatic or on users demand readjustment of the document. Images are made smaller and the text is squeezed in order to fit the screen space. In such a way users have to navigate the document essentially from the top to the bottom. However, this strategy does not work with spatial data. It does not work, for example, in the case of a spreadsheet. By readjusting rows and columns the document would lose its peculiar structure. The same happens with geographic data. If displayed in smaller size, these data will be analyzed by the user with difficulty, whilst if displayed with a reasonable map scale, they would lose part of their geographical context.

Devices equipped with touch-screen technology usually have totally flat screens, that is, they have no (tactile) reference points. Although this design choice is aimed to make the device very perceptible, it cuts visually impaired users off the mobile devices market. For this reason, multimodal interfaces can help visually impaired users to interact with devices by using gestures and through audio and tactile feedbacks. On the other hand Rana et al.[94] state that mobile devices are primary instruments capable of enhancing visually impaired users' mobility. So that the current challenge is to reach the goal of universal design to support physical and cognitive disabilities.

Relating to the text-entry keyboard, as described in [37], text input is annoying at best.

Entering data on mobile devices is boring and requires a certain period of training. Virtual Keyboards (VK, for short), Handwriting Recognition and Voice to Text represent the most popular and effective solutions [125].

3 – Research question and Research approach

By the broader context the *usability issue* emerges as the main issue relating the world of mobile devices. Therefore starting from the issues described previously my research question is:

"***How to enhance the usability of mobile users interfaces for spatial data***"

I have to split it into two parts, considering user interface as a means to give and receive information. So the research question will be satisfied by giving a solution to the two following issues:

1. *How to display spatial data on small-sized screens?*
2. *How to enhance text input methods?*

This thesis mainly focuses on the first issue, but I will also tackle the second one, mentioning some recent investigation I have carried out and the promising results gained so far.

I selected the **Design Science Research approach to investigate the above research questions**. The idea underling this approach is "*you build artifact to learn from it*", in other words researchers clarify what is new in their design.

Simon [104] conceptualizes the Design Science. He states that it allows researchers to deal with real-world problems by a pragmatic research paradigm that involves the development of innovative Information Technology artifacts. In [56], the authors highlight the importance of this scientific approach in the field of IT. Indeed, it leads towards two main IT issues: the central role of the artifact in the research [121][85][15] and the need of professional relevance of research Information Systems [13][58].

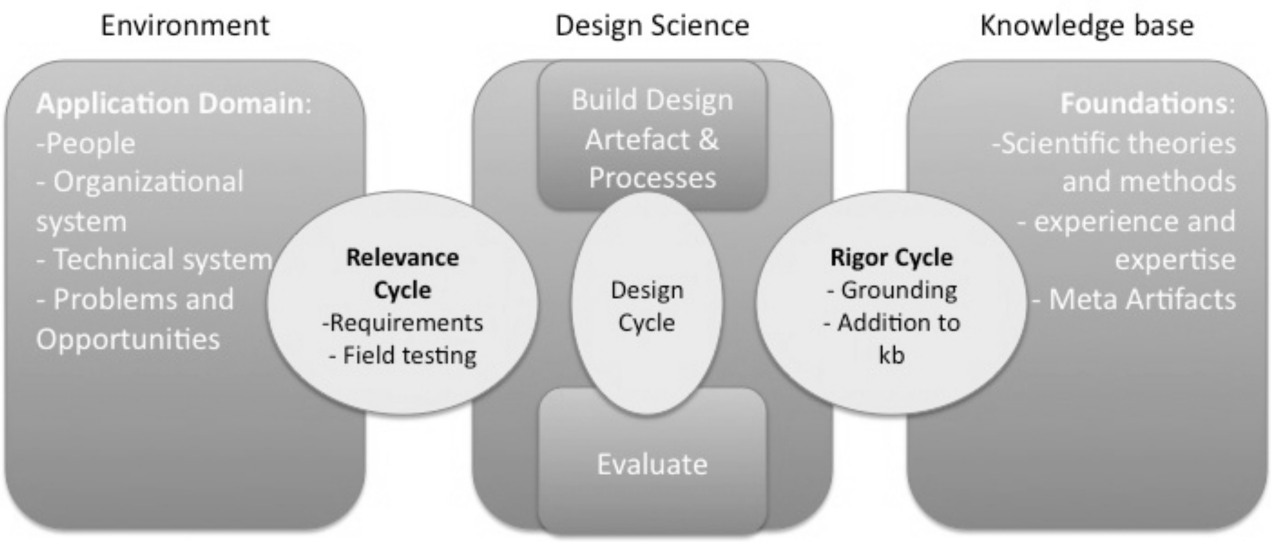


Figure 1 – Design Science Research Cycles

In [55], the authors identify in any design research project three design science cycles, namely: the *Relevance Cycle*, the *Rigor Cycle* and the *Design Cycle* as shown in figure 1. The presence of this three cycles in a research project distinguishes the design science from other research sciences.

The *Relevance Cycle* puts requirements from the related environment into the research project and immerses the artifact into the field testing.

The *Rigor Cycle* provides grounding theories and methods along with domain experience and expertise from the foundational knowledge base into the research and adds the new knowledge generated by research to growing knowledge base.
The *Design Cycle* provides the research activity with the building and evaluation of artifact and with design processes.

In [81] the authors describe the design research via a conceptual framework made of guidelines or principles useful to conduct and evaluate a good design science research (see table 1).

Guideline	**Description**
Guideline 1: Design as an Artifact	Design science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation
Guideline 2: Problem relevance	The objective of design science research is to develop technology-based solutions to important and relevant business problems
Guideline 3: Design evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods
Guideline 4: Research contributions	Effective design science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies
Guideline 5: Research rigor	Design science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact
Guideline 6: Design as a search process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment
Guideline 7: Communication of	Design science research must be presented effectively to both

research	technology-oriented and management-oriented audiences

Table 1 – guidelines for the design science research approach

In “Design Science Research in Information Systems”, the authors present a checklist derived from the previous guidelines. The checklist is useful to be sure that projects follow the design science research approach (table 2). Figure 2 shows how the eight questions are mapped into the three design science cycles. This demonstrates the relationship between the checklist and the research cycles.

In the last chapter of this dissertation I shall show how my investigation has answered to the questions of the Design Science Research highlighting the parts of the thesis in which every single question has been answered.

Questions
1. What is the research question (design requirements)? 2. What is the artifact? How is the artifact represented? 3. What design processes (search heuristics) will be used to build the artifact? 4. How are the artifact and the design processes grounded by the knowledge base? What, if any, theories support the artifact design and the design process? 5. What evaluations are performed during the internal design cycles? What design improvements are identified during each design cycle? 6. How is the artifact introduced into the application environment and how is it field tested? What metrics are used to demonstrate artifact utility and improvement over previous artifacts? 7. What new knowledge is added to the knowledge base and in what form (e.g., peer-reviewed literature, meta-artifacts, new theory, new method)? 8. Has the research question been satisfactorily addressed?

Table 2 - checklist for the design science research approach

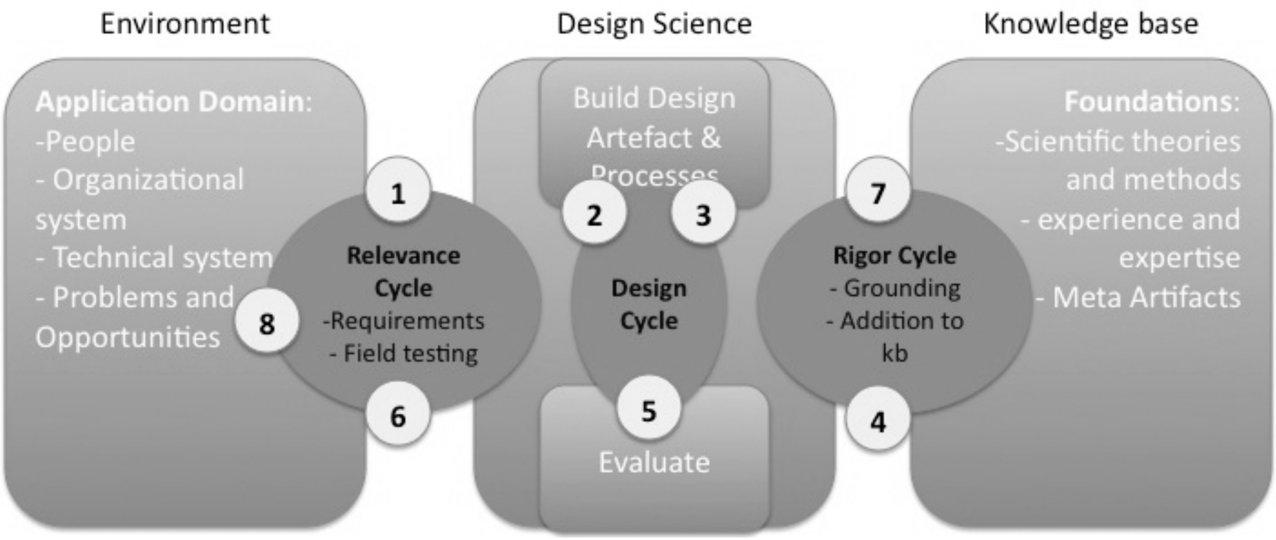


Figure 2 Questions mapped to three design research cycles

4 - OUTLINE

The remaining part of the thesis is organized as follows. In Chapter 2 I present the visualization technique called Framy. The technique is designed to support users in visualizing geographical data on mobile map applications. The chapter also presents the process that led me to design the technique and the first prototype. The usability tests on the prototype will be described and analyzed.

In Chapter 3 I extend the Framy visual interface by adding sounds and vibrations in order to obtain a complete multimodal interface. After that I present the process that turned the multimodal interface into a means to allow visually impaired users to interact with Framy.

Chapter 4 shows some projects in which the visualization principles of Framy are involved. The first project exploits the traditional Framy visual interface to provide decision makers with a powerful visual analytics instrument. Moreover in this project the Framy technique is also used to represent temporal information. In the second and in third projects a modified version of Framy is applied to support users during the exploration activities by means of the augmented reality. The last project is a collaborative spreadsheet-based system that exploits the Framy technique to support mobile users to work with a complex interface.

Chapter 5 introduces focus on the work done in the area of virtual text input, namely the second issue introduced by the research question". A new kind of virtual keyboard called TaS provides users with an input system more efficient and effective than the traditional QWERTY keyboard. A comparative study is presented and the results analyzed. Although the Framy technique has been modified to fit each different problem, the principles underlining the original multimodal technique have been maintained.

The last chapter discusses the obtained results and presents an interaction design pattern carried out from the proven principles of Framy. It is based on an existing pattern called Infinitive Area Pattern. This pattern is studied to support developers in dealing with issues of visualization of information that is actually infinite such as exactly points of interest and maps. Moreover, a set of guidelines are given by generalizing the principles underling the TaS keyboard. The guidelines support designers in developing virtual gestures based keyboards.

Finally the chapter summarizes the work done so far and explains how the eight questions of the Design Science approach have been answered during the present work. Considerations on the possible future research directions conclude the thesis.

Chapter 2 - Visual Interface for GIS Applications

1- Introduction

The present deals with the issue of spatial data visualization on limited sized screens. Spatial data are characterized by a spatial structure that cannot be modified without compromising their meaning. Therefore when these data are very large and virtually infinite, their representation on small screens will become very challenging. Often they are represented as a single image but the image is so large for the screen that just a portion per time can be visualized and users must perform several actions, such as zooming and panning, in order to explore the whole image.

I especially focus on the field of map based applications and on the deployment of geographical information systems (GIS) through mobile devices. Indeed geographic data such as maps are composed of a structure made of geo-referenced geometric elements such as POI (points), streets (arcs) and plans of building (polygons), which would lose their geographic meaning if their structure is modified.

Today map based mobile applications are widespread and many business activities use them to get the best visibility. Advantages deriving from maps are countless, they provide people with the ability to show and analyze the world as they perceive it, namely by verifying topological, directional and metrical relationships. People use maps in a number of tasks, including finding the nearest relevant location, such as a gas station, or for hand-optimizing a route. To have a complete and exhaustive evaluation of a region it should be possible for users to:

1) have a global or wide enough view of the map portion they are taking into account and

2) have a vision of the map where details can be well distinguished . If above two features are not supported then comparisons as well as evaluations of spatial relationships may become very difficult because users may be presented with insufficient or excessive amount of information on the screen.

This is especially the case for maps visualized on mobile devices, where viewing a wide portion of the map conflicts with showing features in a well defined and separate fashion, due to the small dimensions of screens.

As an example, if we perform a search for the closest hotel from our current location, the result may fall either inside or outside the screen. In the first case, we do not have problems to reach the hotel because we can distinguish it on the map. Vice versa, in the second case, we do not know which direction we have to follow to arrive at the target and we have to gropingly advance.

Visualizing the entire map is not the right solution. This can result in objects from a query task appearing improperly overlapped. As an example, if we are visualizing a layer showing the locations of farmhouses located in a given region and we want to see all of them together, we might want to represent the entire region on the screen, hence using a reduce scale for the map. In that case, there is a high probability that, below a certain proximity threshold, farmhouses will be overlapped and will then be hard to distinguish.

In the literature, several techniques have been proposed to display large information spaces on desktop screens. An interesting paper by Chittaro classifies the different approaches adopted to visualize maps and images on small screens [29]. The author argues that the techniques traditionally adopted to combine panning and zooming with either compression (the so-called *overview-detail* approach) or distortion operations (known as *focus-detail* approach) may still present severe limitations when applied to mobile devices, due to the very small screen dimensions. A promising approach, specifically conceived for visualizing distance and direction of off-screen locations, consists in providing visual references to off-screen areas, by augmenting the detail view with interactive visual references to the context. Such an approach has been successfully adopted in systems like Halo to enable users to complete map-based route planning tasks [12].

My work started by an innovative technique called Framy [79, 80]. It has been designed to visualize geographic data on mobile devices. The technique exploits a visual metaphor based on nested frames in order to give information clues about POIs located outside the screen. During my investigation I improved the technique and I have developed some mobile applications based on it in order to experiment Framy in different research environments.

The chapter is organized as follows. In section 2 I present the common approaches followed to visualize geographical data on mobile devices, in section 3 I show the process that led me to developing my technique, namely Framy and the idea underlying it. In the same section I illustrate three typical scenarios where my technique can be employed, which show the effectiveness of *Framy*. Subsequently (section 4) I present the results of a usability evaluation studyFinally, in section 5, a summary is given.

2 - Related Work

There are several works in the scientific literature that show how researchers in the last years tried to tackle the problem of visualization of geographical data on small screens.

One of the simplest ways to analyze the information depicted in maps shown on mobile devices is the traditional *Pan & Zoom* method.

Maps may be seen at different levels of detail by applying the *Zoom* operation while the visualized region of interest may be changed applying the *Pan* operation. Typical styles of interaction concerning with the former are the selection of the detail level by means of specific buttons (one for each level), by sliders, by menus or by managing the wheel of the mouse. The *Pan* operation is usually implemented by dragging the mouse over the map or by scrolling panels.

An approach combining Pan and Zoom together was presented in [68]. At the start of an action, two concentric circles are placed so that the location of the action on the display is at their centre. As the user drags the pointing device, a direction line is drawn between the starting position and its current location, indicating the direction of work. If the pointer remains within the smaller circle, no scaling of the information space occurs, only scrolling. As the pointer moves further away from the starting position, the scroll rate increases.

When the pointer moves beyond the inner circle, both scaling and scrolling operations take place.

Several papers have been also presented concerning with the technique named “Jump & Refine” [52][96][97]. This technique segments the map into several sub- segments, each of which is mapped to a key on the number keypad of the smartphone. By pressing one of the buttons, the region represented by that button is automatically put in evidence on the screen. At this point the user may either pan the visualized region in order to reach the required zone or recursively apply the segmentation for augmenting the detail level.

Another interesting approach has been presented in [12]. The software implementing this methodology focuses the attention on discovering points of interest located outside the visualized region. As a matter of fact, each point of interest is the center of a circle whose ray raises or decreases as we get close or far from that point. In such a way, we may verify anytime the proximity of the point. A variation of this approach is CityLights [76]. Here, compact graphical representations such as points, lines or arcs which are placed along the borders of a window to provide awareness about off- screen objects located in their direction (fig. 4).

Other interesting techniques for visualizing large amounts of data l spread over map not fitting the available screen size, may broadly be divided into two main categories, Overview&Detail and Focus&Context [69].

In order to have the awareness of a particular region and of its surrounding context, Overview&Detail techniques present simultaneously two maps where one refers to a limited/detailed region and cover the entire screen while the second one is the whole scaled map located just in a corner. Optionally, the detailed region is also highlighted by a rectangle on the whole map. Panning the first map changes the rectangle position on the second one. Even though today this approach is largely used, it was first described in [26]. The *perspective overview-display* is another example of a Overview&Detail technique. Here, two completely distinct areas are used to display the overview (top) and detail (bottom) of an image. To save valuable screen space while displaying the overview, the image is prospectively warped.

The Focus&Context technique is based on the reasonable assumption that the attention of users is focused on the center of the screen. FishEye View [95] is an example of this technique. Here, the center of the map is clearly displayed in the center of the screen while distortion augments starting with less distortion near the focus to strong distortion near the borders of the available display size. Based on the FishEye approach, three possible implementations of the distortion function are provided in [69], uniform context scaling, belt-based context scaling, non-uniform context scaling.

Finally, an approach merging together Overview&Detail and Focus&Context is presented in [69]. Two different images are used. These images are created by a transformation function. To display the context, the whole image in the logical coordinate system is scaled to the available display size. The focus is created as during panning, but using an equal or smaller size than the available display size. Afterwards the images are combined by the transformation function by applying a fixed or time-variant α-blending.

3 - Design of a new interface

In this section I describe my solution Framy that is a visual technique useful to handle with large amounts of geographical data.

Mainly my goal was to develop a mobile user interface usable and useful. In order to achieve this aim, I followed a user-centered design approach: I studied potential users and included them in the initial conceptual design activities. During the first step of the develop process I looked into two main factors: the last mobile technologies and advanced user interfaces dealing with similar issues. In particular, I focused on two approaches, namely Halo Halo [12] and CityLights [76]. The former methodology allows users to discover POIs located outside the visualized region. Each POI is the centre of a circle whose ray increases or decreases as the user gets closer or farther. A variation of this approach is CityLights. Here, compact graphical representations such as points, lines or arcs are placed along the borders of a window to provide awareness about off-screen objects located in their direction.

Tables 1 amd 2 summarize the strengths and the wiknesses of the two solutions, as they influenced some basic design choices with Framy :

Halo	
Strength	**Weakness**
Users may verify anytime the direction and the proximity of the off-screen POIs through the dimensions of the circle sector depicted inside the screen.	The technique is not very precise. The precision depends on the POI position: a POI located on the corner direction of the screen produces a circle whose sector could not be fully represented on the screen. Many POIs produce several circles. The representation of many circles can cause a visual crash so that users cannot well distinguish different sectors of circles and cannot evaluate the distance and the direction.

Table 1 - strengths and weaknesses of Halo technique

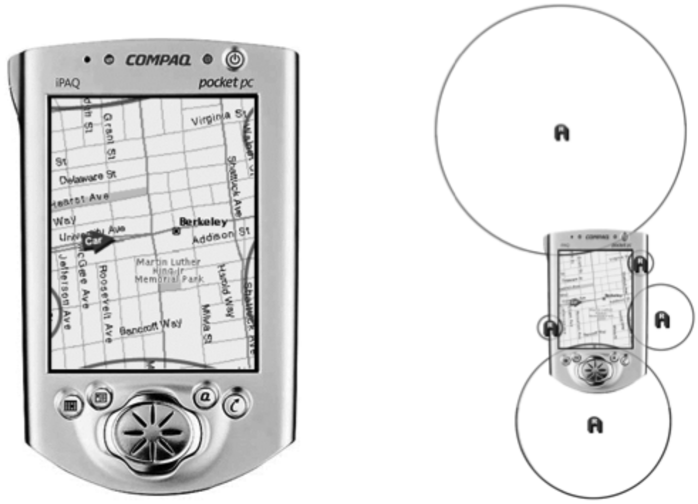


figure 3 – Halo interface

CityLights	
Strength	**Weakness**
The technique is developed to work in desktop environments but can be easily adapted to work on mobile devices.	CityLights cannot give qualitative or quantitative information about off-screen elements but just indicate their position. In other words it can tell users that something exists in a certain direction but users do not know how many objects can be found and how far they are positioned.

Table 2 - strengths and weaknesses of CityLights technique

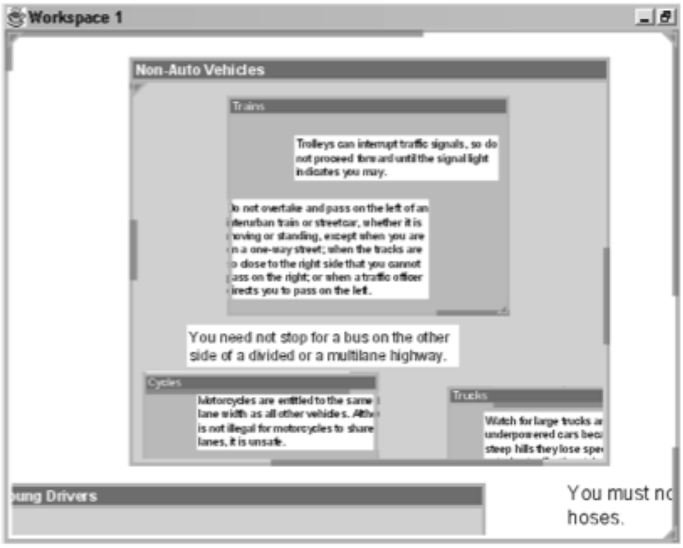


figure 4 – CityLights interface

3.1 - FRAMY - A NEW VISUALIZATION TECHNIQUE

Framy is a visualization technique, which aims to provide users an appropriate tradeoff between the zoom level needed to visualize the required features on a map and the amount of information which can be provided through a mobile application. Framy exploits an interaction metaphor for picture frames, to provide hints about off-screen objects, resulting from a given query. The idea is to visualize a frame along the border of the device screen. The frame is divided into several semi- transparent colored portions, corresponding to different sectors of the off-screen space. For a given query, the color intensity of each frame portion is proportional to the number of resulting objects located in the corresponding map sector. Thus, the frame may indicate both the distance and direction of specific Point Of Interests (POIs), as in Halo, but it may also represent the amount of POIs located towards a specific direction. In general, the frame portion color intensity represents a summary of data located besides the screen border. Moreover, the number of frame portions can be interactively increased so as to refine the query results, indicating, e.g., the exact direction where certain objects can be found. If the query involves several layers, nested frames are visualized along the borders, each one corresponding to a different layer, with a different color.

I developed a prototype of a mobile GIS application, called *MapGIS,* designed to perform typical GIS operations and queries. MapGIS combines typical mobile interaction controls with the proposed FRAMY visualization technique.

3.2 - THE ADOPTION OF FRAMY IN A MOBILE GIS APPLICATION

Framy has been initially experimented on the prototype of a mobile GIS application, called *MapGIS*, designed to perform typical GIS operations and queries, combining common mobile interaction controls with the proposed visualization technique. .

MapGIS is based on a typical GIS architecture realized for different mobile platforms. It actually runs on iOS firmware 4.2.1, Google Android 2.2, Nokia Maemo Linux 2.0. It allows users to gather information about localities on the considered map by querying the data pre-loaded and stored in a structured repository of the device. It manages the browsing of the map by using a specific pointer that is moved all round the screen through the directional keys on the device.

Two kinds of functionalities are currently available on *MapGIS,* namely:

4. basic spatial operations, and
5. advanced selection operations.

Panning and zooming are examples of basic operations. They allow users to easily explore maps everywhere and at different scales. So, in order to accomplish such tasks as easily as possible and guarantee a good level of usability, rapid controls have been provided through classic touch-screen gestures.

As for the advanced selection operations, they can be used to process both geographic and descriptive data in order to answer specific user's requests about the real world data. As an example, in *MapGIS* a search functionality is provided on descriptive data by pointing out specific localities of the map. This functionality represents the operation generally called "Spatial Selection". It allows users to reference every point located on the map by means of the browsing pointer and returns the descriptive data which are strictly connected to the pointed locality.

Besides the usual route planning functionalities, which also rely on some optimization algorithms, *MapGIS* provides an advanced search functionality, which allows to localize points of interest of specific categories (theaters, parks, museums, cinemas, etc) by specifying some descriptive information set up by users.

Once the user performs the spatial requests, results are visualized on the map by applying the *Framy* visualization method which helps users to discover results located off-screen.

The user may choose to divide the map into any number n. Starting from the center of the screen a fictitious circle is drawn and the map is divided into n sectors of equal width (360°/n). Figure 5 gives an idea of this subdivision using n = 8, that is I divide the screen into 8 sectors. I use the notation *Ui* to represent the parts within a sector which lie outside the screen, whereas *Vi* represents the inside screen parts.

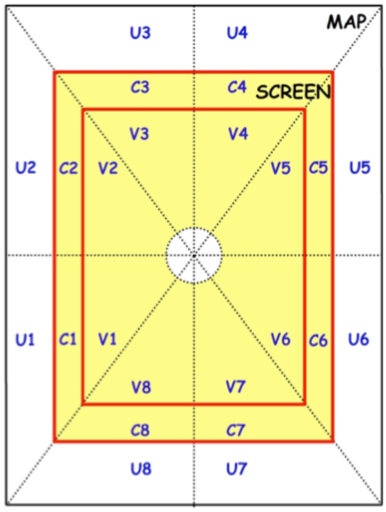


Figure 5 - The (off-) screen subdivision by *Framy*

The idea underlying this approach is to inscribe a semi-transparent area (Cornice) inside the screen. This area is partitioned in *C1, ..., Cn* portions, each identified by the intersection between the *Cornice* and the *Vi* parts.

Once the user poses a query, the color intensity of each C_i, which corresponds to its saturation index in the *HSB* model, is modified on the basis of a value which either aggregates a property of objects in U_i, such as sum and count, or calculates the distance between the map focus and a POI in U_i. Namely, the color intensity may be expressed as

intensity(Ci) = f(g((Ui)) for each $i \in \{1, \ldots, n\}$ (1)

where *f* is a monotonic function and *g* is a function which calculates a numeric value starting from a set of spatial data.

Starting from the *HSB* model, I have specified how its components may be calculated in order to determine the color value of each C_i, namely the HSV value associated with each portion. In particular, I set the Value parameter to 100, thus implying that the highest color brightness is always associated with C_i. The Hue component corresponds to the color assigned to the whole frame.

As for the saturation index, which corresponds to the color intensity, it is determined on the basis of the type of the function *g* in (1), namely an aggregate or a distance function. In particular, if an aggregate function is requested, I consider the distribution of the n_i objects within the U_i sector. The incremental value (step) that each object provides in terms of intensity is calculated by considering the maximum number of objects that each U_i contains. This value is associated with the most intense available color, namely S = 100, whereas the absence of elements will correspond to S = 0. Then, the step will be: Step = 100/MAX.

As an example, let us consider the following SQL query, where *g* corresponds to the *count* operation applied to the features of the Parking-Area layer with vacancy above 9, namely:

```
SELECT count(geometry)
```

```
FROM Parking_Area
WHERE vacancy >= 10;
```

Then, the higher the number of selected features within U_i, the more intensely C_i is colored (i.e. *f* is a monotonic increasing function). This is to say, the color for each C_i corresponds to:

$Color(Ci) = (H_{Layer}, Si, B)$, where:

H_{Layer} is the hue assigned for the given layer,

Si =Step * n_i

B = 100.

Analogously, if *g* computes the shortest distance from the current position, then the C_i with the highest color intensity indicates the U_i containing the closest feature (i.e. *f* is a monotonic decreasing function). In this case the distance of the closest feature is calculated as follows:

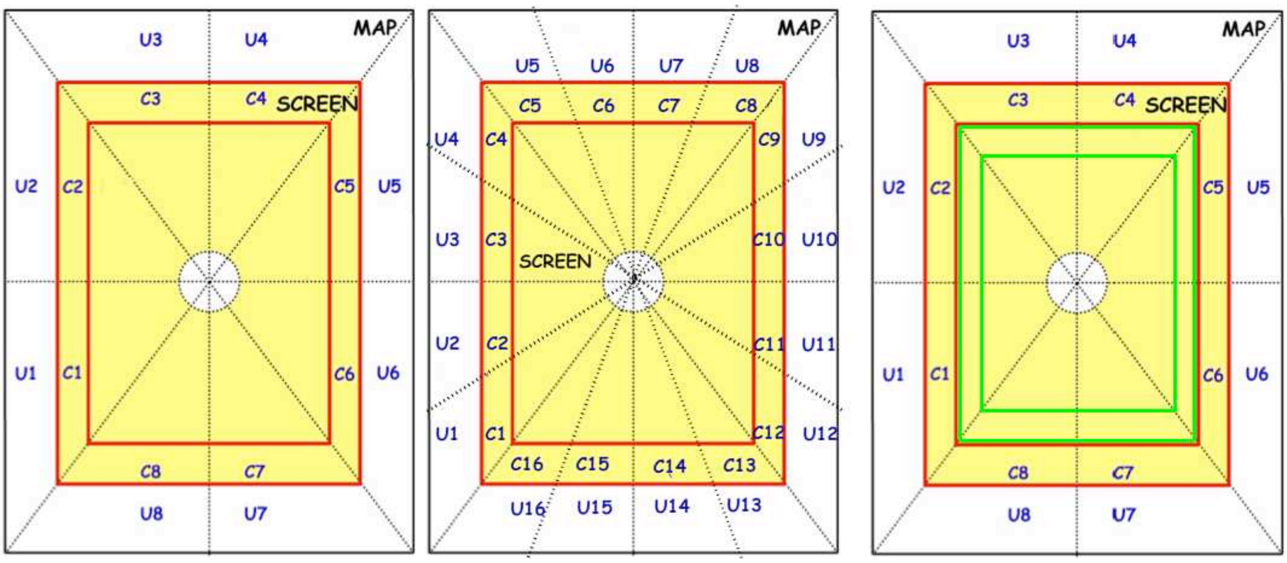
$Si = 100/(MAX – MIN)*(g(U_i) – MIN)$,

where MAX is set to the distance from the closest feature, and MIN is associated to the distance from the farthermost.

In order to make information clues coming from the frame portions more effective, I have enhanced the Framy visualization technique with color rules derived from Itten's theory of contrasts. In particular, the rules I have adopted concern two aspects of the mobile application interface, namely:

- the color combination of the frame and the corresponding features;
- the color combination of possibly nested frames.

With respect to other kind of approaches, *Framy* is not only addressed to visualize a results of a specific function (i.e. the proximity of features), but may be customized according to chosen aggregate function. As a matter of fact, the user may even choose the layer onto which it applies and the granularity level of the subdivision, that is how many parts compose the cornice.



(a) (b) (c)

Figure 6 - (a) a Framy subdivision using 8 parts, (b) one using 16 parts, and (c) a concentric subdivision

For this reason, as an example, the user may apply the shortest distance function on both the Hotel layer and the Parking area layer in order to locate the *Ci* with the closest hotel and the *Cj* with the closest parking area, respectively. Moreover, in order to identify the direction to reach a particular target, the user may increase the number of subdivisions so that the *Ci* identifying the correct direction is as smaller and more precise as possible (see Fig. 6 (a) and 2 (b)).

Another important characteristic of *Framy* is the possibility to create more cornices and visually compare them. As a matter of fact, as shown in Figure 6(c) cornices may be nested in order to compare color intensity inside a sector. This is to say, the user may visualize the closest hotels on a cornice and the closest parking areas on a nested cornice in order to discover which hotel/parking pair is best located with respect to the current position. This may support user to choose the best place to reside by taking into account the hotel proximity and the number of points of interest in a map.

Another way to use *Framy* is by checking the color variation as the center of the map changes. As an instance, if the cornice is used to locate the closest hotel for each *Ci,* We can verify whether we are approaching to a particular hotel by controlling the intensity of the color in the chosen direction. This is to say, the hotel is approaching by a panning operation when the color gets more intense.

3.3 – The color theory

I recall some basic concepts taken from Itten's theory of colors, which concern the effects created by color contrasts (Itten 1996). The theory of colors is part of the knowledge base of my research and supports the artifact design and the design process.

In order to explain such concepts, I primarily recall the underlying Hue- Brightness-Saturation (HBS) model (see Figure 7a). The model defines a color space in terms of three constituent components:

3. *Hue,* the color type (such as red, blue, or yellow). It ranges from 0 to 360 in most applications. Each value corresponds to one color. As an example: 0 is red, 45 is a shade of orange and 55 is a shade of yellow (see Fig. 7 for the complete color scale).

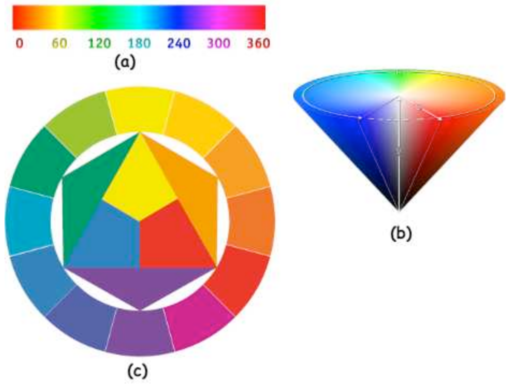


Figure 7 - (a). The hue scale. (b). The conical representation of the HSB model is well-suited to visualizing the entire HSB color space in a single object. ©. Itten's color wheel

- *Saturation,* the intensity of the color. It ranges from 0 to 100%. 0 means no color, that is a shade of grey between black and white. 100 means intense color. Sometimes it is called the "purity" by analogy to the colorimetric quantities excitation purity and colorimetric purity
- B*rightness* of the color. It ranges from 0 to 100%. 0 is always black. Depending on the saturation, 100 may be white or a more or less saturated color.

Hue, brightness and saturation - the three perceptual attributes of color - can be envisioned as a solid as shown in Fig. 7b. Hue varies around the solid; brightness varies from top to bottom and saturation is the distance from the centre.

The basic point of Itten’s theory is the study of the effects created by color contrasts. In order to describe his results, Itten uses a spherical color order system with a chromatic circle of twelve hues, namely color types – three primary hues, namely red, yellow and blue, three secondary hues, namely orange, violet and green and three tertiary hues, as shown in Fig. 7c.

Through his research, Itten devises seven methodologies for coordinating colors utilizing the color contrasting properties. The first and most common contrasting technique is referred to hues: when a high *contrast of hues* is required, then the selection of a minimum of three very different hues, may be accomplished. The contrast is formed by the juxtaposition of such different hues. The greater the distance between hues on a color wheel, the greater the contrast.

Hue contrasts may be accompanied by other variations with respect to the intensity and/or brightness of the chosen hues. Thus, other typologies of contrasts are specified as follows:

- The *contrast of saturation* (intensity): the contrast is formed by the juxtaposition of light and dark values and their relative saturation.
- The *contrast of light and dark:* the contrast is formed by the juxtaposition of light and dark values, best exemplified by *white and black.* This could be a monochromatic

composition.

- The *contrast of extension:* also known as the Contrast of Proportion. The contrast is formed by assigning proportional field sizes in relation to the visual weight of a color.

– The *contrast of complements:* the contrast is formed by the juxtaposition of color wheel or perceptual opposites.

– *Simultaneous contrast:* the contrast is formed when the boundaries between colors perceptually vibrate. Some interesting illusions are accomplished with this contrast.

– The *contrast of warm and cool:* the contrast is formed by the juxtaposition of hues considered ‘warm’ or ‘cool’, a purely psychological association mostly used for color compositions.

Besides these typologies of contrasts, some other parameters may affect the way human eyes perceive the real world. *Proportion* & *intensity* may be used depending on the proportions of allocated areas in order to emphasize some specific objects within a set, or to properly balance the foreground with respect to the background. Analogously, *Contrast & Dominance* may be used to determine the final impact of the whole presentations. By varying the contrast of the dominant elements the impact may be enhanced or minimized. Finally, using a color wheel divided into various shades and tints allows designers to identify possible options for color schemes. In particular, by varying the saturation and experimenting with shades and tints within the hue relationship, a variety of palette options may be achieved, which satisfy a wider range of requirements and combinations.

3.4 Typical Spatial Query Scenarios

In this section three scenarios will be shown in order to exemplify three different ways to adopt *Framy* as a visualization technique in *MapGIS.* In particular, in the first example I use *Framy* to indicate the quantity of objects belonging to the layer of interest. In the second one I show how to use nested frames to combine information coming from different layers. Finally, in the third scenario, I describe how to use *Framy* to follow a path toward a specific POI.

Example 1: Framy as a visual synthesizing technique The first scenario I describe shows the use of *Framy* to make the user aware of the distribution of the whole set of data over a map, disregarding of the presently visible map extension.

Figure 8 depicts the layers of the banks and of the streets in Sydney. The screen of a mobile phone is overlapped with them and the blue dotted lines indicate the chosen subdivision of each frame, namely 8 portions. It is possible to note that the color intensity of each sectors proportional to the number of banks located in the corresponding off-screen sector. As an example, the sectors corresponding to the bottom side of the map are associated with a zone with few banks, then they result either transparent or colored with a very light red color. On the other hand, the red color associated with the sectors on the right get the more intense the higher the quantity of off-screen banks.

Figure 8. Overlapping layers of interest with the screen of a mobile phone

Example 2: Framy as technique for visually comparing distributed information

In this scenario, I show how to use *Framy* in order to compare values resulting from spatial aggregations.

In this example two layers showing banks and train stations have been added to the map. Besides taking a look at the map, the request is to understand in which direction we should go in order to find a zone where it is easier to find simultaneously both a bank and particular train stations.

In order to derive this information, I configured two nested frames – red for banks and green for train stations, respectively.

Given the data distribution, few *Ci* have been colored. In particular, colors are more intense on the right and up sides where the map shows numerous POIs. As a result, the top part better satisfies the initial requirement because the red and green colors are simultaneously more intense with respect to other parts (figure 9).

Figure 9. A visual comparison by using Framy

Example 3: Framy as technique for satisfying a specific request

Framy can be also used to guide users along a given direction to reach a specific target. Suppose that the user is interested in locating the closest restaurant with respect to her current position (i. e., the map focus). The produced result is unique and only one frame portion is colored (see Fig. 10). Of course, the higher is the subdivision number set by the user, the better will be the indication on how to reach the target restaurant. Then, the user may zoom the map which implies both to capture more details and increase the *n* value, accordingly.

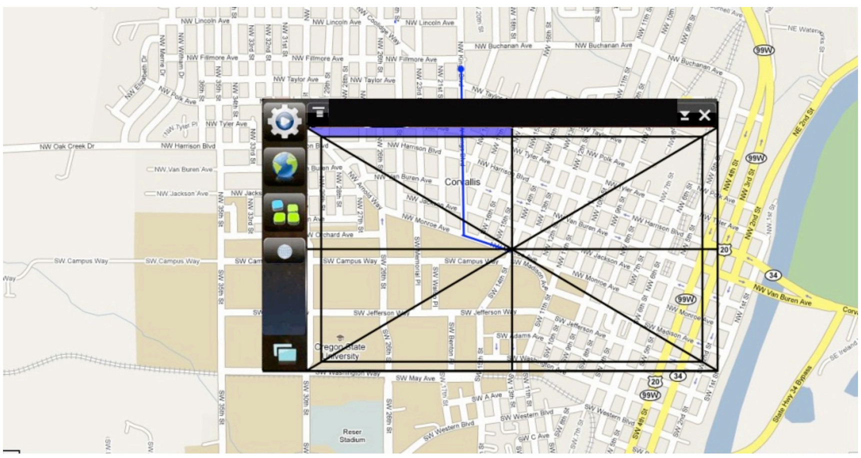


Figure 10. Identifying a specific off-screen location

Fig. 11 shows the feedback coming from *Framy* after a zoom operation which has divided the screen into 16 frames and has identified a smaller off-screen map area containing user's destination.

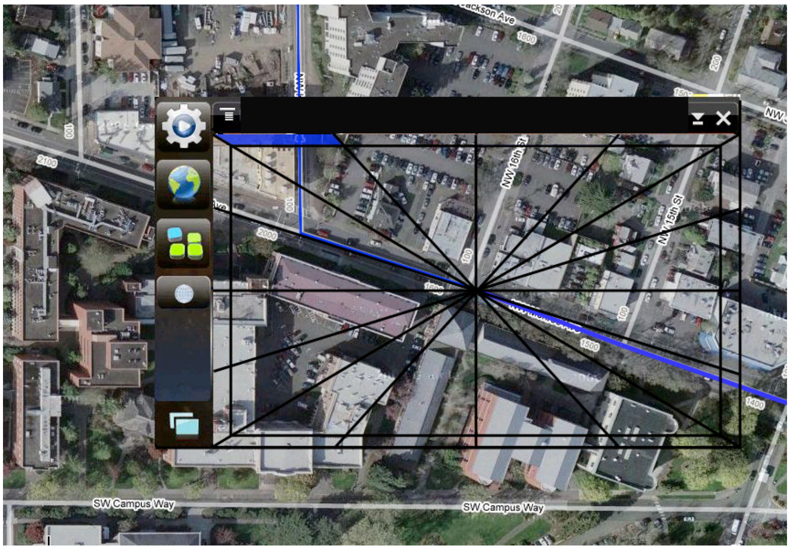


Figure 11 - Zooming and following a path

4 - EVALUATING THE PROTOTYPE

In this section, I describe the comparative usability study I have carried out on *Framy* and a traditional map application that allows people to visualize maps and POIs. Using Framy users have a visual representation of the surrounding POIs so they know where looking for them. the goal of this study was to evaluate if this knowledge gives a significant advantage in terms of efficiency and effectiveness.

The first task is designed to evaluate the time spent by users to explore POIs on a map by using, alternatively, a map application enhanced with Framy and a traditional map application. The second task is used to understand if Framy helps to explore POIs depicted on a map decreasing the number of unexplored POIs.

The Tasks: The first task, from now on *Task1,* consists of searching 50 hotels located two kilometers far from the current position. Users must record the street name of each POI. After completing the task each subject indicated the number of hotels with corresponding street names discovered during the exploration of the map. The reason why users were asked to record the street name for each POI is that in this way users are forced to analyze the region in detail that is what they are expected to do during a typical map consultation activity. Because of the dimensional limits of the device screen POIs are only partially depicted in the same screen view so that users have to navigate the map in order to visualize them.

The second task, from now on *Task2*, consists of searching restaurants located one kilometer far from the current position. Differently from the *Task1* users do not know the number of restaurants, that is 40. After completing the task each subject indicates the number of restaurants with corresponding street names discovered during the exploration of the map.

Independent and Dependent Variables: The independent variable in the experiment is the application which the subjects uses to perform the tasks, namely *Framy* (F) or the iPhone application *Maps* (M).

The dependent variable in Task1 is T*ime* that is the time users spend to accomplish the task and in Task2 E*rrors* that is the number of POIs that have not been explored by users.

As for the efficiency, it is computed by taking into account the time required to find out the surrounding hotels. I calculated the effectiveness by counting the number of omitted hotels.

Subjects and Groups: I involved forty subjects which were randomly distributed over four groups of ten subjects named: G1, C1, G2, and C2. G1 and C1 are the experimental and the control groups which performed the task *Task1* by using F and M, respectively. On the other hand, G2 and C2 are the experimental and the control groups which performed the task *Task2* by using F and M, respectively.

Data and Discussion: The data collected during the experiment will be briefly discussed in this subsection. As for efficiency, data show that there could exist significant improvements. In the first task, the experimental group required 36% less time than the control group. Specifically, the experimental group required 19,6 minutes on the average whereas the control group required 28 minutes. In the second task, the experimental group G2 explored 95% of the POIs while the control group C2 73%.

Tests and Hypotheses: In order to prove that the improvements were not casually derived I have applied a one-tail t-test with a p-value < 0.05 on the collected results for each pair of groups I want to compare. Thus, I have formulated two pairs of hypotheses, each including the null hypothesis and the alternative one.

H0-1(*null hypothesis)*: The time to complete *Task1* by subjects in G1 and C1 groups is the same: μ_{Eff} **(C1, Task1) =** μ_{Eff} **(G1, Task1) vs** μ_{Eff} **(C1, Task1) <** μ_{Eff} **(G1, Task1)**

H0-2(*null hypothesis)*: In *Task2* ***t***he number of errors made by subjects in G2 and in C2 is the same: μ_{Effe} **(C2, Task2) =** μ_{Effe} **(G2, Task2) vs** μ_{Effe} **(C2, Task2) <** μ_{Effe}**(G2, Task2)**

Test Results: Essentially, the hypotheses where I claim that the averages are equal must be rejected in favor of the alternative hypotheses. Indeed, for H0-1 the t value is 5.4172 with p value 0.0004 and for H0-2 the t value is 11.0 with p value 0.0001. The signs provide further information about the hypotheses. In fact, the t-value is positive if the control group mean is greater than the experimental group mean and negative if it is smaller. As for, H0-1 and H0-2, the t-test values are both positive. These values indicate that the control group means are larger than the experimental group mean. Thus, I can claim that statistically users employ less time to perform the *Task1* using *Framy* than using the traditional map application and in *Task2* users make less errors using Framy.

5 - SUMMARY

In this chapter I faced the issue related to the visualization of geographical data with mobile map based applications. The visualization of Geographical data is a specific case of the visualization of spatial data on limited screen sized devices. I presented the Framy technique, which was proposed as an effective solution to the issue. I also explained, through a comparative analysis, how I leveraged existing visualization techniques that address similar issues. I discussed the strengths and weaknesses of those techniques, as considered during the design process. I showed that with respect to these analyzed methods, applications embedding Framy may be configured to work with different modalities and different kinds of aggregates. In fact, besides choosing the aggregate by which data are grouped (e.g., count and distance.), the user may choose the object(s) on which the aggregate may be applied, whereas the colour representing the result is automatically displayed so as to maximize contrast between the frames. Moreover, the granularity level of the subdivision can be suitably adapted to the user's needs. Another important property of this visual representation is the possibility to create nested frames and combine the derived on-screen or off-screen information.

Finally, I reported the usability evaluation process and the related results which demonstrate the validity of my technique.

Chapter 3 – Enhancing the Visual Interface with Multimodality

1 - Introduction

Recent advances in technology have been urging IT researchers to investigate innovative multimodal interfaces and interaction paradigms, able to exploit the increased technological power. The common key goal is to reproduce in the best possible way the interaction through different channels, typical of a human-human dialogue. Multimodal interfaces are characterized by the (possibly simultaneous) use of multiple human sensory modalities and can support combined input/output modes. They are designed to emulate the natural multi-sensorial forms of human-human dialogue, relying on the integration of advanced interaction modes [101].

In this chapter I introduce the multimodal interface designed to extend the interaction flexibility of the former visual Framy interface,presented in the previous chapter.

The first part of the chapter reports on the work done to enhance the usability of Framy interface with interactive sound and tactile input capabilities, whereas the second part describes the experimental study carried out to derive accessibility requirements for visually impaired users.

My idea is to enhance *Framy* with interactive sound and tactile information capabilities, that can exploit the auditory channel and the sense of the touch to convey the same information clues as those visualized on the interface. The auditory channel is one of the primary means of human interaction and several researches have been recently carried out, meant to exploit this interaction modality in the design of usable interactive systems [20]. Auditory communication has been adopted in multimodal interfaces both as a means to improve usability by distributing information to different modalities, and to provide alternative communication channels for the same piece of information. In either cases, a common approach has been to define techniques for translating visual information conveyed by the interface into sonification. Much of this work puts special focus on reducing the mobile device users' visual workload, relying on sonification as a way to emphasize visual information presented on the GUI, and to overcome possible problems due to uncomfortable situations [19][70][54].

Several advantages come from the adoption of auditory interaction in information-seeking tasks and other activities that users usually perform consistently with their everyday experience. This has motivated the design of multimodal interfaces that specifically support users acting in uncomfortable situations, providing them with incremental means to access information [92]. Amongst others, several sonification techniques have been proposed to 'visualize in sound' graphical features characterizing also geographic and environmental data [71][126]. This is the context where my present research can be located, aiming at extending accessibility of *Framy* - enhanced applications to users, who may be interested in gaining summary information about off-screen data.

Given the interest that the solely-visual version of *Framy* has attracted in common users,the rationale behind the sonification design process I have carried on, has been to provide users with an incremental interaction paradigm which is built upon the same mental model that users adopt to deduce information about data residing out of the current view. The resulting multimodal prototype relies on tactile input and non-speech sound output as alternative interaction modalities.

Since as multimodal interfaces supply several alternative ways of interaction between users and devices, they are also an interesting means to provide impaired users with accessibility to mobile devices.

In the last few years there is a growing interest among community and researchers to develop systems which allow impaired people to enjoy a self-determining and autonomous life. In this context, to overcome daily difficulties with mobility I can use software applications and assistive technologies.

In particular, considerable efforts have been made in developing software for navigation and way-finding, especially for visually impaired people.

A detailed investigation of the current solutions devoted to these purposes has highlighted that these can well-accomplish precise tasks in specific fields, such as searching a point of interest. However, a common concern is their inherent difficulty to be easily adapted to more general searches and visualizations, where a wider overview may be required.

As an example, there is no software which allows visually-impaired users to perceive how the surrounding geographical objects are distributed and how the context changes when the subject is moving in. This specific feature may be useful when people moves around and needs to make decisions on-the-fly.

Following that research direction, the accessibility degree of the multimodal prototype of Framy has been evaluated by some visually impaired people. Significant feedback was derived from this study, which allowed me to both understand specific needs of those users and identify critical design issues for a new prototype. The participatory design methodology I applied involved a group of potential stakeholders, featuring different degrees of visual impairment and different technological backgrounds, and allowed me to re-design the prototype interface so as to overcome any limitations detected by subjects taking part in the study.

The chapter is organized as follows. In Section 2 the sonification design process is described, meant to enhance *Framy* with an additional auditory interaction mode. Then a typical scenario is run, which illustrates the new *Framy* functionality in supporting map navigation and feature search. Section 3 introduces readers to the current software, techniques and solutions developed for visually impaired users. After that it describes the initial survey I conducted to understand the world of visually impaired persons, and the pilot study I performed to re-design Framy and adapt it to new specific requirements. Finally, a summary is given in Section 4.

2 – Design of Framy multimodal interface

An auditory counterpart that is functionally equivalent to the visual interface has been added to the *Framy* environment in order to allow users to trial a more complete interaction experience. To this aim, tactile input and non-speech sound output have been added as alternative interaction modalities. In particular, the visualized portions of each frame are associated with auditory feedback triggered by user's touch. Given a touch-screen display, users can drag their finger along the frame and hear a sound whose pitch is synchronized with the colour intensity of the corresponding frame portion.

As for the users' mental model, I aim at allowing users to interact with *Framy* interface by using an approach similar to the one underlying the visual interface. Therefore, I have chosen to map each frame into a different sound source (instrument) and to sonify each portion in the frame on the basis of the corresponding colour intensity thus conveying the same information as the visual counterpart.

The pitch values in MIDI ranges within [1 ... 127]. Thus, by means of a simple proportion:

127 : 100 = *pitch* : *intensity*

I can calculate the correct pitch, as:

pitch= 127**intensity*/100

Provided this approach, it is worth to note that sometimes limiting the conveyed information only to features lying outside the screen may be not sufficient for users who are in uncomfortable conditions. As matter of fact, when the visualization is hampered, it may result useful to have information about the feature distribution within a whole sector, i.e., both in- and off-screen, Then, in order to guarantee this further capability, I have decided to provide users with a visualization / sonification strategy which takes into account also this requirement, namely, to merge information concerning both in- and off-screen.

In this case, Formula (1) is transformed into:

$intensity(Ci) = f(g(\mathrm{Sec}_i))$ for each $i \in \{1, \ldots, n\}$, (2)

and the color intensity as well as sonification of each frame portion is related to a value which either aggregates a property of objects in Sec_i, such as sum and count, or calculates the distance between the map focus and a POI in Sec_i.

This extension of the *Framy* interaction strategy corresponds to an additional facility that users may exploit on demand, when interacting with a map on a mobile device. Figure 12 shows the multimodal interface in action.

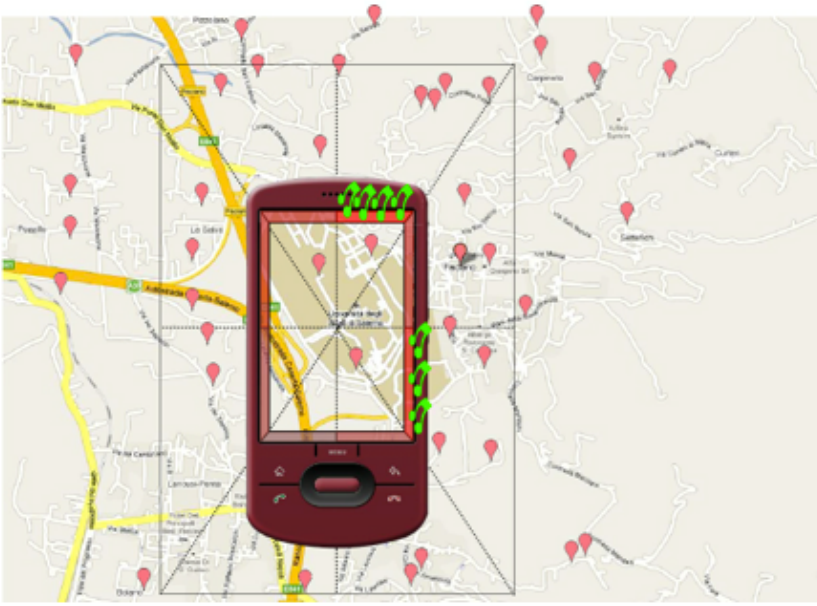


Figure 12 - Framy visual and audio feedback for off-screen features

The interaction task that the user performs when analysing the results of a query, can be modelled in terms of an adaptation of Norman's execution-evaluation interaction model which was explicitly conceived to model multimodal interaction [101]. The steps characterizing the extended interaction cycle are:

1. *Establishing the goal* - At this stage the user is willing to analyse the query results, and possibly decide to move map focus towards a suitable direction.

2. *Forming the intention* - The user wishes to interpret the information about off-screen geographic items, as conveyed by *Framy*.

3. *Specifying the multimodal action sequence* in terms of human output modalities. The user may exploit two alternative human output sensory modalities, namely sight and tactile utterances to (sequentially) explore a frame along the interface display.

4. *Executing the multimodal action* - The user drags her finger along the frame and looks at the corresponding coloured portions.

5. *Perceiving the system state* in terms of human input modalities. The user has a global view of the frame, and the sound issued when a frame portion is touched represents an additional (yet useful) feedback on the information about off-screen map objects.

6. *Interpreting the system state* - Exploiting either the different colour intensity of the portions in a frame or the different pitches issued for those portions, the user can identify the directions of interest.

7. *Evaluating the system state* with respect to the goals and the intentions. At this stage the user is able to evaluate whether the audio-visual information clues coming from *Framy* allow her to decide how to move the map focus (which corresponds to her current position).

Of course a good mapping should be achieved between the execution and the evaluation phases in order to bridge what Norman calls the *gulf of execution* (i.e., the distance between user's specification of the action and the actions allowed by the system) and the *gulf of* *evaluation* (i.e., the distance between user's perception of the new state and her expectation).

A prototype application featuring the new version of Framy was developed by using the Maemo Mapper, an open source software specifically conceived for geographic mapping visualization. It allows to download maps from the most popular repositories, such as OpenStreetMap, and enables users to manage many typical GIS operations such as tracking, routing, POI finding, and other facilities usually required from navigation devices. The audio-visual Framy interface runs on a Nokia N810 platform, which supports Maemo operating system, based on the popular Debian GNU/Linux, and provides developers with an environment and a SDK based on the C language.

In order to prove the effectiveness of the application embedding *Framy*, the following typical scenario of a mapping navigation and search has been run.

The user is looking for restaurants located at most 3 kilometres outside the current display. In order to support the user in this task, the system should determine the restaurant distribution, by colouring each frame portion with a proper intensity.

The initial subdivision of the screen is proportional to the running zoom level, in this case n = 8. Starting from this setting, an outside screen-shaped *buffer* is applied, as shown in Figure 13, and a *count* function is invoked on the restaurant layer. Fig. 2 shows the feedback the user gets for this query.

The frame depicted in the figure also shows the visual feedback the user gets. It indicates that the highest number of restaurants, located in a 3 kilometres off-screen area, can be identified moving towards North-East. By touching the border of the screen along the frame a sound will be produced with a pitch intensity proportional to the corresponding colour intensity. It improves the user's awareness about the distribution of restaurants in a 3 kilometres off-screen area, and helps her to recognize the right direction to follow. Moreover, as the user moves towards the given direction, the map focus changes accordingly, and she may refine her search, e.g. querying the map application for a seafood restaurant.

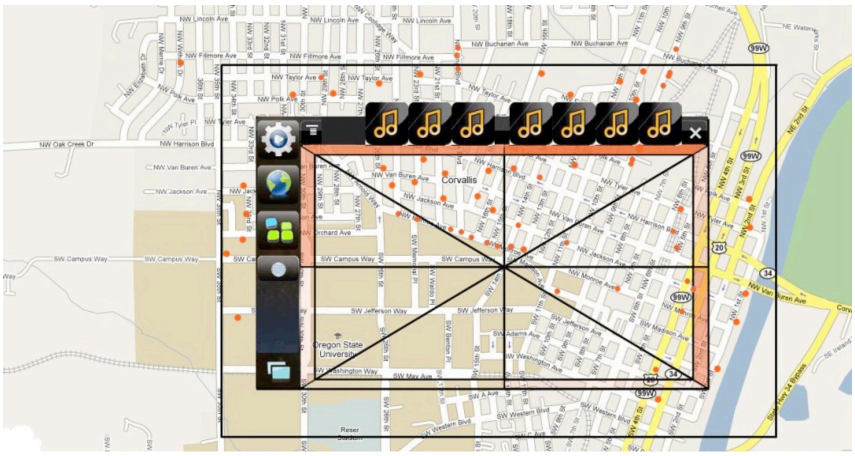


Fig. 13 *Framy* visual and audio feedback for off-screen features

Finally, let me consider a request posed by a user who finds herself in an awkward situation due to a strong reflection on the screen. The user's goal is to determine the sector with the highest number of restaurants, with respect the same map focus as depicted in Fig. 13. In this case, the application should analyse the restaurant distribution within each sector Sec_i, and apply both a visualization / sonification proportional to it.

3 – A NEW CHALLENGE: ADAPTING FRAMY TO VISUALLY-IMPAIRED USERS

Starting from Framy multimodal interface, I have investigated whether this approach could support partially sighted and sightless users.

The multimodal interface proved useful to common users, the audio and tactile feedbacks increasing their engagement with the application and improving their capabilities to understand, navigate and analyse maps. Moreover, the previous scenario also shows how the interface can be very useful in supporting users during uncomfortable situations whenever they cannot pay sufficient attention to the screen.

The positive comments gained from common users about the multimodal version of Framy, encouraged the investigation of ways to fit the interface to the needs of visually impaired and blind users, so that they may also benefit from the provided services.

As a first step, I conducted a survey meant to gain a better understanding of the world of sight-impaired users and of their cognitive and physical needs.

3.1 ANALYZING/REVISING USERS' REQUIREMENTS

After reviewing specific literature on perceptual cognitive psychology [24], I had interesting discussions with a group of people who work with local organizations for sight-impaired people, some of them having long experience with those people and others being blind themselves. Among them, Mr. Giuseppe, a fully autonomous person who has become blind after a car accident and is the director of a rehabilitation centre for blind people, has provided me with useful demonstrations of how blind people exploit their cognitive capabilities to perceive the world around them. The aim of the rehabilitation centre is to help visually-impaired and blind people gaining self-sufficiency in their everyday lives. Giuseppe explained that any low-vision or blind person can cook, work and travel on his own, provided that the mental and cultural barriers that often surround those people are pulled down appropriately. Should this not be the case, any efforts to make a blind person self-sufficient will be unhelpful and even dangerous.

After illustrating the Framy multimodal interface, I inquired my interlocutors about possible requirements to transform it into a useful tool for my target impaired users. my interviewees illustrated different approaches adopted to let a blind person orient himself/herself in the real world autonomously. Usually, the person is allowed to create a cognitive map of a new place by means of a detailed description and/or by exploring it carefully, possibly accompanied by an able person during his/her first visit. Any detail will be useful in the description, including, e.g., the positions of street numbers, public transportation stops etc.

When inquired about the use of dedicated instruments, the group acknowledged their importance, mentioning many, from the simple white cane to modern mobile devices, as a support to avoid obstacles and orient a blind person within an environment. However, they all pointed out the importance of the fact that use of technological instruments does not replace other sensory abilities, given the high adaptability to other senses a blind person is able to achieve if adequately trained. Indeed, if a technological instrument fully replaced one of the other senses, for instance hearing, a blind could risk his/her life in case of malfunctioning or calculation errors.

From my interviews, I also found out that the places especially difficult to explore are the open spaces, such as squares. In those places orientation points are not many, the buildings are far from one another, often there are no sidewalks and, when they are inside a road system exploration can be very dangerous. Thus in open spaces some technological instrument to supplement the traditional ones can be very helpful. For instance, if the person can perceive the light and hence detect the sun position, combining that information with a Braille/talking watch provides the right orientation. If the light cannot be perceived at all, other instruments can be very useful, such as a digital compass provided as an application for mobile phones and designed to interact with blind users. Another instrument which was mentioned as a popular one, despite its significant margin of error, is the mobile application VoiceGPS, which gives information about the distance between the user position and the nearest street number. Satellite navigators are also considered useful while travelling but, again, when a user is in an open space they lack sufficient precision and can be very intrusive giving users continuous audio info that can annoy her auditory capability.

When explaining to my stakeholders Framy interface and the interaction paradigms it supports, one interesting issue was raised by some of them, related to the way visually impaired people understand geometric shapes. They claimed that only those who have appropriate cultural background are able to figure out the geometric shape of an object described on the interface, such as the rectangle representing a coloured frame. However, blind people perceive the world through senses of touch and hearing so usually they learn something about a shape by simply touching and memorizing it. Therefore, a recommendation coming out from my interviews was to enhance the vibro-tactile feedback used to guide user's finger along a frame on the device.

In order to understand how to make Framy as useful as for able-bodied users, I tried to identify the key aspects which can provide a solution if properly addressed.. Indeed, I soon understood that the problem space is much wider than what I expected, especially because the subject typologies may extensively change in terms of both percentage and quality of sight. Most international non-governmental organizations agree on four broad categories of visual impairments, namely *partially sighted*, *low vision*, *legally blind* and *totally blind*. *Partially sighted* are persons who have some difficulty seeing and reading information, requiring special assistance with learning and reading. *Low vision* refers to persons with more severe visual impairments, where reading at normal distances is not possible and the use of supportive tools is needed. Incidentally, to this category belong persons with complete colour blindness, who are unable to discriminate hues, all colours of the spectrum appearing as neutral greys with varying shades of light and dark. *Legally blind* persons have a vision less than 20/200 and a limited range of vision. They cannot see things clearly, irrespective of the distance. *Totally blind* refers to persons who have no vision at all. Their eyes are not able to process images, and they learn through non-visual resources, including Braille.

Among the group of people who took part in my preliminary discussion, I selected three visually impaired participants (one color blind and two totally blind) to perform a pilot study meant to identify further specific requirements I should satisfy to make Framy effective and useful to visually impaired users. The study was also intended to lay the basis for future usability evaluation experiments, once the re-design was complete and a new prototype was built. In order to gauge the potential effectiveness and usefulness of Framy, I applied a "think-aloud" technique, inviting participants to perform some representative tasks with the current prototype and provide me with precious suggestions on how to improve it. Basically, I focused on three aspects of the interface, namely:

- The capability to navigate the frame: I needed to determine the best size of the frames, with the goal to find the right tradeoff between a size comfortable to navigate by human finger and a sufficient space to visualize the underlying map.
- The capability to understand the interface: I checked whether the optical audio and tactile information clues are effective to guide users in accomplishing their tasks. The interface must not confuse user or make him/her feel awkward.
- The capability to analyze results: I wanted to evaluate the goodness of the feedback used by Framy and its usefulness to identify the most intense sector of the frame.

I asked subjects to comment any critical step carrying out the following tasks on an Apple™ iPhone™ 3G, with firmware 4.1. The screen size of the device is 3.5 inch with 480 x 320 pixel resolution .

Task1: After adding two frames on the map, put one finger on the frame and navigate it.

This operation was done both on the external and the internal frame. I repeated this task considering both a 40px cornice and a 60px cornice in order to determine the optimal size of the frames.

Task2: Count how many times, moving the finger along the frame, you perceive a new sector.

With that task I wished to understand whether the addition of sound and tactile output would help a user or not, and, what improvement I could make to the multimodal interaction paradigm to make the interface accessible to visually impaired users.

The third task was finally meant to evaluate the ability to interpret my interface and, to understand how to make it effective for the new target users.

Task3: Evaluate which sector is more intense with respect to the others.

As for the participants, the first user, named Pasquale, is a fifty years old man, who is colour blind. He started having sight problems when he was forty. He is an office worker and he cannot use mobile technology so well, while he can use a PC quite well as he works with it. Pasquale found it easy to run my test thanks to his enthusiasm. Indeed, he is interested in helping the development of assistive technologies dedicated to users in his condition. This attitude was common among all the users who tested my system. Pasquale is colour blind so he can’t distinguish colours. Before starting I was expecting that the user would not be able to perceive the differences between the frames and the colour intensities of the various sectors, due to his pathology. I was rather expecting he would be supported only by the sound and tactile interaction modes. Surprisingly, he succeeded in distinguishing the different frames and the intensity of the different sections. Despite his pathology, he could distinguish the strong contrasts between the different frames realized on the basis of Itten’s wheel of colours. Pasquale was able to succeed in performing the tasks similar to a normally sighted user. However, he pointed out that the proposed use of vibration was distracting him from the objective he was pursuing while performing the task. His observation on possible better uses of tactile feedback was annotated and considered in the brainstorming activities that followed the experiment.

The second participant is named Anna, she is a 33 years old and totally blind. Anna started to lose the sight slowly since she was 8 years old. Although Anna was very enthusiastic and willing, the real problems with the current version of Framy became apparent with her performance. Since Anna was not blind from her birth and also thanks to her knowledge of geometric shapes she easily understood my description of the Framy interface. However, Anna never used a mobile device with touch-screen technology before. The first issue she raised on the iPhone device was that there are no (tactile) reference points on the screen. The iPhone screen is completely flat-faced and there is no way to distinguish the tappable area from the non-tappable one. This aesthetic choice turns out to be a strong obstacle to Anna. She could perform the experiment using only the long side of the device. Once she started the tasks she experienced some problems in following the frames and determining when a sector starts or finishes in case there are no objects in that sector. Another useful observation she made while performing the tasks was that when the sound stopped she got lost because there are no audio or tactile clues to understand where to move next.

The third user is Giuseppe, who is 40 years old and had lost his sight completely when he was 20 years old. Different to previous users, Giuseppe attended a special school for impaired sight users where he was taught how to act in the most common situations. He learnt how to orientate himself, how to walk around by using tools like white canes etc. Furthermore, he is an expert user of both computers and touch-screen devices. He daily uses an iPhone, supported by Apple™ VoiceOver™ technology [119], so he was very happy to help me running my tests. After the initial introduction, he was well guided by the sound-tactile interface and he succeeded in completing the tasks on one frame with no problems, but he started having difficulties when I added the inner frame. He found it too close to the first one and he could not accomplish the task as easily as with only the outer frame. At the end of the tasks, he suggested that there is no need to nest frames inside each other, because blind people are able to distinguish many sounds at once and the sounds of two frames may be condensed (as a way to aggregate the underlying information) into one without creating a difficulty of interpretation. Another difficulty that surfaced in this experiment was the un-intentional interaction with the map part of the interface. During the test, by sliding his finger along the frame, Giuseppe moved sometimes into the map and moved the map focus changing the current frame setting. He argued that this is a relevant problem that I should solve.

As for the best resulting width of the frame, all three participants judged that 60 px is better, even if there are no significant differences with respect to 40 px. So I could conclude that 40 px is the right tradeoff between a comfortable size to navigate and the sufficient space to visualize the map.

3.2 - The Derived Design Guidelines for the new Framy mobile interface

The interviews and the pilot tests allowed me to identify some useful guidelines for the design of the next Framy prototype aimed for visually impaired users.

1. The interface should provide two interaction stages: *consultation* mode and *action* mode. The former allows user to retrieve information from the interface and does not

allow him/her to give commands to the system. The latter allows user to give only commands. This specific guideline has been introduced to avoid that the user inadvertently moving the map focus.

2. As suggested by Giuseppe, the audio channel should be better exploited to convey a very high number of information pieces because they help users to detail the mental map of the application. Thus, the aggregated information about multiple layers, previously supplied by nested frames, is now given in the form of (possibly complex) audio feedback.
3. The problems experienced by Anna and Giuseppe when following the rectangular shape of the frame, suggested to me that the use of tactile feedback should be used to follow geometric shapes. Thus, the shape of the frames may be now followed by using a continuous vibration which is interrupted in case the user slides out of it.
4. The application must be a useful support for visually impaired users but absolutely it must not replace one or more users' senses.
5. Larger shapes may be better but the minimum size of the frame could be 40 px for totally or color blind people.

As a result of the re-design process, I built a new Framy prototype providing an appropriate audio-tactile interface.

In order to guarantee the accessibility, the new Framy system allows users to select between two different multimodal interfaces, on the basis of their characteristics. Users belonging to partially blind or normally sighted categories may interact with the first (default) interface while totally blind or low-vision users may interact with the second one. In the first interface, the default frame width is 40 pixel but users can customize it. A contiguous vibration *along the whole frame* is triggered by users' touch. This is to avoid user losing contact with the frame. A new "road bump" sound is added to the interface. As a user drags a finger along the frame he may hear: a road bump sound that informs when he reaches a new sector, and a sound whose frequency is synchronized with the colour intensity. Moreover, *each frame is mapped onto a different sound source (instrument)*.

The second interface is very similar to the first one but allows users to inscribe inside the screen at most one frame. In order to give information about two or more different categories, when user touches a frame portion he/she hears a sequence of sounds corresponding to categories, which are represented by the frame as shown in Fig. 14. Moreover the interface provides the two interactive modes. When user drags one finger he/she receives information from the system, that is the *consultation* stage. When he/she drags two fingers he/she moves the map focus, being in the *action* stage.

Figure 14.The sketch of the newFramy interface

3.3 – Related Work

In the last few years, researchers from different domains have investigated needs and requirements for visually impaired people in order to improve their life through technological devices capable of supporting their learning, mobility and in general self-sufficient capability. Sethu Selvi et al. [102] indeed state that blindness is considered the main issue impacting on daily life. It is a major challenge to identify tools and provide solutions.

In literature several approaches have been followed, each affecting a specific technological and methodological aspect. One of the most relevant research fields refers to the users mobility. In this domain researchers have focused their attention on software applications capable of providing special routes for visually impaired people, and have proposed advanced solutions aiming to allow interactions between users and technological devices, ranging from desktop to mobile devices, from voice to multimodal interfaces.

A valuable work in the area of mobile GIS accessibility has been carried out by Yairi and Igi, who follow a universal design approach to develop their Mobility Support GIS conceived for a variety of pedestrians including elderly, disabled, pregnant, and infant users [124]. The system is developed as a desktop oriented application.

An interesting application targeted at disabled users is presented in [24]. The authors describe a Web-GIS providing impaired people with pedestrian routes. The overall route characteristics are determined by taking into account the difficulties of each obstacle as well as psychological factors and disabilities related to the specific users' characteristic.

Based on the observations by Rana et al. [94], who state that mobile devices are primary instruments capable of enhancing visually impaired users' mobility, different solutions have been presented which exploit mobile device capability. A constantly updated information about obstacles is the basic characteristic of Völkel and Weber's route calculation system [120]. In order to have frequent updates, users may send new information through a semi-automatic system running on mobile devices. In [3], Amemiya et al. describe an application aimed to guide visually impaired people along a route by means of a mobile device. The approach is based on a haptic prototype that suggests users the right route, by generating asymmetric oscillations along cardinal directions. The same concept has been implemented by Xu et al. In [123] through a speech and non-speech interface. They propose a software application which guides users towards a destination. The application allows users to avoid obstacles by means of an image recognition technique. The non-speech interface is based on three different features of sound, proportional amplitude, frequency and tempo, in order to emphasize the change via a sound event.

A speech and non-speech interface is also used in Soeda [107] for the interaction with visually impaired people. The system guides users by means of synthesized voice while a non-speech sound notifies them a close point of interest.

Another interesting application by Sanchez et al [98] running on windows mobile device, guides users through a speech synthesizer from a point to another on a map. The system exploits the clock metaphor, namely the hour notation system, to indicate directions.

Researchers have exploited multimodal interface capability of mobile devices also for other types of situations, such as social interaction [102], web navigation [94], entertainment [25] and learning systems [31]. In particular, the results carried out by Cohen et al. in [31] have been useful for my work. They have investigated ways to reduce the learning gap in the area of computer science between visually impaired students and able-bodied students by means of touch-screen mobile devices. They state that learning gap is caused by the typical visual approach used to describe many concepts. Then, the authors focus their attention on presentation of graphs due to their wide usage in describing many data structures. They propose a software system called exPLoring graphs at UMB (PLUMB) that displays a graph drawn on a Tablet PC and uses auditory and vibration cues to help visually impaired users to navigate and interpret the graph. PLUMB uses a continuous sound to indicate the contact between users' finger or stylus with an edge, and modifies the sound tone supporting it by a vibration to notify nearness to the end of the edge. While users move toward a vertex, PLUMB increases the vibration intensity.

Finally, as for vibration feedback, in [25] authors describe a multimodal approach based on a haptic prototype device. They state that in certain cases visual feedbacks can be even replaced by tactile feedbacks. In [21] Brown et al. specify a tactile language based on them. They describe three features of vibration in order to characterize the language, namely rhythm, vibro-tactile "roughness" and spatial location of transducers on the body.

4 - SUMMARY

In this chapter I described how I extended the Framy visual interface to obtain a multimodal interface. The multimodal interaction is a way to better involve users into the applications. Moreover multimodal interfaces are also a primary means to allow impaired users to interact with devices. Thus it is a very impotent aspect of this investigation. . In this chapter I first presented a multimodal interface designed for able-bodied users and a short scenario.

Next I showed the process I used to transform the multimodal interface to one that is suitable for visually impaired users. Although the first interface was equipped with many features which should allow them to use Framy without particular problems I had to recognize that the solutions I adopted were not always the most suitable for visually impaired users and in many case I had to re-design the interaction on the basis of the user's suggestions.

The pilot study I conducted with visually impaired users and the interviews with a group of knowledgeable people helped me to significantly improve Framy and transform it into a technique suited for visually-impaired users. Thanks to the pilot tests and the interviews I got enough information to write some guidelines useful for re-design the multimodal interface taking in to account the different abilities of visually impaired users.

Chapter 4 – Use of Framy in other Application Contexts

1 - Introduction

In this chapter I describe four applications that users Framy technique to overcome difficulties associated with visualising spatial data. These applications are from different areas. This demonstrates the adaptability of the technique that I have developed.

The first application uses the classic Framy technique in a 2-dimensional map environment. The application is designed to support decision makers who work directly on disaster sites during crisis management. The idea is to provide them with light devices and to exploit the visual analytical power of Framy to give them immediate and intuitive information about relevant objects distributed on a map.

In the second application the geographical information is not represented on a map but in a augmented reality environment. The application exploits the augmented reality to assist users to explore the surrounding environment. It was designed to support both able-bodied users and impaired users in their tasks.

The third application exploits the augmented reality technology and social network concepts to provide users with a powerful communication means. Users are able to communicate with their friends as in a social network but they are also able to visualize them in two ways; on a map and within an augmented reality environment. Here solutions based on Framy are adopted to orient users and avoid the visual information overcrowding the screen due to the large number of users that has to be depicted on the screen.

Finally I present a new collaborative system designed to support the collaboration in the context of Small to Medium sized Enterprises (SME). This work derives from a collaboration between the researchers at **University of Western Sydney**, Australia and the **HCI lab of the University of Salerno**, Italy. The goal of this application was to enhance the business processes presently carried out by SME using spreadsheets. This was achieved by designing and developing a web based spreadsheet mediated business collaboration system. We have developed two interfaces, the first one is desktop oriented while the second one is mobile oriented. The work done on the latter relies on the use of of Framy to convey information about off-screen cells of the shared spreadsheet, and further shows the adaptability of this technique to different domains.

2 - An application to support the onsite emergency management

In 2006, the research community of Visualization, Analytics & Spatial Decision Support joined together for drawing up the agenda to identify major problems, and define direction for future research in their field. Results were published in [6]. Among the several issues, during the meeting a specific spatial decision problem was identified which strongly affects human activities, that is decision making in time-critical applications, in particular in emergency situations. A typical example of this kind of applications is planning the evacuation of people from a disaster-affected zone.

Many proposals as [5][6][44][126][61] have been introduced to this aim, all sharing the observation that applications based on a visual analytics approach are highly suitable due to their ability to visually elaborate and communicate significant information to decision-makers. In particular, they can support domain experts to immediately visualize the status of the crisis, plan the evacuation and address people towards vacancies in emergency centres. However, a weak point in terms of intuitiveness, easiness of use and hardware requirements limits the effectiveness of such functionalities. As a matter of fact, many tasks require a long training with the underlying technology, thus deviating users' efforts from the key questions of their studies. Moreover, the need of relevant on-site hardware implies the growth of the investments required in terms of equipment.

Mobile devices and visual interfaces represent a solution to overcome such limits. In fact, the pervasive nature of mobile devices is stimulating developers to realize applications useful for both human daily and extraordinary activities, whose aim is to enhance users' exploration activities and allow expert users to focus on key questions. Thus, the development of advanced visual applications meant to support visual analytics tasks through small and handheld devices can improve expert users' activities by providing them with immediate and light solutions, without losing their communicative efficacy and their capability of processing data.

The research I am carrying out along this line is meant to provide users with advanced tools and functionalities where mobility comes into play, such as user's navigation, provided through services addressed to capture a qualitative global view of a scenario, by simplifying the detection of relevant elements. In particular, I aim to realize an integrated visual system with which domain expert users, as well as ultimate users, may interact and query datasets in order to obtain immediate and easily understandable cues about events and environmental changes, useful to the management of evolving scenarios.

Thanks to Framy, sets of data can be summarized and qualitatively displayed on mobile devices by means of visual aggregates. The idea is to associate a set of features with a frame visualized along the border of the device screen. Based on a selected feature property, the frame is partitioned and coloured with different intensities of a given colour, thus conveying qualitative cues about the property value within the different sectors of either the on-screen or the off-screen space.

In this section I present an artefact based on Framy, meant to integrate spatial and temporal information through a notation which visually summarizes it on mobile device screens. In particular, my aim is to realize applications embedding Framy which allow expert users to work on the field in critical situation, by both suggesting more convenient solutions which cannot be directly seen from elsewhere, and allowing decision makers to consider constraints not detectable from remote sensors.

Starting from the visual Framy approach, the technique has been extended by including further computations related to a temporal evolution. In particular, two orthogonal views have been designed, each of them associated with temporal requests. The former allows users to focus on a single frame and displays it in different time instants, thus visualizing its temporal evolution. The latter allows users to visualize a set of frames in a chosen time instant which can be modified (backwards or forwards), thus enabling a visual comparison among events associated with them.

From a design point of view, the above methods are again associated with the colour intensity of the frame portion of interest. In particular, the temporal evolution of a phenomenon is caught by examining how the hue intensity varies along time, whereas the comparisons among the features featuring a whole scenario are visually performed by observing the evolution of the corresponding frames.

2.1 - The Design Process

The design process I have performed to derive the evolutionary visualization system which exploits Framy technique, has been mainly inspired by Rosson and Carrol's scenario-based design method [98]. Scenarios of usage were in fact chosen as my primary design objects, thanks to their simultaneous ability to guide design and to facilitate usability evaluation and assessment during the iterative development process. Starting from a field study conducted within potential real contexts of usage, I have in fact built scenarios of emergency management practices and I have used them to derive user's requirements. I have then exploited HCI usability principles and guidelines to derive a prototype of the system, which has been iteratively refined through an empirical evaluation that has also involved users' feedback whenever a crucial design decision was to be made. In the following subsection, I discuss the fieldwork results, and I describe the envisaged problem scenario and the derived users' requirements.

2.1.1 - The field study

The study involved 2 different organizations who operate in the domain of emergency management in the territory of Salerno, Italy, namely the civil defence departments of forest rangers, and of fire brigades. The preliminary activity I performed for my field study consisted in a contextual inquiry on the use of software applications for emergency management and on the processes performed for real time management. The 12 subjects who took the survey, 6 for each organization, had different backgrounds and different ages and experiences in that field. All of them had sometime used computer applications during emergency management activities, with an intermediate to advanced expertise. The main goal of the inquiry was to gain a comprehension of activities requiring the use of computers, as they really occur during emergency management and of the activities which could benefit from the adoption of (mobile) computer application. I therefore posed questions to subjects on the kind of activities they commonly perform when dealing with an emergency and on the extent to which mobile devices (including cell phones and PDAs) are adopted for continuous information exchange between on-site operators and the emergency operating centre. For each department, I observed:

- the physical settings where collaborative activities for emergency management are performed (e.g., whether co-located or distributed stations are involved),

- the means by which those activities are usually coordinated (e.g., whether by broadcast or by telephone/computer mediated communication),

- the means by which an on-site operator notifies other operators of the actions he has performed to get the activity done (e.g., by direct communication or by sending this information to the operating centre, or letting information on those activities to be sought on a shared computer application).

The kind of emergency response activities most of the interviewees described followed predefined protocols, that mainly relied on central computer-based decision making and on the use of mobile phones for real-time communication with on-site operators. As a result of my study, I was able to understand that in common crisis management practices, software applications used to understand the current situation and its evolution are able to collect heterogeneous data coming from different sources (e.g., local sensors, camera-enabled cell phones, etc.). However, in most cases, the application is not shared among the actors engaged in the activities, but it is rather centralized and used by the operating centre to make decisions which are eventually communicated on site. Also, some of the interviewees reported that the effectiveness of the derived decisions often relies on the ability of a restricted group of people who are not on the ground at the time of the crisis and may therefore fail to grasp critical aspects of the situation. When inquired about possible improvements to the overall emergency management process, all interviewees mentioned the adoption of mobile applications that could allow on-site operators to quickly analyze the crisis situation and perform timely actions, while keeping real time connection to the operation centre and to the other on-site actors.

2.1.2 - The problem scenario

In order to formalize the requirements elicited from the interviews, I capitalized the knowledge gained from the fieldwork and envisaged a scenario of emergency management practices, from which I could start a brainstorming activity for the design of a possible solution. Based on that knowledge, I built a persona, who could represent the archetype user of our mobile application, and, I envisaged his tasks inside a representative interactive collaboration scenario.

Persona John Brown is a 56 years old fireman with long experience in emergency/disaster management. John is the manager of a mobile station located in the emergency area, and he acts as an intermediate between the command and control center, located at the fire brigade headquarters and the fire brigade groups and individuals distributed around the emergency area, who are responsible to assign the evacuees groups to the appropriate routes. Due to critical situations John is often forced to quickly elaborate the collected data and make timely decisions before receiving orders from the command and control center. He is aware that several benefits could come from the adoption of some geovisualization system running on mobile devices, to provide decision-makers with information about the instantaneous and historical status about evacuees groups, who are on site, those who are on the way towards the shelters and those who already reached the shelters. However, he is afraid that the training activities that emergency operators should undergo to actuate such transformation would be too costly and even ineffective for those who have limited familiarity with computer systems.

Scenario John is connected to the on-site emergency responders by radio communication and by cellular phones, used to receive real-time information about the evacuation state at the different spot points. Responders send information about the number of evacuees still on site, and the number of people directed toward some shelters. The shelters managers send updated information about the number of vacancies. John then communicates the collected context data about the evacuation state to the command and control center, by means of wireless mesh networks, and waits for appropriate instructions on the subsequent phases. At some point, due to the unexpected critical situation of an overcrowded evacuation point, John is forced to quickly elaborate the collected data and make timely decisions before receiving orders from the command and control center. He asks the locale fire brigades to assign one group of evacuees to the western route and another group to the north-eastern route. He then realizes that the lack of an appropriate overview of the evacuation status of the emergency area, has led him to a wrong decision, since a group of 35 people has meanwhile left another evacuation point and reached the North- East shelter, which has therefore not sufficient vacancies left.

2.1.3 - User requirements

The depicted scenario gave us the opportunity to reason about what claims about current practices emerged. In fact, the first general requirement that all observed evacuation management activities seemed to raise is the necessity of suitable mobile interfaces to visualize spatio-temporal information about emergency cases, that would yield an improvement in the efficiency of the related activities and, hence, of the overall emergency management process, while preserving the emergency management policies actuated so far. The derived interface requirements consisted in finding the right trade-off between the small screen size of the mobile device and the need to convey sufficient timely information about relevant map-related elements. A second general requirement, strictly related to the former, which is also represented in the scenario, is that the visualized information should be easily interpreted by mobile emergency managers, also with respect to the geographic and the temporal contexts, so as to provide effective support to rapid decision making. The corresponding interface requirements consisted in in making the conveyed spatio-temporal information easily perceivable on the device display by on-site operators. Those aspects would also imply limited learning efforts by emergency operators and satisfy the further requirement to minimize training costs and time needed for the actuation of the envisaged transformation, as resulted from the contextual inquiry.

In the following section I illustrate how the *Framy* interaction technique has been suitably exploited in the design of the evolutionary geo-visualization system satisfying the described requirements. The transition to this kind of system has required to move the focus of interaction from map POIs only to *events* which evolve over time and whose status is related to map POIs. The ability of *Framy* to visualize nested frames corresponding to different map layers has been exploited to summarize information about groups of related events at a given time. The same capability has also been used, as an alternative interaction mode, to analyze the evolution of a single event across a given time interval. In the specific context of the described emergency management scenario, three related evolving events have been defined as crucial support to the evacuation process:

- the distribution of evacuees around the event site

- the evacuees who are on the way towards a given shelter

- the vacancies available at a given shelter

Aggregates will be defined so as to summarize information about the identified events,

so as to inform responders about the instantaneous and historical status of evacuees.

2.1.4 - Displaying temporal evolutions

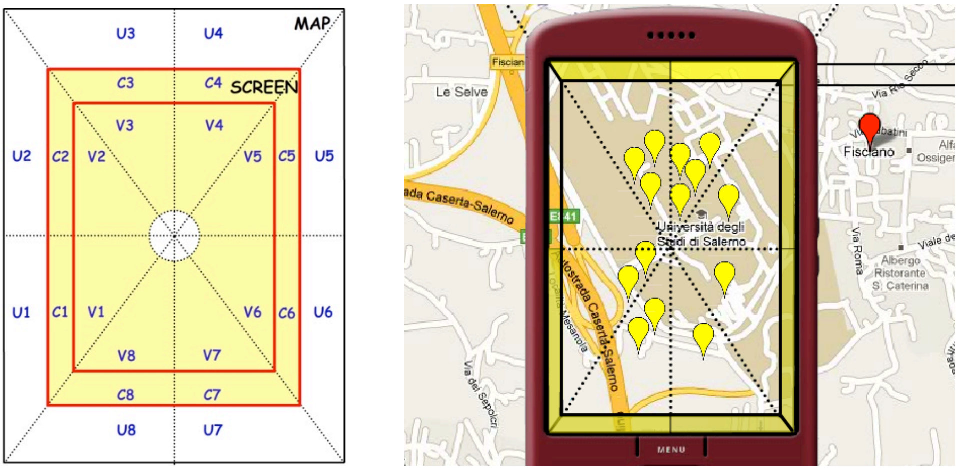
In the basic *Framy* technique, each frame only visualizes the current situation, while different frames refer to different aggregates of objects and/or events. The extension I present in this Section concerns the management of time in terms of visualization of temporal evolution of aggregates.

Differently from the desktop approaches, the temporal evolution of the considered aggregate cannot be entirely visualized because mobile devices lack screen space sufficient to display different situations each depicting a single time slice.

In order to overcome this limitation the present version of Framy has been extended by including further computations related to temporal evolution of events. In particular, two orthogonal views have been designed, each of them associated with temporal requests. The former allows users to focus on a single event and display it in different time instants, thus visualizing its temporal evolution. The latter allows users to analyze the status of a group of related events over time, moving backwards or forwards along the timeline.

In particular,

1. in the first case, a set of nested frames may be used for visualizing all together different status of a given event at selected time instants. Each frame is associated with the status of the event at a given time. Formally, given a subset of time instants $\{t'_1, t'_2, ..., t'_p\}$ belonging to the sampled set $\{t_1, t_2, ..., t_n\}$, and a set of frames $F = \{f_1, f_2 ..., f_m\}$ associated to the same aggregate g, then the colour intensity of the sector S_i of the frame f_k at time t'_j is calculated on the basis of the value $g(S_i, t'_j)$.
2. In the second case, nested frames are normally used to represent a group of events at a given time, while previous or successive status of such events may be visualized by simply interacting with the device. That is to say, given a time instant t_j belonging to the set $\{t_1, t_2, ..., t_n\}$, and a set of frames $F = \{f_1, f_2, ... f_m\}$ associated to the aggregates $G = \{g_1, g_2, ..., g_m\}$, then the colour intensity of the sector S_i of the frame f_k at time t_j is calculated on the basis of the value $g_k(S_i, t_j)$.



(a) (b)

Fig. 15. (a) An example of (on/off-)screen subdivision accomplished by Framy. (b) A snapshot of Framy where the frame is associated with the distribution of POIs around the map focus.

From a design point of view, I had to face two important issues related to the visualization of the frames, namely the frame size and the number of sectors composing frames.

As for the frame size, I had to find out which is the best trade-off between the necessity of showing as many frames as possible and the limitation of the available space of the specific devices. By considering the experiences I made during the development and validation phases, the answer is not unique and it depends on the number of frames currently visualized on the screen. I realized that a lower bound of 20 pixels for the frame size seems to be the minimum value which allows users to correctly interpret the frame sectors without a significant loss of information. As for the upper bound, I made an experiment where I asked users to read an emergency scenario represented by means of 30 and 40 pixels sized frames. In this context, I did not find any difference in terms of reading easiness which implies that such an increment of size does not improve the effectiveness of *Framy*. Consequently, I decided to set the frame size to 30 in case we are visualizing just one frame, and to lower it to 25 pixels in case of two or three frames, to save enough space for the visualized map. More than three aggregates are even possible but the sufficiency of the remaining space to correctly read the underlying map might depend on the specific mobile device. For instance, the HTC dream I used for the experiment has a 420 x 320 size screen. When using four 25 pixel frames, the remaining space corresponds to a 280x120 sized rectangle[1].

It is worth to notice that if the first method is used, namely the visualization of a temporal evolution of a single event, a smaller frame size may be suitable, because the continuous saturation value changes of the single colour associated with the event may be better perceived. However, in order to preserve the tactile interaction used to gain information details about a frame sector, a size of 20 pixel has been set as the default choice.

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1 The experiment and the considerations we made in this section about the frame sizes in terms of pixels are strictly related to the mobile platform we are using. It is due to the fact that the sizes of pixel could change depending on the used device. In order to export the information to other platforms it could be possible to express them with the corresponding meter lengths. However, results might change because of the sensibility of the platform sensors.

As for the second relevant issue, namely the frame sector number, I had to choose whether using a constant number for all the visualized frames or to allow users to choose a number for each frame. On one side, a constant number allows a better readability. In fact, each sector represents the same region to analyze and results of comparisons are immediate because no misalignments are allowed. On the other side, providing users with a customizable sector number for each frame allows to set the frames to work with different granularities. As an example, the user can visualize a frame associated with specific POIs, such as Turistic InfoPoints, for showing their distribution around the map focus. In this case, a low granularity could be useful for detecting the direction. At the same time, it could be useful to know where right bus stops are located for each direction in order to better address people for reaching the chosen place. In this case a higher granularity may be more appropriate.

Based on these observations, I preferred to use a fully customizable approach, where each frame can be set with any number of sectors. The reason is that this application is addressed to specialists in emergency who need to perform analyses on sets of features that are spatially distributed with different granularities. Thus, the capability of fully customizing the application in agreement with their needs represents a productive means to derive good knowledge of facts about the area where the catastrophic event occurred.

2.2- The Working Scenario

In order to provide an example of the Framy capability to support expert users to perform temporal analyses, in this Section I describe a scenario where it is required to evacuate an event zone and transport people to some gathering places by means of buses.

In order to improve the organization of the people sorting, it is necessary to provide on-site responders with information about the instantaneous and historical status about evacuees, i.e., those who are on site, those who are on the way towards the places and those who already reached the Shelters. This is to say, in any moment decision makers should be able to choose where the empty transportation means should be directed and where they should be directed when loaded based on both the available vacancies and the number of people who are currently directed towards the shelters. To this aim, it is necessary to provide three kinds of aggregates:

g_1 - it computes the number of people within a given buffer from the event site,

g_2 - it counts the number of people who are on the way and directed towards some gathering place,

g_3 - it counts the number of available vacancies for each place.

As shown in Figure 2, each frame is colour rendered in agreement with the rules of Itten's theory. In particular, the first aggregate is yellow (hue 60), the second one is red (hue 120) and the third one is blue (hue 180). By default, the brightness is always set to 100 for all of them, while the saturation depends on the corresponding aggregate values.

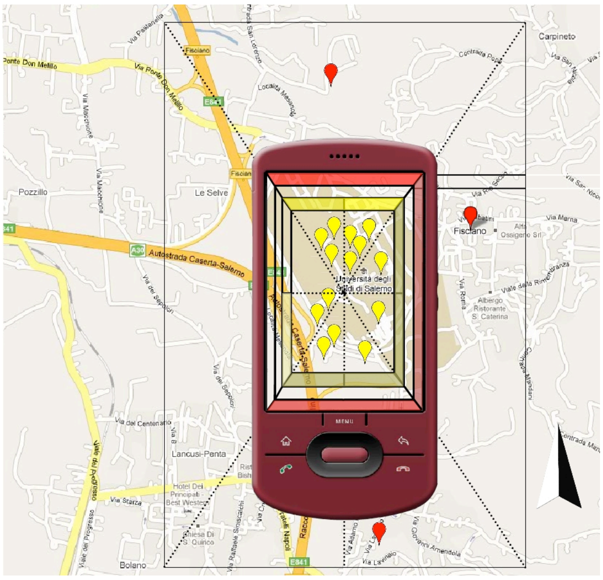


Fig. 16. A snapshot of Framy representing the initial status of the evacuation.

According to the subdivision depicted in Figure 15(a), the functions which calculate the colour saturation are defined as follows:

$$s_{1i} = \frac{g_{1i} * 100}{G_{t0}},$$

where $g_{1,i}$ represents the result of g_1 in V_i and G_{t0} is the number of people who should be evacuated at time t_0,

$$s_{2i} = \frac{g_{2i} * 100}{G_{t0}}$$

where $g_{2,i}$ represents the result of g_2 in U_i, and finally,

$$s_{3i} = \frac{g_{3i} * 100}{H_{t0}}$$

where $g_{3,i}$ represents the result of g_3 in U_i, and H_{t0} is the total number of vacancies available at time t_0.

During the setting step the user can also specify how many sectors compose each frame. This choice turns out to be fundamental because it allows to contextualize the results of the aggregates to some areas of the territory. In this example, the frame representing g_1 is divided into 8 sectors, while g_2 and g_3 are subdivided into 4 sectors (the minimum value for allowing each place to fall into a different sector), thus representing aggregates grouped for emergency places. The nesting position of each frame is set in agreement with the Itten's theory, namely the innermost frame is yellow, followed by the blue and then by the red. On demand, the user may modify such an arrangement provided the observance of the basic constraints regarding colour contrasts.

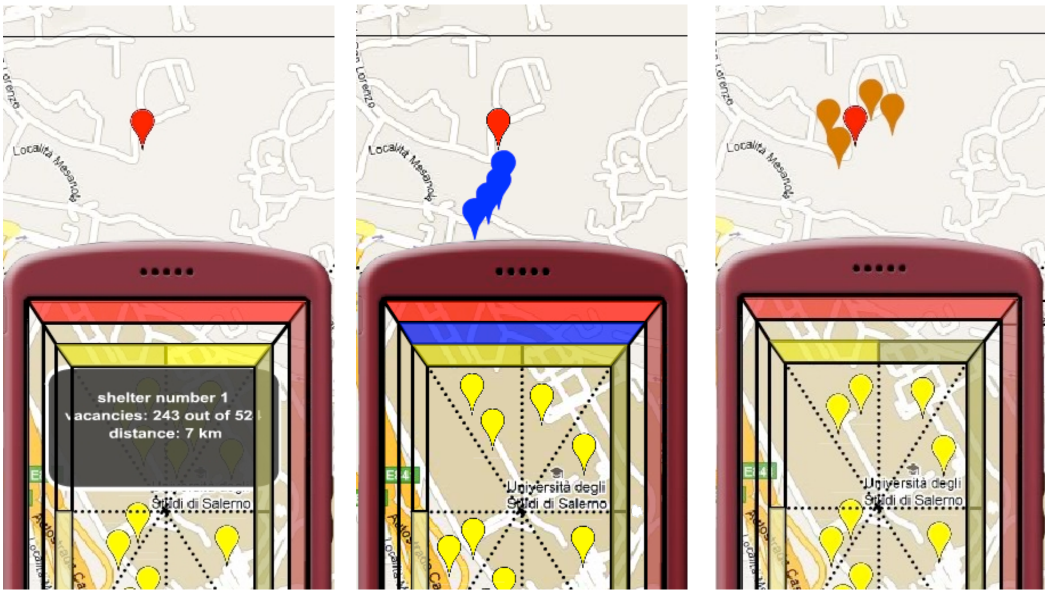
Figure 16 represents the initial situation just after the event. The user is near to the event place and a number of people all around has to be transported towards three gathering places located outside the visible space of the screen (red balloons in the figure).

The yellow frame shows that most of people is gathered to the North. Specifically, the right side is slightly more intense with respect to the left side because it contains a higher number of people. In the other sectors, the colour intensities are quite similar except for the top-West sector which is transparent. As a matter of fact, this configuration shows that a similar number of people is waiting for a transportation in several sectors except for the transparent one where nobody is waiting.

The blue frame is completely transparent because no one is currently on the way to be transported towards any gathering place.

Finally, the red frame shows the number of available vacancies for each sector, provided that in the current setting each gathering place corresponds to just one sector. As we can notice, the most receptive place is located to the North which corresponds to the most intense red colour, an intermediate receptive place is to the South, a less receptive place is to the East and, finally, no vacancy is available to the West because there is no gathering place.

Details about the visually summarized information can be displayed on demand for any frame sector. Thus, for instance, before sending a group of people towards the suggested direction, the user may know the exact capacity of each shelter lying in the corresponding sector and the exact number of vacancies, to be sure that the chosen shelter can accommodate the people (see Fig. 3.a). At this point, the user is immediately able to decide where to address the transportation means and to observe the evolution of the evacuation in real time. For instance, in case the user decides to first evacuate people from the North-right side and routes them towards the North gathering place, s/he will observe the corresponding yellow sector becoming less intense, whereas the blue sector increases its intensity when the bus leaves. Similarly, when the bus reaches the destination, the blue sector gets back to the transparent status and the red sector appears less intense. Figure 17 shows the temporal sequence of the evacuation for this scenario.



(a) (b) (c)

Fig. 17. (a) Visualization of details at the event time, (b) representation of the emergency with some people on the way, (c) representation of the event when some people has reached the shelters.

Besides the visualization of temporal evolutions related to areas or facts, Framy can be also used to perform more specific analyses meant to acquire knowledge useful in crisis situations.

In the following I consider a further request meant to determine a temporal summary of the monitoring activities on selected features, in order to settle evacuation plans if necessary. In particular, I are interested in understanding the evolution of the evacuation from an event area during the last hours. As I previously exposed, users are able to discriminate the visualization of such data on the basis of their necessity. In case they need to make a comparison between the evacuation and other cues of information represented by frames, they can change / move forward and backward the temporal reference by using the smart-phone joystick.

By using the same interaction method, the user can compare snapshot instances of the same aggregate and isolate a specific event by visualizing a sequence of its snapshots.

Figure 18 shows the example of the temporal evolution visualization by means of a snapshot sequence applied on the g_1 aggregate.

Intuitively, the figure shows that the number of evacuated people has quickly decreased in areas 1 and 2, it tends to be constant in area 7, while in the other areas 3, 4, 5, 6 people are completely evacuated after a few hours.

Fig. 18. A snaphost of Framy where nested cornices show the temporal evolution of people evacuation.

2.3 - RELATED WORK

In the last decade, the development of time-critical applications and in particular of applications for the crisis management has become an important challenge that GIS researcher communities are facing in order to provide domain expert users with systems capable to solve complex geographic problems.

In this perspective, the attention is focused on various issues involved in this scope, ranging from the spatial data mining to the exploratory data analysis, from the cartography to the information visualization, each contributing to the whole discipline for a specific aspect.

Taking into account the goal of the research described in this work, I have faced two precise aspects which play a relevant role within the above domain, namely the design of visual interfaces and the methodologies for the output visualization.

As for the visual interfaces, the investigation of advanced solutions has led to well-established results. Decennial conferences and international journals give evidence of such a statement. On the contrary, research efforts have been just recently devoted to visual interfaces for mobile devices, due to the interest demonstrated by international companies. As a matter of fact, in a recent publication [9] the authors affirm that the user interface is one of the main challenges for mobile application design, because the development of mobile interfaces is bound by the small screen size and, as stated in [30], by the limited memory capacity. Moreover, in this latter, although previous work on user interfaces for mobile applications the authors retain that touch-screen-based user interface (UI) is an ideal choice for mobile devices, because it eliminates the necessity of the hard keys and increases the screen size. Moreover they propose a single-layer based UI. Indeed, mobile interfaces are usually multilayered, so in order to perform any operation, the user should know where that command is or how to find it. This is not considered user-friendly. Differently, within a single-layer based UI, all the functions are in front of the users, so they can choose the command to perform the desired functionality.

Applications embedding Framy may be configured to work with different modalities and different kinds of aggregates. In fact, besides choosing the aggregate by which data are grouped (e.g., count and distance.), the user may choose the object(s) on which the aggregate may be applied, whereas the colour representing the result is automatically displayed so as to maximize contrast between the frames. Moreover, the granularity level of the subdivision can be suitably adapted to the user's needs. Another important property of this visual representation is the possibility to create nested cornices and combine the derived on-screen or off-screen information.

Another aspect involved in my research refers to the decision-making discipline. I have applied the Framy technique to this discipline to provide expert operators with tools based on a visual analytics approach. In a relevant study [119]. Visual Analytics is defined as "the science of analytical reasoning facilitated by interactive visual interfaces" and the Geographic Information community, very active in this area, attempts to provide decision makers with advanced tools capable of semantically and visually integrating quantitative, qualitative and cognitive aspects of different domains of interest.

In [5] the author introduces a visual analytics approach to support decision-makers during emergencies. Aggregates are grouped for describing specific facts. Groups are therefore represented by means of bar charts where the horizontal dimension represents the time component and each bar is composed by overlapping bars representing the group aggregates. Each break indicates a change in an aggregate status. With respect their work, in my approach, the aggregates are visually subdivided on the basis of geographical properties, so that every aggregate part is visually “geo-referenced.” Moreover, Framy is specifically optimized to work on mobile devices with bounded space screens whereas the previous proposal requires larger screens to be fully operative.

Similar to my work, [109] propose a software for mobile devices aimed to allow first responders to achieve a rapid on-site decision-making through visual analytics. A slide-bar may be used for navigating and visual-analyzing the aggregates on different temporal instants. Differently from my solution, their solution is oriented to work in closed environments monitored by sensors. Additionally their solution is able to visualize the visual analysis of an event for time such as temperature and CO spread.

Finally, in order to classify my results also in terms of time visualization, I have taken into account an overall survey which compares and categorizes the most important time-visualization methods [2]. According to this subdivision, the approach I have presented is classified as an “ordered time domain” method, that is suitable for representing things that sequentially happen. Among the various discussed proposals belonging to this method, the ThemeRiver technique seems to be the closer to my approach. It is a metaphor of a river that flows through the time. It describes each time-oriented data as a coloured current that changes its width over time. Differently from my approach, such a technique is able to describe quantitative data over time but cannot relate them to their geographical component.

3 – A SYSTEM BASED ON AUGMENTED REALITY AND USER PROFILE MODEL TO SUPPORT PEOPLE DURING EXPLORATION ACTIVITIES

The system we present here, *Framy-AugmentedReality* (*Framy-AR*, for short) suitably combines the benefits of the Framy visualization technique with those of augmented reality (AR) to enhance user's navigation activities with mobile devices. In the new combined visualization method a semi-transparent colored strip is used to summarize information on the points of interest located inside the camera's visive cone, and augmented reality techniques are used to emphasize those points in the current field-of-view. A customizable interface characterizes the system, thanks to the definition of a new technique for computing the best user-adaptive pedestrian route. In fact, the support to the pedestrian navigation is achieved by considering specific features of the pathway under exploration weighting them against user's profile. Moreover, in order to fully exploit the communication potentials of current mobile technology, we have designed a multimodal interface, including visual, audio and tactile interaction modes.

The main advantage that users may gain from Framy-AR is that they can immediately obtain hints about objects located around them. Moreover, weighting elements along a pathway allows to detect the routes which best satisfy requirements derived from user's profile. This latter characteristics makes the resulting application suitable also for physically impaired people, who may benefit from the customized calculation of the best route and from the way such information is delivered through the mobile device, i.e., audio, visual and tactile modalities.

3.1 - THE *FRAMY-AR* MULTIMODAL TECHNIQUE

Framy-AR consists in a project which merges the concepts introduced with Framy into an augmented reality environment to improve the perception of the objects or objects properties on a mobile application characterized by a strong geographic component.

Recent advances in technology have been urging IT researchers to investigate innovative multimodal interfaces and interaction paradigms, able to exploit the increased technological power as explained in [101]. In Framy-AR, users may benefit from two different visualization modalities, namely Basic and Augmented. The former corresponds to the basic two-dimensional Framy view while the latter exploits augmented reality features to improve users' sensory perception of the context. Users can switch between the Basic mode and the Augmented mode by laying down and drawing up the device.(see Fig.19)

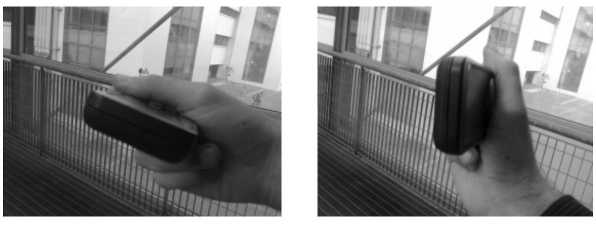
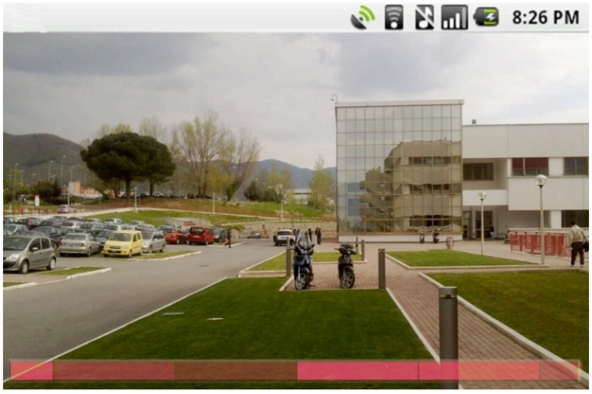
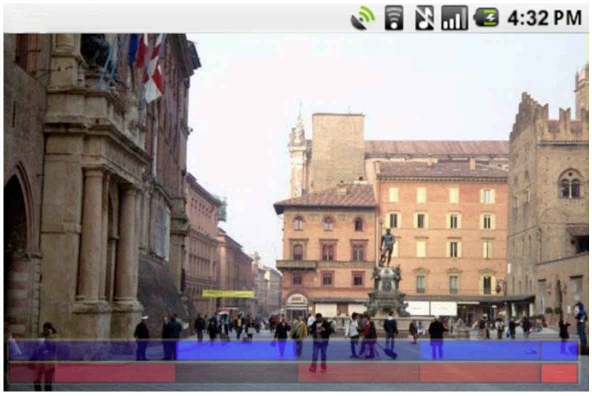


Figure 19. Device positions for Basic Mode and Augmented Mode

With respect to the Basic mode where information is presented by physically inscribing a colored frame all around the border of the screen, in the Augmented mode information is described and visualized by means of a strip which is depicted on the bottom of the display (see Fig.20).



(a)



(b)

Figure 20. Framy-AR in Augmented Mode.

The idea behind Framy-AR is to divide the space around the user into n sectors S1,…, Sn of equal width, 360°/n. Figure 7 gives an idea of this subdivision using n = 16. The surrounding physical environment is augmented by a semi-transparent colored strip which is divided into the corresponding n portions C1,…, Cn. Once the user poses a query, the color intensity[2] of each Ci, is modified on the basis of the value of an aggregate function such as sum, count, etc., applied on a property of the objects located in Si. Thus, the color intensity may be expressed as

$intensity(Ci) = f(g((Si))$ for each $i \in \{1, \ldots, n\}$ (1)

where *f* is a monotonic function and *g* is a function which aggregates a numeric value starting from a set of spatial data.

2 the intensity corresponds to the saturation index in the Hue-Saturation-Brightness (HSB) model.

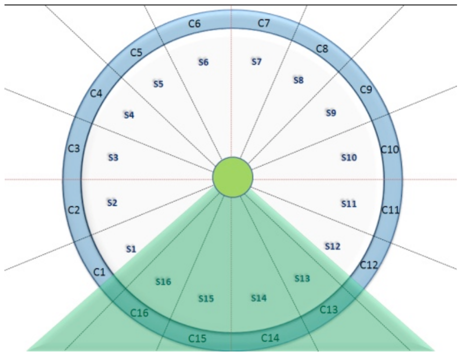


Figure 21. An example of screen subdivision accomplished by Framy and visual cone of user

When in Augmented mode, users will see only the sectors of the surrounding environment which are being captured within the camera visual cone, and the projections of the corresponding strip portions on the vertical plane of the display, to convey information about objects lying in the focused sectors. His view will dynamically change as he turns the camera around.

In Figure 20.a, we applied the sum aggregate function on the POIs located in the University of Salerno (Italy). It is possible to notice that most POIs are located on the front right hand side of the user.

When different aggregates of POIs are needed (e.g., hotels and monuments), Framy-AR can visualize the colored strips representing each of them separately so that the user may summarize information from the displayed strips and make suitable decisions, e.g., about the best direction to the target destination. As an example, in Fig. 20.b the aggregates of hotels and of monuments are considered. Besides taking a glance at the map, the user may want to understand in which direction he should go in order to find the easiest-to-reach area where both hotels and monuments lie. In order to derive this summary information, two strips are visualized – red for monuments and blue for hotels, respectively. The user will notice that the lower red strip has the highest color intensity on the right-hand side of the map, and that the upper blue strip has the highest intensity on the same side. This indicates that, in response to the request, the user may expect many POIs moving the map focus to the right.

In order to extend the capability of Framy-AR to transmit information about the surrounding spatial data, the semitransparent strip can be used to convey information clues both about POIs lying inside the camera's field-of-view cone and those outside it.

As an example, in order to enable a comprehensive view of all surrounding objects, the whole surrounding strip may be visualized on a logarithmic scale (see Fig.22). The scale was chosen to give a priority to the elements inside the camera's cone. So, a scale of measurement that uses the logarithm of a physical quantity instead of the quantity itself is visualized.

Figure 22. Logarithmic scale for 360° view

As shown in Figure 23, degrees are displayed on a logarithmic scale from 0 to 180, both right and left, summarizing the most significant information coming from the front by more extended intervals.

The trend of intervals can be customized by the user changing the base of the logarithm that modifies the layout and size of intervals. In the figure the default value 10 was left for of logarithm base. A user may choose either to represent the intervals using a logarithmic scale, or to display only equally sized portions of the circular strip that correspond to the captured sectors.

Figure 23. Augmented Mode with Logarithmic scale

In order to allow the adoption of Framy-AR by individuals with hearing or sight impairments we exploited the power of the multimodal interaction. The idea is that a user can use a device as a detector that identifies objects. When a user directs the device in the suggested direction, he will perceive an increasing frequency of a beep or of the vibration.

Given a data distribution, users can direct the device towards the suggested direction and hear a sound or feel a vibration whose pitch is synchronized with the color intensity of the corresponding frame portion. Each frame is mapped onto a different signal (sound or vibration) and each frame portion onto a different signal intensity, computed on the basis of the corresponding color intensity thus conveying the same information as the visual counterpart.

3.2 - THE CUSTOMIZATION MODEL

In the area of pedestrian routes calculation, differently from car route, in order to reconstruct a good pedestrian route it is necessary to take into account possible obstacles to the user based on his physical abilities [93][62][124]. Thus, in order to adapt the system to the specific requirements of possibly physically impaired users, we enriched the system with a customization model which allows to highlight those sectors which better respond to user's accessibility needs and preferences. To this aim, we take into account the accessibility score of each POI *a* belonging to a sector *S* computed on the basis of the conditions of the roads conducting the user *u* to that POI and the parameters characterizing *u*. Formally,

$$Score(S, u) = \sum_{a \in S} Score(a, u)$$

where *Score(a, u)* is the score that the model computes for a POI *a*. Basically, my customization model measures the minimum effort that any user has to experience for reaching a given destination. The basis of this model is the length of the paths leading from the user's location to the destination. These values are successively increased on the basis of the path conditions or decreased on the basis of the user's preferences:

1. we penalize a path in a way proportional to the difficulties that users would face by walking along it, while
2. we reward the path on the basis of the specific interests of the user in the destination POI.

From a general point of view, penalizations are specifically due to the presence of obstacles that users find along the paths while rewards are special motivations for the POIs to be reached.

Thus, the score of each POI may be expressed as the difference of two components:

$$Score(a,u) = w_1 P(a,u) - w_2 R(a,u)$$

where *P(a,u)* is the least penalization to reach *a*, *R(a,u)* is the total rewards, while w_1 and w_2 are the corresponding weights whose values belong to [0, 1] summing up to 1. Each weight specifies the importance of a component in the formula. Basically, if either w_i is set to 0 or 1 the corresponding component should be not considered or it is the only feature considered for the final score computation. In order to balance the significance of *P(a)* and *R(a),* weights may be set to 0,5.

In particular, $P(a,u)$ may be calculated by the following formula:

$$P(a,u) = \min_{i=1}^{t}(\mathrm{d}(\mathrm{p_i}) + \mathrm{P}(\mathrm{p_i},\mathrm{u}))$$

where $\{p_1, p_2, \ldots, p_t\}$ are the paths the user may use to reach the POI *a* starting from the his location, $P(p_i,u)$ are the total penalization along the path p_i and $d(p_i)$ is its length.

The final computation of the penalization may be, in turn, divided into two components on the basis of the obstacles typologies that users have to face. From now on, we will distinguish between discrete and continuous obstacles. The former represent obstacles whose degree of difficulty is not dependent on the path length (e.g., stairs or holes) while the latter are dependent on the path lengths (e.g., dirty or steep roads). In general, we defined a pair of matrices (*Disability* x *Obstacle*) where the weight associated to each cell corresponds to the total penalty in case of a discrete obstacle and the unitary penalty in case of a continuous obstacle.

TABLE I. Weights associated to (a) discrete obstacles, and (b) continuous obstacles.

	D_1	D_2	…	D_n
O_1	W_{11}	W_{12}	…	W_{1n}
O_2	W_{21}	…	…	…
…	…	…	…	…
O_p	W_{p1}	…	…	W_{pn}

(a)

	D_1	D_2	…	D_n
O'_1	W'_{11}	W'_{12}	…	W'_{1n}
O'_2	W'_{21}	…	…	…
…	…	…	…	…
O'_s	W'_{s1}	…	…	W'_{sn}

(b)

More formally, let us suppose that:

1. the path *p* is divided into *m* segments $\{s_1, s_2, \ldots, s_m\}$ so that each segment contains an instance of either only discrete $\{o_1, o_2, \ldots, o_k\}$ or only continuous $\{o'_1, o'_2, \ldots, o'_l\}$ obstacles, with $m = l+k$.
2. the lengths of the segments containing continuous obstacles are $\{d'_1, d'_2, \ldots, d'_l\}$
3. the weights of the obstacles along the path, as defined in Table I, are $\{w_1, w_2, \ldots, w_k\}$ and $\{w'_1, w'_2, \ldots, w'_l\}$, and
4. the disabilities percentages of the user *u* are $\{u_1, u_2, \ldots, u_k\}$ for the discrete obstacles and $\{u'_1, u'_2, \ldots, u'_l\}$ for the continuous obstacles, then

$$P(p,u) = \sum_{i=1}^{k} u_i w_i + \sum_{i=1}^{l} u'_i w'^{i}_i d'_i$$

On the other hand, the interest in POI *a* could be considered as a further motivation for reaching it. Basically, it could be seen as a reward which should be set against the penalties. Rewards are based on two values, which consider a classification of the POI domain *I(a,u)* and the POI characteristics mapped onto user's general interests *Is(a,u),* respectively:

$$R(a,u) = I(a,u) + Is(a,u)$$

Initially, when building a user profile, the system stores the score the user assigns to each domain as well as to its derived subcategories. For our purpose, we have considered a classification of 7 POI categories. As an example, the domain museum has the item subcategories archaeology, sculpture, painting, etc. Each category is then described by means of a set of terms which are successively used for calculating the similarity with the POI description. When a user *u* initially registers to the services, she/he is asked to assign an interest value to each general category, and an interest value to each of its subcategories. For every domain, information concerning interests assigned by user to the categories and their specific item subcategories are stored as vectors, as shown in Table II.

TABLE II. User-specified interests for the (a) categories, and for (b,c) their subcategories.

Cats	**C_1**	**…**	**C_m**
u	i_1	…	i_m

(a)

C_1	**$S_{1,1}$**	**…**	**$S_{1,n1}$**
u	$i_{1,1}$	…	$i_{1,n1}$

(b)

…C_m	**$S_{m,1}$**	**…**	**$S_{m,nm}$**
u	$i_{m,1}$	…	$i_{m,nm}$

(c)

As each POI has a pre-assigned subcategory, selection with respect to this reference is immediate. Each POI a is assigned the score associated with the corresponding specific category in the corresponding user profile. Thus, the interest in a POI *a* of a user *u*, classified as belonging to subcategory $S_{i,j}$, corresponds to the interest assigned to the subcategory $S_{i,j}$ by the user *u*, namely:

$$I(a,u) = S_{i,j}(u)$$

In order to calculate the second part of the reward formula, a similarity value $sim(a, C_i)$ is then computed between the description of the POI *a* and the general categories C_i, by exploiting the cosine similarity formula for the vector space model. In particular, in this work we used a simple approach where each term weight of the POI description is set to 1 if the normalized term frequency is higher than a given threshold. Consequently, the relevance between a POI *a* and all the general categories of a user model *u* is computed using the following formula:

$$Is(a,u) = \frac{\sum_{i=1}^{7} \mathrm{sim}(a, C_i)\, i_i(u)}{\sum_{i=1}^{7} i_i(u)}$$

3.2.1 – A WORKING EXAMPLE

Let us suppose that two users u_1 and u_2 have to reach the city town hall from the train station. User u_1 has a partial visual impairment while u_2 has a motor impairment and uses a wheelchair.(Table III) Basically, three paths, p_1, p_2 and p_3, are available from the starting point, the length of p_1 is 100m, p_2 is 160m and p_3 is 200m (Figure 24). Two discrete obstacles are located along path p1, a continuous obstacle is located along p2 for the entire length and, finally, there is no obstacle in p3.

TABLE III. Visual impairments for u1 and u2.

	O_1	O_2	O_3	$\%u_1$	$\%u_2$
visual	30	40	0.2	1	0
motor	50	60	0.5	0.1	0.7

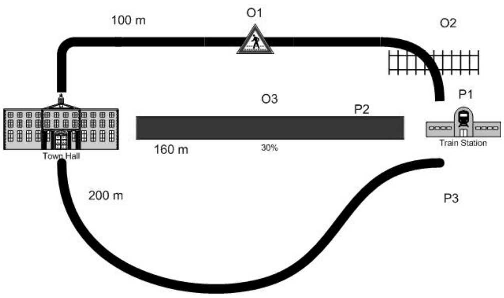


Figure 24 A schematic example of the obstacles located along the paths for reaching the town hall from the train station.

$P(Town\ Hall, u_1) = min_{t=1}^{3} P(p_i, u_1)$

Then,

$P(p_1, u_1) = 30 * 1 + 40 * 1 + 30 * 0.1 + 40 * 0.1 = 77$

$P(p_2, u_1) = 0.2 * 50 * 1 + 0.2 *$ = 11

$P(p_3, u_1) = 0$

and,

$P(p_1, u_2) = 30 * 0.7 + 40 * 0.7 = 49$

$P(p_2, u_2) =$ = 7

$P(p_3, u_2) = 0$

Finally,

$P(Town\ Hall, u_1) = \min\{100 + 77, 160 + 11, 200 + 0\} = 171$

$P(Town\ Hall, u_2) = \min\{100 + 49, 160 + 7, 200 + 0\} = 149$

As a matter of fact, it is possible to notice that even if the shortest path between the train station and the town hall is p_1, the topology of the obstacles along the paths changes the resulting scores. In our example, the impairment of u_1 with the obstacles along p_1 increases its distance of 77 meters which is much more than the 11m calculated along p_2. In the same way, the impairment of u_2 modifies the real distances of p_1 and p_2 by adding the increments due to the obstacles, in this case, 49 for p_1 and 7 for p_2. Given this obstacle and impairment configuration, the path with the shortest calculated distance for u_1 becomes p_2 and the differences between any pair of calculated distances (177, 171, 200) are smaller than the distances without obstacles (100, 160, 200)). On the other hand, p_1 continues to be the best desirable path for u_2 As a matter of fact, the penalization calculated along p_1 is not sufficient to make p_2 the best path.

3.3 - Related work

A valuable work in the area of mobile GIS accessibility has been carried out by Yairi and Igi, who followed a universal design approach to develop their Mobility Support GIS meant for a variety of pedestrians including elderly, disabled, pregnant, and infant users [124]. The routes in their system are represented by lines and nodes. Lines are associated with attribute data of barrier/barrier-free features often found on the sidewalks while nodes are points indicating a nexus with lines carrying different attributes. The gained know-how is proposed in the form of useful guidelines for the development of pedestrian oriented accessible GIS.

An interesting application targeted at physically disabled users was presented in (Izumi 2007). The authors describe a Web-GIS providing impaired people with pedestrian routes. Each route is divided into segments, so that each segment has homogeneous characteristics. The overall characteristics of a route are determined taking into account the difficulties of each obstacle as well as psychological factors related to the specific user. Obstacles are mapped onto a database and a weight is assigned to each of them, so that users can plan the route and analyze the obstacles carefully. We found this very appropriate for a mobility support GIS and decided to apply a similar technique also in the customization model of Framy-AR. Also, the distinction between discrete and continuous obstacles has been retained in the model. However, in Framy-AR weights not only depend on user's ability, but also on user's interest in the target destination and on user's degree of disability. Furthermore, the addition of the tactile and auditory interaction modalities makes our system also suitable for visually impaired users.

Recently, growing attention is being devoted by researchers to the adoption of augmented reality techniques for mobile devices, as a means to guide users or to assist them in the recognition of objects [17][23][57].

The AR technique we present here is based on user's position and on sensors providing orientation on the mobile device. It was partially inspired by the pedestrian navigation system presented in [17]. Based on augmented reality techniques, the user is capable to see the POIs superimposed on the captured video image, he can recognize their location outside the view limits of the camera. The same technique is adopted in Framy-AR, better targeting the use of the original Framy orientation technique to all kind of mobile pedestrian users.

In [57] the authors exploit technologies related to augmented reality and geo-localization to provide visually impaired users with pedestrian routes. The equipment used for the purpose consists of a wearable computer, a microphone and a headphone. Outdoor user's position is provided by a GPS receiver. Indoor position, instead, is retrieved through the ultrasonic receivers. Similarly, our prototype uses a GPS receiver in outdoor areas but it uses a wi-fi hotspot triangulation technique for indoor areas. Finally, the system is smart-phone based.

Also inspired to the benefits of augmented reality, it is worth mentioning the system presented in [57]. The authors propose a walking guide on mobile devices presented as a sequence of “augmented photographs”. Geotagged photographs are retrieved from a database and are automatically augmented with navigational instructions.

Finally, a domain-specific augmented reality application is described in [23]. The authors propose a software for mobile devices capable of recognizing cataloged objects in a museum. The technique is based on user's position and on image recognition algorithms.

4 – An augmented Geo-Community

In this section we present Link2U, an integrated solution for mobile devices which combines the potential of augmented reality with the ability to “communicate” of the social network. In particular, the rationale behind Link2U is to meet mobile users’ requirements of continuously acquiring information about the surrounding environment, essential for their activities. In order to achieve this goal our studies have been especially focused on advanced modalities of geo-localization and on augmented reality techniques. We have in fact decided to combine the potentials of mobile devices with augmented reality features to create a social network that allows members of a group (SNU: Social Network User) to invoke several functionalities, ranging from traditional functions such as messaging, to the calculation of a route on a map and the identification of other SNUs and/or of points of interest (POIs) through the support of augmented reality.

Fundamentals of such an approach can be found in [28][59][80], where initial solutions are described which combine augmented reality and virtual reality, thus forming the basis for modern research. Moreover, a significant prototype of geo-community for mobile devices is described in [80], where maps are used to represent the users’ position. Finally, an example of a guide for mobile devices that involves also community features is proposed in [27], where the users can obtain and share information about points of interest shown on the device.

Two applications recently developed, namely Google Latitude (www.google.com/latitude) and Enkin [17], are representative examples of applications meant to provide intuitive and light navigation systems for mobile devices by suitably exploiting a combination of camera, GPS, and 3D graphics with permanent Internet connection. Latitude is a social network with a worldwide diffusion, which has been introduced by *Google* as a new concept of mobile social network. When connected, a SNU is allowed to display on a map the position of other members of the group she/he belongs to, and she/he can invoke the calculation of the fastest route to reach them starting from a focus point which corresponds to her/his position. Google Latitude is freely distributed on the latest version of Google Map for mobile devices. Enkin is an augmented reality application for mobile devices which has been validated through a scientific approach. It offers a new concept of pedestrian navigation (handheld navigation concept) based on the augmented reality that combines reality with a typical display of maps. In particular, on the screen and superimposed to video image, the user is capable to see the POIs represented in 3D, and can recognize their location outside the view limits of the camera. From a technological point of view, Enkin takes advantage of the camera eye, the GPS, the compass and the motion sensors to detect the point of view. Moreover, through a little radar view-like frame visualized on the display, Enkin also allows a 2D vision of POIs by using the classic map view.

Our proposal combines benefits coming from both approaches and is based on a geolocalization technique which integrates GPS and WiFi Positioning System (WPS). The latter allows to accurately determine the location of wireless access points (APs) to estimate the physical location of a WiFi enabled device, thus overcoming limits of GPS in terms of coverage and accuracy.

Thus, the ultimate goal of our research has been to design and develop an advanced mobile interface able to support users' daily activities, within a mobile social community. As a result, users are provided with services where mobility comes into, such as services that support navigation and location based services (LBS), which may further enhance their activities inside a wide community of people.

A prototype of Link2U is being tested at the University of Salerno. A cross-cultural community has been involved, which includes students and teachers from different faculties. The prototype allows SNUs to determine individual indoor/outdoor positions and calculate the path towards some target POI or some other connected SNU. To build Link2U we exploit a modern mobile device that combines an integrated camera for video-image capture, a Global Position System (GPS) device to detect the position, a compass and motion sensors to detect user's point of view.

4.1 - Representation of the geographical information: regrouping methods

In order to avoid confusion due to SNUs crush on the screen, a selected number of them or alternatively a grouping metaphor should be displayed. In this section, we present two grouping methods which allow users to avoid a "sensorial overload" due to the visualization of multiple elements.

The first can be used to visually summarize information distributed within an area of interest. The basic idea is to divide the world around the user into sections exactly in the same way described in section 3.

As an instance, Figure 25(a) divides the world into 16 sectors (S1-S16). The green triangle located on the bottom shows the camera visual field. Figure 25(b) shows an example of visual representation. On the bottom of the screen, the system visualizes an arc, representing the portion of the world bounded by the camera visual field, divided according to the corresponding sectors. The color intensity of each portion is proportional to the number of SNUs located in the corresponding sector.

The technique we have adopted for assigning a color and its different intensity degrees to a circle is based on the Hue, Saturation, Value (HSV) model. Starting from this model, we have specified how its components may be calculated in order to determine the color value of each part, namely the HSV value associated with each portion. In particular, we set the Value parameter to 100, thus implying that each part is always associated with the highest color brightness, while the Hue component corresponds to the color assigned to the whole circle.

As for the Saturation index, which corresponds to the color intensity, it is determined on the basis of the number of SNUs located in each sector, that is to say:

$$s_i = \frac{SNU_i * 100}{SNU_{Tot}}$$

where s_i represents the saturation of the i-th sector, SNU_i is the number of SNU in the i-th sector and SNU_{TOT} is total number of SNU within a given buffer.

A further improvement of this technique allows users to disaggregate SNUs belonging to different contact lists. In this case, each list is associated with a differently coloured circle. Each part of the circle is then associated with a different intensity of the chosen colour on the basis of the number of SNUs related to that circle.

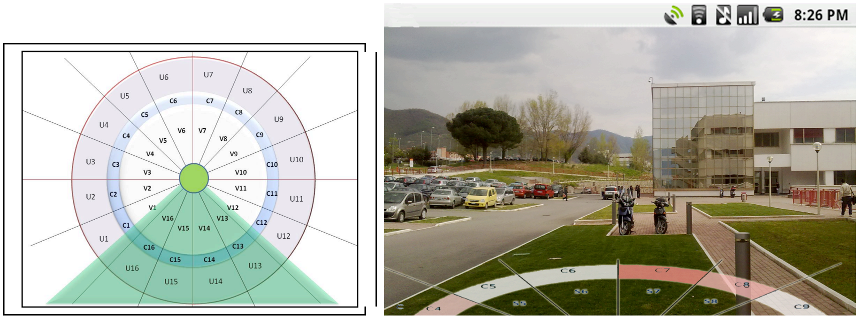


Figure 25. (a) Sector division of the region around the user, and (b) an example of the visual representation.

The second approach can be used to visually summarize information distributed within an area of interest. The idea is to map meeting places on the basic cartography, such as library, classroom and swimming pool, where SNUs are used to gather. Such places can be detected as Area of SNU Aggregation (ASA) through the  icon. When the SNU number / ASA surface ratio is bigger than a threshold value, the icon evokes the presence of a set of SNUs as shown by the associated label. This approach is exploited in Map mode when the zoom level is within a specific range, and in Live mode when the user position is outside the ASA. Figure 26 depicts the visual representation of this visual aggregation technique.

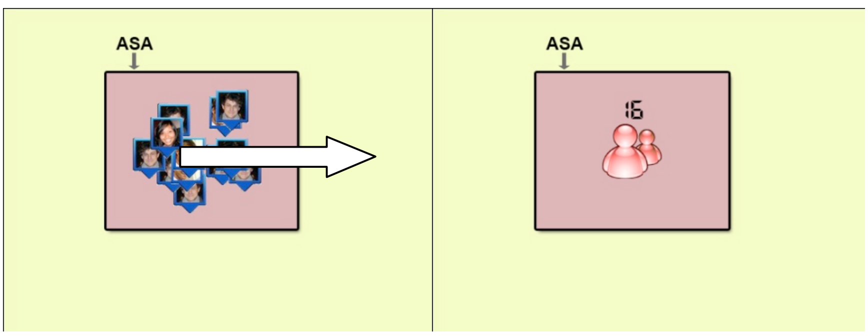


Figure 26. Visual aggregation technique

As a matter of fact, both aggregate methods presented in this section allow to catch a general vision of the world surrounding the user in a easy and intuitive way avoiding the sensorial overloading due to the SNUs crush. In particular, they can be invoked as a sequence of representations which allow users to generalize or detail the content of a given region, depending on the required data. As a matter of fact, they can be applied within two different scenarios in order to extract two different kinds of information. In particular, the aggregation based on circles plays the role of a long distance scanner capable to qualitatively transmit the number of contact list SNUs currently available in given directions. Such an approach can be used when the region of interest is not directly visible through the camera, due to the topology of the region or the distance from the point of view. Differently, in case SNUs fall within the camera view and are topologically located within an area of interest, they could be aggregated by using the second method. In fact, this latter results more suitable when aggregations are required for delimited regions and can be used to represent a summary of the people who can be found in POIs.

In fact, the two methods may be considered as a sequence of representations which allow users to generalize or detail the content of a given region.

4.2 - Scenario

In order to provide an example of the effectiveness of the Link2U approach, a prototype has been realized, namely Link2U@Unisa, and the following scenario of a mapping navigation and social interaction among SNUs has been run.

The scenario is representative of the experiments we have carried out at the Fisciano campus of the University of Salerno. It includes two tasks describing the functionalities offered by Link2U.

In the first task, Monica receives a new student named Davide. Monica does not personally know Davide but she knows he is registered on Link2U community.

In order to accomplish the first task, Monica adds him to her contact list and accesses to Link2U@Unisa in Map mode. The application provides her with a distribution map of the SNUs belonging to her contact list. In this case, the Map mode is useful to obtain a global view of the campus.

Figure 27 (a) shows the resulting map where Davide is visualized. In particular, Davide is in the parking area of the swimming-pool and his status is *free*. Monica asks the system to calculate the route towards Davide.

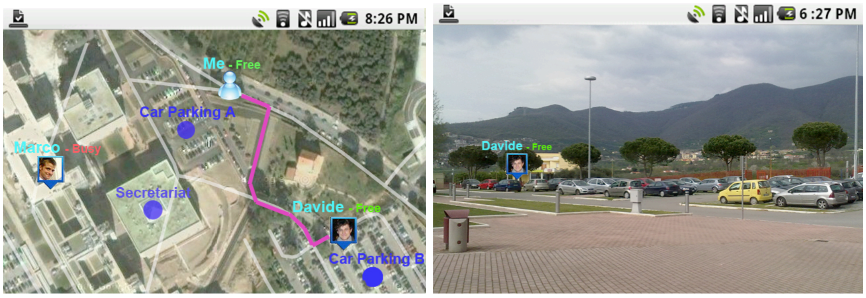


Figure 27.(a) Map mode visualization of Davide's position. (b) Live mode representation of Davide's position

Monica reaches the car park and switches to Live mode. This helps her to recognize Davide, as shown in Figure 27 (b).

In the second task, Enzo is located at the main entrance of the campus and wishes to reach a meeting for foreign students organized in a contact list.

In order to carry out this task, Enzo looks on the device in Live mode and takes a look at the distribution of the people of the foreign contact list (see Figure 28a). In this case, he enables the aggregation method based on colors and recognizes that the most numerous group is located on the right-hand side, thus deciding to follow that direction.

After 200 meters he is in the center of the campus and decides to switch the system to visualize aggregates by ASA (see Figure 28b). He finds out that a crush of foreign students is located in the library and decides to reach the building.

A relevant functionality within task 2 is represented by the route calculation. Such a service may be invoked by both modalities according to user’s purpose, such as car navigation and pedestrian exploration.

Once invoked this functionality in Map mode, Monica obtains the route towards Davide and starts navigation

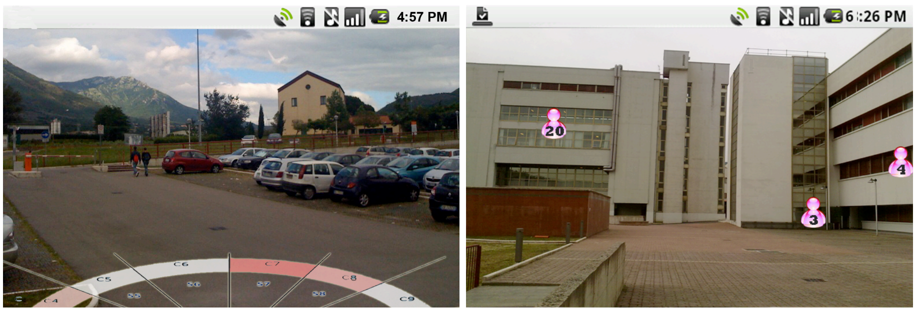


Figure 28. (a) Aggregates of foreign people based on color gradients in live mode, (b) aggregates of foreign people based on ASA

4.3 - The system prototype

Link2U@Unisa is an initial version of a prototype realized in order to validate some of the functionalities underling the approach previously described.

In the following subsections we present the software frameworks used to develop the application on mobile device and illustrate the underlying architecture both in terms of system network and client application.

4.3.1 - The System Network

The architecture of the system is client-server based, where the server is responsible for coordinating and updating the positions of the various clients. SNU personal data are stored in the database A in Figure 29

In our case, the server works as a broadcast node, receives information from clients related to their position and their ID, and rebroadcasts such information to all clients. The client represents the SNUs currently connected to the network, recovers their position to make them known to the server and collects information related to other SNUs from the server.

The update of a SNU position is delegated to a server that receives the new position and sends it to all SNUs. When the position of a SNU moves significantly from the last recorded position, its device registers the new location and sends it to the server.

As shown in Figure 29, the localization of a client is obtained through two methods. The former corresponds to the classical localization through the GPS standard. The latter calculates the position through the triangulation of the WiFi hotspot signals.

The technology works by sniffing for the surrounding WiFi networks, then measuring signal strength and comparing those results with a database. This implies that a service provider would need to conduct periodic sweeps of an area to catalog the WiFi hotspots that populate the database B. It is worth to note that the client connection is not really required, i.e., the client only scans the hotspots to measure relevant factors used for the database lookup. The location accuracy is proportional to the number of hotspots present in the area around the device.

The client collects data related to the signal strength and its SSID, and transmits them to the server, which in turn calculates the position of client according to the data contained in the database and sends an "Update Position" to all clients.

The GeoServices block embeds two servers which offer external functionalities targeted at generic users, thus reducing the computational work load on the mobile devices. The block communicates via HTTP with the clients, no intermediate node is needed.

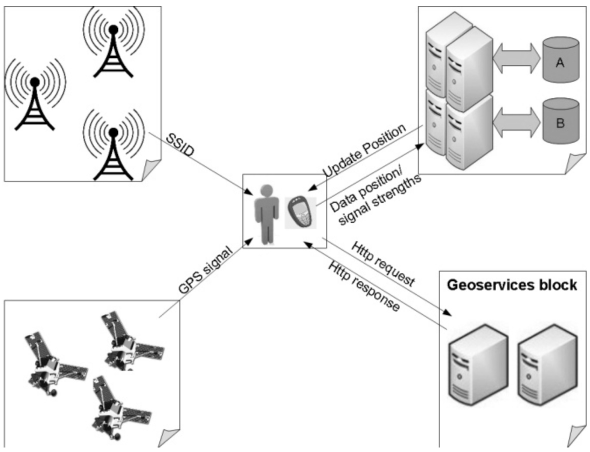


Figure 29. Hardware architecture

4.3.2 - The Client

The client application has been developed on a G1 HTC DREAM that incorporates the needed hardware along with a Linux embedded system (Android) which allows great freedom in the development of applications.

From a technological point of view, the HTC Dream combines an integrated camera for the video-image capture, a GPS device to detect the position, a compass and motion sensors to detect the user point of view. Moreover, WiFi allows to identify user's position with a good accuracy inside the area not covered by GPS signal. This is possible through a technique of triangulation of the access point positions. Obviously, this service can be offered only within WiFi covered areas, where positions of access points are known.

Android includes a set of core libraries that provides most of the functionality available in the core libraries of the Java programming language. It provides applications with access to the location services supported by the device through the classes in the android.location package. The central component of the location framework is the LocationManager system service, which provides an API to determine location.

The access of a map is provided by MapView that displays a map with data obtained from the Google Maps service. MapView captures key-presses and touch gestures to pan and zoom the map automatically, including handling network requests for additional maps tiles. It also provides users with all of the UI elements necessary for the map control. The applications can also draw a number of Overlay types on top of the map. In general, the MapView class provides a wrapper around the Google Maps API [49].

Android also supplies 3D libraries, an implementation based on OpenGL ES 1.0 APIs. The libraries use either hardware for 3D acceleration (where available) or the included highly optimized 3D software rasterizer.

Link2U@Unisa uses LocationManager for identifying the current position when the GPS signal is accessible, otherwise it exploits the WiFi hotspot triangulation technique.

The Map mode uses the MapView framework to view data either on a street plan or on a satellite image. The Live Mode displays data in a 3D environment by using the OpenGL ES and superimposes them on video-captured by camera.

Typically mobile devices have some computational limits that can slow down the application performances. To overcome such limits we exploit some Web Services, thanks to the Internet permanent connection of the device. In particular, for outdoor navigation a route from a user to a POI/SNU is provided by the GPX Driving Direction [51]. As for the indoor mobility, an ad hoc campus cartography and a service have been realized. However, both services receive two couples of coordinates representing source and target points, calculate the path between them and transmit it in GPX format (the GPS Exchange Format) [50] . GPX is a light-weight XML data format for GPS data interchange between applications and Web services on the Internet, such as waypoints, routes and tracks. In Map mode a route is designed according to the list of waypoints in the GPX file.

In Live mode, more information is necessary, namely the height of points. Due to the low accuracy of the height detected with the GPS, it can be achieved through the geo-service GeoNames [47]. Finally, by sending the coordinates of each point belonging to the waypoint list the corresponding heights computed at sea level are obtained.

5 – Use of Framy for a Spreadsheet-Mediated Collaboration Environment

In the previous sections we describe GIS applications designed involving the *Framy* technique. In this section instead we show an application of the technique in a totally different field that is the area of collaborative systems for the context of Small and Medium sized Enterprises (SME). This example shows the adaptability of the technique to different areas.

The SME, the enterprises with less than 250 employees, represent the most important business sector all over the world. In the European Union, for instance, they represent 99% of businesses which corresponds to over 23 million of companies which drive the growth, the innovation, the employment and the social integration of all the continent. In Italy the percentage is even higher, indeed SME are near 4 million which is 99.9% of all the companies in Italy. With these numbers, it is clear that much work and research need to be carried out in order to support their activities and promote their growth by helping them tackle the problems which hamper their development. The document entitled "Small and Medium Enterprises and ICT" looks at how the knowledge-based economy has impacted small and medium enterprises (SMEs); explores why so few SMEs have adopted ICT so far and provides some policy recommendations for promoting SME adoption of ICT [71]. The authors observes that many small and medium enterprises have not yet fully benefited from ICT support, especially because they lack engagement in regional and global business networks. Access to ICT is a necessary prerequisite for SME to get business opportunities by connecting to networks both as part of the global market and as to support distributed internal business activities.

Unfortunately, the process of migrating from traditional activities towards IT-supported activities, known as *eTransformation* process, is in fact slowed down by several practical issues which small organizations have to face in order for the process to be effective [59]. The small size and the limited human and financial resources, which usually characterize SME are one of the main obstacles to making business processes more effective by using appropriate information and communication technologies. Nevertheless if a cost effective solution can be found which is both easy to use and maintain then these organizations will benefit immensely.

Spreadsheets are intensively used for crucial management activities by several organizations. Since the introduction of the first computerized spreadsheet, VisiCalc, in 1979, the adoption of spreadsheet applications has been continuously increasing in different domains, and is today recognized to play a central role in the evolution of work systems. Many years ago Nardi and Miller observed that spreadsheets functioned as de facto cooperative work, but they lacked technological support for cooperative work environments [82]. Since then, little progress has been done in that direction. Grossman and colleagues concluded from their research on the use of spreadsheets as an effective software development platform that 'spreadsheets are vitally important to business, and merit sustained research to discover techniques to enhance quality, productivity, and maintainability' [59]. This is especially true for SMEs, where the way how collaborative activities using spreadsheets are performed, namely by email exchange of the spreadsheet artifact or by keeping it on a network drive, may seriously mine the effectiveness of the business process.

We investigated SME business in order to understand which problems and which solutions can be adopted to improve their work in terms of efficacy and efficiency and, then, increase their opportunities. The goal of this research project is to enhance the business processes presently carried out by SME using spreadsheets, designing and developing a web based spreadsheet mediated business collaboration system. In the next section we resume the field study and the user interface requirements derived from it. In the third section we describe briefly the interaction design we used to meet the requirements. In section 5.4 we show a prototype of a mobile interface and we describe the related visualization problems and the solutions we used to tackle off them through Framy. After that in section 5.5 we describe a modified version of the MVC model we studied in order to develop the architecture of the collaborative system.

5.1 - The field study and user Interface requirements

We investigated SME business in order to understand which problems and which solutions can be adopted to improve their work in terms of efficacy and efficiency and, then, increase their opportunities.

The preliminary activity we performed for our field study consisted in a survey on the use of spreadsheet applications conducted among people with different backgrounds and operating in different application domains.

Analyzing the survey results, we were able to set up the right investigation thread for the contextual inquiry and observations that followed. We identified a group of 5 SMEs operating in the Western Sydney Region as interesting subjects for further observation. In fact, the collaborative nature of some of their usual activities accompanied with a minimal or non-existence of information technological support to such activities, turned out to be the right context of study for our research. The 5 SMEs were selected out of a cluster of 30 companies taking part in a wider project carried out at University of Western Sydney [71], meant to provide a methodological roadmap. The goal of this fieldwork was to depict scenarios of established work practices, from which user's requirements could be derived for a spreadsheet-mediated collaborative web environment. The informal interviews performed *in situ* allowed us to gain a comprehension of collaborative activities requiring the use of spreadsheets, as they really occur in small working environments. As a result, we gained useful insight of the obstacles which, in the context of small organizations, appear to hinder the full exploitation of the powerful functionalities of spreadsheet applications as a way of supporting to collaborative activities. Indeed, the major problem turned out to be the small size and the limited human and financial resources, which usually characterize SMEs. Although all the interviewees recognized that great benefits would come to their business process from the adoption of a web-based collaboration environment for their spreadsheet sharing activities, their major concerns were related to the cost of this technological evolution within their small organization.

In order to formalize the requirements elicited from the interviews, we capitalized the knowledge gained from the fieldwork and envisaged some scenarios of working practices, from which we could start our brainstorming activity for the design of a possible solution.

The brainstorming activity allowed us to draw a suitable set of collaboration scenarios that the target web environment should provide. Figure 30 depicts one of such scenarios, which captures essential aspects of the spreadsheet mediated collaboration, namely: the participants, their individual status (idle vs. *busy),* the feedthrough (the dashed arrows in the figure) gained by locking cells during modification and by highlighting cells after modification, and, finally, the observability of the overall collaboration process by means of a revision history associated with the shared artifact.

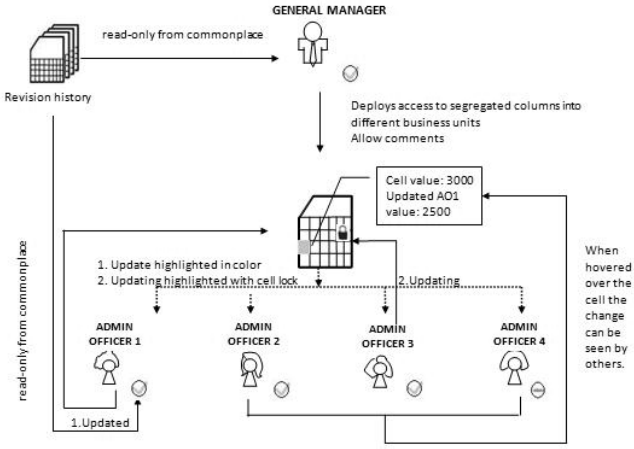


Figure 30. A spreadsheet mediated collaboration scenario.

We identified three main separate categories of user interface requirements for a web based spreadsheet mediated collaboration system, namely:

- *Collaboration environment awareness*
- *Shared spreadsheet manipulation*
- *Overall collaboration process analysis*

The first category comprises all the functionalities that allow collaboration awareness issues to be properly addressed by the environment, both during synchronous or asynchronous collaboration through a spreadsheet. The second category includes all the functionalities that would allow the spreadsheet artefact to be effectively manipulated by multiple participants through the web environment, in terms of either data updating or structure modification. The complete list of requirements is reported in Table 1.

Requirement	**UI functionality**	**Rationale**
	Collaboration environment awareness	
R1	list of participants steadily visible in the collaborative environment, each one associated with an	At any time the user might wish to understand who is sharing the spreadsheet application and who is actively operating on it.

	idle/busy/absent flag.	
R2	access control setting: tool available to the spreadsheet creator, who associates a role to each participant.	Data access rights should be properly distributed among participants.
R3	a visual cue associated to each participant to indicate the role.	The visual cue is needed to inform a participant of what are his access rights to a given portion of the spreadsheet. Moreover, a participant's role should be immediately understood by the others. One may wonder who is going to share access to a given portion of the spreadsheet and with what privileges.
R4	individual status setting: from *idle* to *busy* for temporary interruptions (this can be either activated by the participant or automatically set by the system); from *idle/busy* to *absent* if the participant abandons the collaboration.	A participant, who is interrupted by external events while collaborating, should be able to notify his temporary absence with a busy flag. On the other hand, an automatic status change from *idle* to *busy* is also desirable, if the system realizes no actions (including navigation or scrolling actions) have been performed for a certain, predefined, time period by that participant. Any further prolonged absence should cause the transition to the *absent* status for that participant.
R5	chatting window tool available on demand.	Synchronous collaboration activities might especially benefit from real time comments shared among participants.
	Shared spreadsheet manipulation	
R6	multiple user conflict resolution - cell editing vs. cell locking notification.	Whenever a participant is editing a cell/a block of cells, those cells should appear 'locked' to the others, to avoid undesirable overlapping.
R7	notification flags associated with each of the updated sheets in the document.	Persistence of the effect of an action performed by other participants should be ensured on the interface. In that way the participant realizes that a change has happened somewhere in the spreadsheet, even if he disabled the WYSIWIS mode.
R8	colour changes highlighting	Collaboration feedthrough. Each participant

	modifications.	should perceive the colour change as a cell change.
R9	spreadsheet re-structuring vs. spreadsheet locking notification	Whenever a participant with the right privileges wishes to modify the structure of the spreadsheet application, the other participants should be warned that the whole spreadsheet is temporarily locked and no data manipulation can occur.
	Overall collaboration process analysis	
R10	revision history tool for evoking any previous version of the spreadsheet from a shared archive. Querying should be done either selecting a single cell or selecting a participant or indicating a time frame.	As explained before, such functionalities are not part of the collaboration but are necessary to provide robustness. A participant might wish to backtrack some of the performed collaboration activities, searching the previous contents of certain cells, and/or searching the modifications performed by a certain participant and/or those performed in a certain time frame.

Table 2. The user interface functionalities

5.2 - Interaction design for the collaborative environment

In this section we briefly describe the interaction design phase, which led to the development of the current prototype of the system.

It encompasses some of the basic design choices we made to fulfill the derived requirements. In particular,

- *R1, R2, R3, R4, R5* were addressed by the following *Design Choice*. The shared spreadsheet is provided with a window which lists the users currently connected. Each element of the list is associated to a given color which indicates the user's status.
- *R3. Design choice.* Any single cell may be accessed in Read/Write, Read-Only or Hidden mode depending on individually assigned privileges. The user will see a cell red if it is hidden, yellow if it is read-only accessible, or in the original background color if he has R/W privileges on that cell.
- *R6, R9. Design choice.* Whenever a participant is editing a cell/a block of cells, those cells are colored with the user's identifying color so as to appear 'locked' to the others, and avoid undesirable overlapping. If a user tries to modify a locked cell, he is notified by means of an error message.
- *R7, R8. Design choice*. After the user changes the content of a cell and unlocks

it, the system draws a line along the border of the cell with the color identifying the user. The colored border is visible to each participant, who may click on the cell to acknowledge the other's update and make the border disappear.

Figure 31 shows the collaborative web interface of the spreadsheet-based prototype, as it appears to one of the participants. The web interface has been developed using Adobe Action Script 3 and runs directly inside a common web browser.

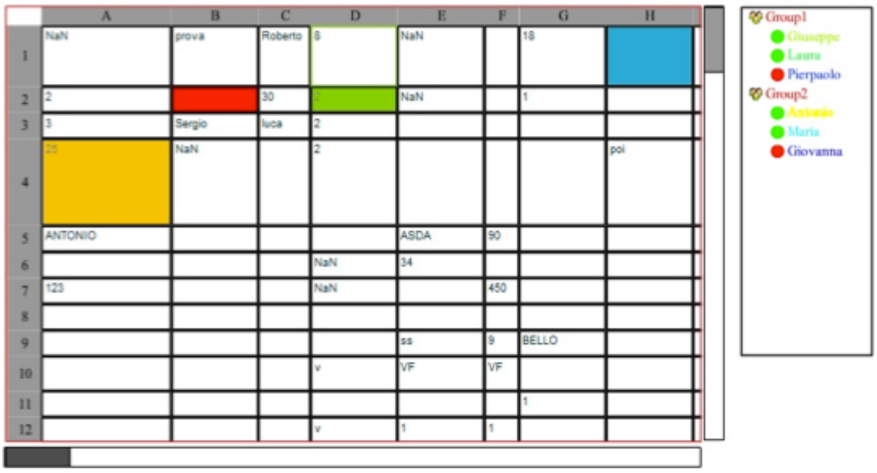


Figure 31. The interface of the Web Collaborative spreadsheet.

5.3 – Collaboration in mobility

So far we have seen how a web system can improve the way SME works. It allows users to collaborate and share information everywhere thanks to the web. The new challenge now is to allow users to collaborate everywhere and anytime in complete mobility. For this reason mobile devices play a fundamental role in the field of the office automation in the perspective of a real "anywhere" collaboration.

The spreadsheet is presented as a single image at a prefixed zoom level. Users can explore the spreadsheet by sliding it with their fingers in all directions. When users touch a cell they do not trigger off the appearance of the text input interface. This choice is due to the fact that users need to touch one or more cells to slide the document. When they want to modify the content of a cell they have to explicitly require the appearance of the text input system by selecting the desired cell and then touching the text area on the top of the document.

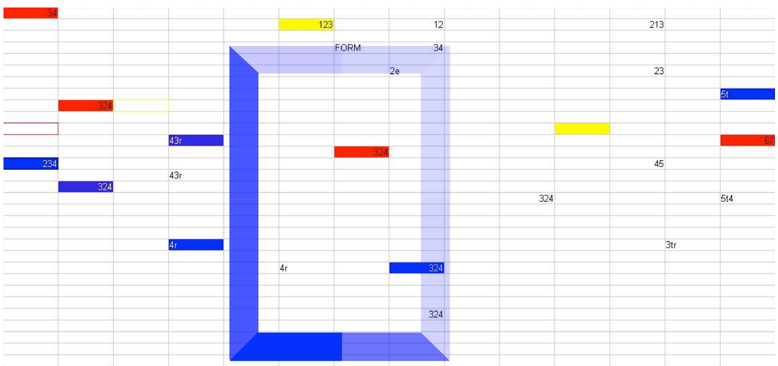
We designed the mobile interface trying to meet the interface requirements. All the requirements were met in the same way they are already met in the web interface with the exception of the first one. It indeed requires a constantly visible list of participants but this is possible only in the case of fairly large screen dimensions. For this reason, we produced two interfaces: one for tablet devices, like the iPad, and one for classic touch-screen phones, like the iPhone. The first interface completely meets the first requirement by showing the constantly visible list while the second one provides a semitransparent list available on users' demand. This is because on a small screens the list would cover a good portion of the document, making it unreadable.

Figure 3 shows the collaborative interface of the spreadsheet-based prototype, as it appears to two participants. The first participant uses a tablet (fig.32 a) and the second one a classic touch screen phone (fig.32 b).

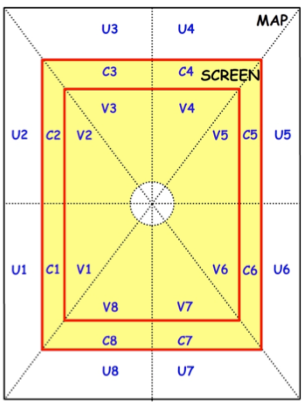
(a) (b)

Figure 32. The interface of the Collaborative spreadsheet

When users visualize the spreadsheet on a large screen do not have problems to perceive the changes of the majority of cells. They know which cells are updated and who worked on them. When they use a mobile device they could just visualize a couple of short columns of the whole document (fig. 33 b) so they are not able to perceive many of the changes of the cells.



(a)



(b)

Figure 33 – (a) the framy technique applied to the spreadsheet. (b) the subdivision of the device screen

The basic idea is to use semitransparent frames to give information about the external distribution of the modified cells. In order to avoid confusion due to frames crush on the screen, the interface displays at the most one semitransparent frame at a time (fig 33a). The default frame gives information clues about the position of all modified cells. The color intensity of each frame portion is proportional to the number of cells located in the corresponding outside sector. According to the subdivision depicted in Figure 33b, the functions which calculate the colour saturation are defined as follows:

$$S_i=(g_i*100)/G,$$

where $\mathbf{g_i}$ represents the result of **g** in $\mathbf{U_i}$ and **G** is the number of modified cells located in $\mathbf{U_i}$.

Users can also retrieve information about the cells modified by a specific user. By clicking a specific username presented in the contact list the frame gets the color of the given user and the color saturation function becomes

$$S_i=(g_i*100)/G_{usr},$$

where $\mathbf{g_i}$ represents the result of **g** in $\mathbf{U_i}$ and $\mathbf{G_{USR}}$ is the number of cells located in **Ui** but modified from **USR**.

5.4 – Extending the MVC model to design the collaborative system architecture

The major differences that a user will perceive with respect to the standalone spreadsheet is the effect of synchronization achieved through cell locking. A user may decide to modify a set of cells which should not be modified by other participants meanwhile. In this case, a multiple cell selection mode is available, named Multilock, which allows users to lock a cell and all the related ones (e.g. when a user locks a formula).

The CoMVC pattern is a specific extension of the Model View Control (MVC) pattern, to which components addressed to manage collaborative access have been added (see Fig. 34). In particular, the Model is described by means of an abstract class which provides a public method *setRestrictedCell* and a protected abstract method *setCell*. As a matter of fact, when a user tries to access some cell, a call to the *setRestrictedCell* method is invoked which verifies the user accessibility to the cell both in terms of user permission (by calling the *isEditable* method) and locking. Then, in a positive case, the *setCell* method implemented by the subclass is invoked, or an error message is returned, otherwise. This solution was driven by the choice to let the user change the policies for storing cell information (by implementing the abstract method *setCell*) and for accessing the cell data (by implementing the interface method *isEditablebyMe*). Moreover, in order to manage locked cells, the *RestrictedModel* class also contains a reference to a set of cells. This class is characterized by two main methods: *unlock* and *lock*, which provide the access and the status of cells in the set.

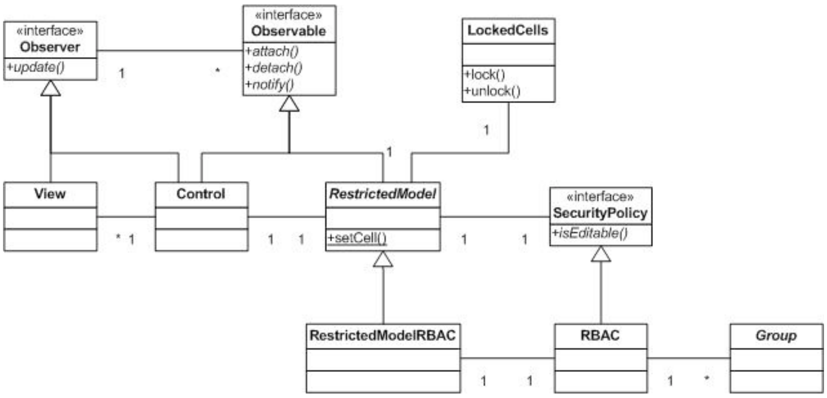


Figure 34. The architectural description of the system.

5.5 - Related Work

In recent years several web based spreadsheet applications have been developed with the aim to exploit the data sharing and collaboration capabilities through distributed manipulation of spreadsheets within complex organizations. Review on existing online spreadsheets proves the emerging need to provide tools by which cooperative activities on spreadsheets could be effectively performed. With no intention to be exhaustive, we mention here some of the available commercial web based spreadsheets and highlight their major limitations. One of the most readily available environment is Google web based spreadsheet [45]. Multiple users conflict resolution is not supported: cell editing is made visible to other participants, but no cell locking is provided, resulting in possible information lost. In any case, cell updates are not notified to other participants, after they have been completed. The collaboration environment indicates the logged in participants, but their current status is not displayed, nor individual status setting functionality is provided. A cell level revision history is present, but no information about who has made certain modifications at a certain time is available. Another product which has the most exploited functions and features is EditGrid [114]. It supports online collaboration through a spreadsheet but presents some severe usage limitations. For instance, cell locking and sharing privileges are only assigned to the spreadsheet creator, role based access is missing, and, although a cell modification is immediately notified to co-participants, no indication is given of who made it. DabbleDB is an online database with spreadsheet as an interface [33]. However, it lacks most common spreadsheet functionalities, and it is especially promoted as a means to import data to the web from local spreadsheet applications, implying critical issues related to information redundancy and collaboration effectiveness. Numbler is another small time spreadsheet application which has limited features but facilitates sharing and collaboration [82]. There is no archiving done as the links to the file that are shared are sent to the email of the users, so tracking of documents have to be done by searching through the mailbox. Finally, BadBlue is an online server which facilitates sharing of spreadsheets and supports collaborative work on them [10]. Conflict resolution is managed at cell level, by means of appropriate locking. However, no notification is given on activities currently performed on the spreadsheet by others, and a participant is notified of a cell locking only when he attempts to save his updates to that cell. Moreover, any additional support to collaboration that may come from, e.g, awareness of active co-participants and direct communication through chatting is missing. Complete revision history can be accessed through log files, which are automatically created at any cell update, but yet change notification flags are not displayed in the shared spreadsheet.

Summarizing from our analysis of commercial online spreadsheets, we realized that a common limitation is that usability issues have not been adequately addressed when conceiving the transformation of spreadsheets from single user to multiple user application. This is in fact the reason why none of those systems have been widely adopted so far by organizations which use spreadsheets for complex collaborative activities, while their use is mainly limited to simple list maintaining activities and to multiple user read-only access.

6 – SUMMARY

In this chapter I presented four applications we developed related to the visualization of spatial data using Framy technique. The first application is an example that shows how the traditional Framy technique can be used as powerful visual analytical instrument to support decision makers during the management of a crisis. I also described the scenario-based approach used to get user requirements, and showed a working scenario in order to provide an example of the Framy capability to support decision makers during a crisis management operation.

The second one is a new system that supports users during the exploration activities through an interface based on augmented reality. The Framy principles are used to design a significant variation of the original Framy visual metaphor in order to orient users towards POI that are not visible on the screen. Through the multimodality and a user profile model, that considers the users' disabilities, the system also allows impaired users to interact with it. A working example is given in order to demonstrate how the system operates.

The third application address the issues related to the geo-visualization of users of a web community. It exploits two different modalities: on map and on augmented reality. Also in this case the Framy plays an important role in the design of visual metaphors that support the users' orientation and avoid the visual information overcrowding on the screen.

The last application is related to the area of collaborative systems. The work provides users with two different spreadsheet-based interfaces. One is a traditional web interface that allows users in different locations to collaborate using desktop computers. The second is a mobile interface that allows users to work and collaborate while being mobile. The mobile interface presents a problem related to the users perception of the modifications of the cells contents. We showed how this problem can be overcome by using a variation of the Framy technique.

The spatial data in these projects can be represented as complex interactive and navigable images that present scattered points of interest as the case of maps, augmented reality and spreadsheet. In each application this issue is handled by applying the Framy technique modified to be fit for the specific case but always holding the basic principles underlying the original idea. The usage of a visual metaphor to regroup information and its strategic positioning on the screen to give users spatial information, and the usage of the multimodal interaction when it is needed are all principles associated with Framy. Therefore the successful application of these principles in several fields demonstrates the effectiveness of our solution.

Chapter 5 – Virtual Keyboard Application

So far I have shown how the visual technique Framy can enhance the interface capability of visualize spatial data. However user interfaces are a means to exchange information between users and device. Therefore they have to handle both output and input activities. In this chapter, I introduce a new soft keyboard, named Tap and Slide (TaS), specifically designed for mobile devices to effectively input information. The new interaction method, on which the keyboard is based, allows to perform text entry operations in a very small space, thus minimizing the space required. In order to evaluate the TaS keyboard from a usability point of view , I performed three studies: the first to find out whether there is a difference in performing text entry operations between technology experts and non-expert users, the second to evaluate the rate at which people learned to use the keyboard by considering the number of errors and the time to perform a given task over a period of time, the third to compare the performance of the soft keyboard with the more common QWERTY soft keyboard.

1 – Introduction

In the context of interfaces for mobile devices, a research area where a lot of efforts have been put concerns text entry methods, for which different interaction design methodologies and text input techniques have been proposed so far. Text entry has become even more significant due to the introduction and the widespread adoption of new single-touch and multi-touch screen technologies for mobile devices. Indeed, touch screen interfaces allow to experiment new kinds of interaction which may produce benefits in different domains. As an example, the concept of pervasive computing may benefit from new text entry techniques embedded within such interfaces, even though related problems may arise from them. In [78] the authors exemplify a real situation, by underlining how tablet computers in the domestic use represent a significant support whose value may be limited by the lack of an efficient text input interface that may make the interaction with common applications complicated.

Virtual Keyboards (VK, for short), Handwriting Recognition and Voice to Text represent the most popular and effective solutions [125]. By reproducing a QWERTY keyboard on the screen, a VK technique exploits the user's experience in using a traditional hard keyboard. However, the limited screen size affects the key dimension, thus reducing the effectiveness of such a solution. So far, researchers have designed many different layouts in order to enhance VKs as said in [74][100]. Handwriting Recognition allows users to write text directly on the device screen usually by means of a stylus. This technique is suitable for users who prefer the traditional way of writing. However, frequent corrections due to the wrong interpretation of text symbols imply a limited speed of writing. By transforming spoken words into text, a Voice to Text system eliminates the need of an interface. The main drawbacks of this technique are due to the lack of privacy, as said in [1], and the error rate in voice recognition.

The analysis of daily situations where the aforementioned techniques may produce a valid contribution has suggested me to focus our research efforts on advanced multimodal interfaces capable to satisfy users' aptitudes in specific circumstances.

In this chapter I present a helpful alternative to the QWERTY keyboard for mobile devices, named Tap and Slide (TaS). Such a VK is based on a new text entry technique, meant to support users in interacting with environments embedding textual input forms. TaS consists of six large buttons reproducing the whole alphabet. Each button holds five letters (or symbols) and the user can select them by tapping and sliding gestures in the right direction. This approach decreases errors caused by both the small-sized conventional keys and their spatial arrangement within a traditional QWERTY keyboard.

In order to evaluate the TaS performances, an empirical usability study have been conducted, consisting of three tests, each meant to analyze a specific parameter, namely speed, accuracy and learning easiness. Results obtained have shown that a replicated usage of TaS strongly improves user's interaction in terms of number of errors and of task execution time. Moreover, accuracy in performing tasks with TaS is independent from user's technological skills, and achieves a higher level with respect to the QWERTY VK.

The chapter is organized as follows. In Section 2 related work is presented. Section 3 describes the TaS VK interface. Section 4 illustrates the experiment planning and execution. The results are discussed. Conclusions are given in Section 6.

2 - Related Work

The QWERTY keyboard was designed in 1873 on the basis of engineering principles different from the modern usability principles [32], thus requiring an initial training effort to remember the spatial arrangement of keys. However, as Jain and Bhattacharya claimed in [66], in the last decade the efforts to substitute the QWERTY keyboard model resulted excessive when compared with the number of users of virtual keyboards.

Nowadays, the virtual keyboard market is growing and stimulates developers and researchers to propose new efficient choices. Two basic approaches are followed, namely enhancing the QWERTY keyboard through advanced functionality, and designing innovative metaphors from scratch. Among the QWERTY-based proposals I recall TouchPal, SwiftKey, Better Keyboard, Swype, SlideIT and ShapeWriter [116] [110][16] [111][106][103].

TouchPal integrates three different layouts accessible through a sliding gesture. The first layout is similar to the traditional QWERTY keyboard, the second one corresponds to a typical mobile phone keypad, the third is a modified QWERTY keyboard where the letters are arranged according to the QWERTY keyboard, but each key contains two succeeding letters. TouchPal exploits a dictionary to predict or correct the words.

SwiftKey is a traditional QWERTY keyboard capable of predicting even a whole sentence on the basis of the user’s text messages. The keyboard utilizes gestures to perform some common tasks, such as deleting words.

Better Keyboard is a QWERTY keyboard with bigger and easier keys to tap than traditional keyboards. As Swiftkey, it can recognize some user's gestures.

Swype, SlideIT and ShapeWriter are three very similar QWERTY keyboards. They provide an innovative interaction technique to write words. Users slide their fingers over the keys and the keyboard application selects the most probable word composed of a partial combination of letters selected by the user.

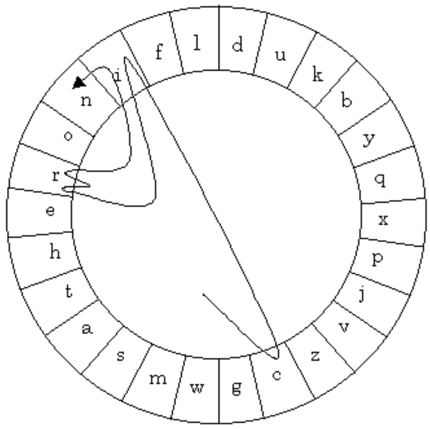


Figure 35. The Cirrin keyboard interaction.

As for new VK layouts, several proposals have been presented to replace the QWERTY layout. Some relevant examples are Cirrin keyboard layout [77], Tap Tap Keyboard layout, Fitaly keyboard layout and Opti keyboard layout [75]. Cirrin keyboard has a very innovative layout. It is designed to work with a stylus, and letters are arranged in a ring shape. Starting from the centre the user moves the stylus from a letter to another without lifting it away from the screen, by simply moving inside the ring to reach each letter as showed in fig. 35. In the Tap Tap Keyboard, the entire alphabet is contained in only eight short words easy to memorize. The new layout consists of eight columns and six rows where the letters are disposed to form the eight words. The Opti keyboard and the Fitaly keyboard share the same approach. They have been conceived to work with a single finger in a single hand. Moreover, the layout is designed in order to minimize the finger movements on the device screen. To support this goal, two space bars are arranged on the Fitaly keyboard layout, while the Opti keyboard layout embeds four space bars in order to speed up user's writing. (Useful to have some images of these keyboards)

8pen introduces a new concept of virtual keyboard. The idea is to allow users to interact with a keyboard using only one finger. Indeed, it differs from both a traditional keyboard or keypad. Keys are arranged in a "X shape", the order of letters is planned so that the most common ones are located near the centre of the keyboard. User touches the centre of the keyboard and slide her/his finger in a sector of the X shape, then s/he turns the finger around the centre of the keyboard in order to select a letter of the sector. When s/he reaches the desired letter s/he has to slide the finger on the centre again. Though this is a complicated interaction pattern it has been claimed that it reduces the number of errors (If possible give a reference). Figure 36 shows the 8pen interface.

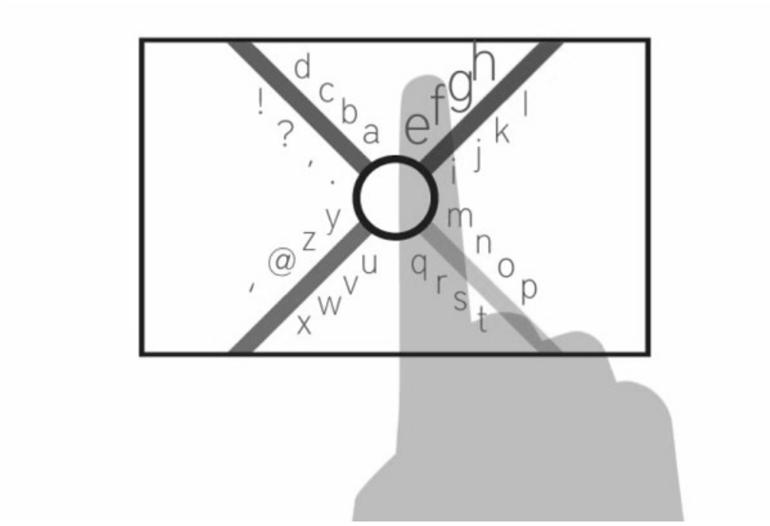


Figure 36. The 8pen keyboard interface.

3 - The Tap and Slide Keyboard

Using a virtual keyboard, users cannot usually perform a writing task without making some mistakes. The main problems are probably related to the difficulty to distinguish and touch correctly the keys on the virtual keyboard.

The idea behind the Tap-a-Slide (TaS) interface is to minimize the number of mistakes done by users during their writing stage by means of a new interface in which the key buttons are easily detected and simple to interact with. As Figure 37 shows, five letters are arranged around a single button. This arrangement allows me to design very large buttons. Only six buttons are sufficient to contain all twenty-six letters of the English alphabet.

The TaS interface offers two different interaction modalities: *tap* and *slide* In order to select the central letter a user simply taps the appropriate button, whereas to select one of the border letters she/he slides her/his finger over the specific border.

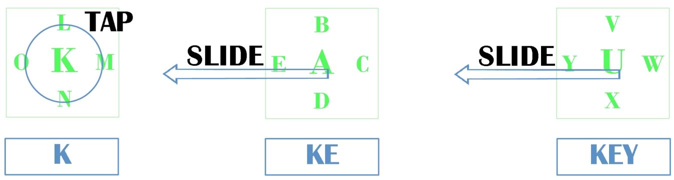


Figure 37 -. The TaS interaction methods.

The size of each button is of 60 X 60 pixels, quite higher than the minimum size of about 44 X 44 pixels indicated by the Apple Human Computer Interaction (HCI) guidelines [7]. This is indeed the minimum recommend size of a tappable object on an Apple mobile device in order to make it comfortable for a user.

my size choice makes users capable to tap a button easily and with little likelihood to make mistakes. This feature allowed me to implement a smaller interface with respect to existing ones. As an example, Figure 38 shows the comparison in terms of screen occupancy between the TaS keyboard and the QWERTY keyboard as implemented in the iPhone 4.

Another design choice concerned the selection of different colors for the displayed 6 buttons. I assigned colors on the basis of the "Itten wheel" [64]. Itten's theory of colors was investigated to enhance the user's capability of distinguishing between different buttons and I assigned highly contrasting colors to adjacent buttons. This choice was also meant to help users to map mentally a group of letters to a specific color.

The letters on the keyboard are arranged according to the following layout: one letter in the middle of the button and the remaining four along its borders. Starting from the center of the square button, and clockwise along its border.

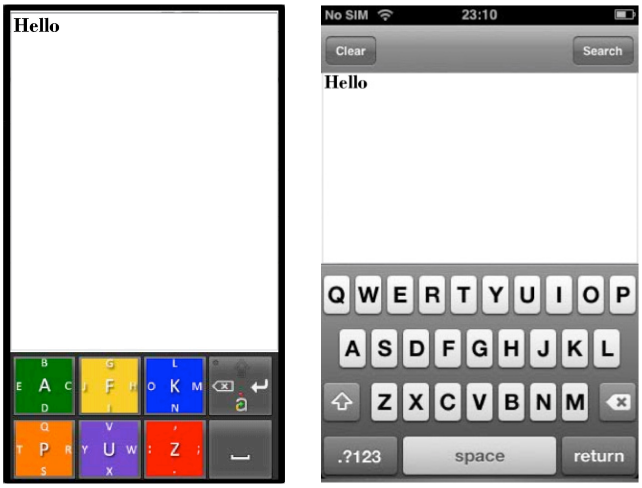


Figure 38. (a) The TaS Interface customized for a right hand user, (b) the QWERTY keyboard as implemented in the iPhone.

The alphabetical order was chosen for helping people to quickly identify where letters are located. Incidentally, I are aware that further investigation on this aspect could lead to a better distribution of letters. For instance, the average frequency of letters in a given language could be considered, rather than the alphabetical order. I are planning a language-dependent version of the keyboard where the 6 top frequent letters are positioned in the central position of the buttons, with the goal to minimize the overall finger movements during a text entry task.

3.1 – A VARIATION OF THE TAS VIRTUAL KEYBOARD

The TaS keyboard is suitable to provide a text input method that works fine and intuitively on small screened devices. The same idea can be applied on large screened devices such as tablets. Tablets usually have a screen of 7" or more so that virtual keyboards have satisfactorily large buttons. Unfortunately, users have some problems in holding the device and writing at the same time. Often they use to lean it on a table or on their legs to make writing easier.

I have redesigned TaS interface in order to deal with this problem. I divided the keyboard into two parts and positioned them in bottom corners of the device's screen. In this way, all the buttons are reachable directly by the thumbs of the users, making to hold and write at the same time far easier (fig 39).

(a) (b)

Figure 39 – tablet version of the TaS VK in the landscape modality (a) and portrait modality (b).

4 – Empirical usability evaluation

In this section I describe the empirical study I have carried out with the goal to test the usability of the proposed TaS soft keypad. I describe the experiments that I designed and carried out with the goal to verify how the keyboard is perceived by possible users and to perform a comparative usability evaluation against the very common QWERTY traditional soft keyboard.
In the following I first explain the experiment setting and I then describe the experimental tasks and goals.

4.1 - Experiment planning

In this subsection I formulate the hypotheses, define the experimental variables and motivate the selection of subjects taking part in the study.

Selection of Subjects and Groups

Since my target users, namely the most likely population of TaS keyboard users, are people aged between 15 and 45, who are more or less technologically engaged I avoided some kind of people groups such as older. For evaluating the experiences of each subject, I prepared a questionnaire to verify their attitude towards technology by analyzing what, how and how long they use it. By analyzing answers to questionnaires I selected two groups of 28 people each (NP and P). Basically, the first group is composed by people who use cellular phones only for basic operations like phone calls, sms and so on, while the second one is composed by people who use more sophisticated instruments like smart-phones or tablets who use them for basic operations and more advanced tasks as well such as email writing, map applications or office automation.

In terms of more general characteristics, as I expected, the first group was mainly composed by older people who do not have an high study degree and do not work in fields strictly related to telecommunication or informatics whereas the second group is composed by subjects which are more uniformly spread in terms of age while their technology knowledge come from different experiences. Indeed, in this group there are students who change the cellular phone once a year, have one or more game consoles, have a computer and use it for writing Internet browsing and for doing their written homework. On the other hand, it contains professionals who use computers for at least 6 hours a day to develop or design software, to manage CAD, etc.

For simplicity I denote the first group as (technologically) unskilled users and the second as (technologically) skilled users.

P and NP were further divided into two equal groups of 14 people each (P1, P2 and NP1, NP2). In order to make experimental results as independent as possible from the subject choice I randomly assigned subjects to groups.

Hypotheses formulation

my goal was to evaluate usability, in terms of accuracy and efficiency. In order to collect as many different data as possible I planned three separate experiments. The former was meant to verify whether the technological expertise could affect user's performance with the keyboard. The second was aimed at evaluating the degree of learnability of the associated text input paradigm. The goal of the third experiment was to evaluate accuracy of the TaS keyboard against accuracy of the traditional QWERTY keyboard.

Experiment 1 (E1) - In the first experiment I focused on two categories of users with different technological skills, namely people who use cellular phones only for basic operations like phone calls, sms and so on, and people who use more sophisticated instruments like smart-phones or tablets who use them for basic operations and more advanced tasks as well. According to our opinion, evaluating the distance in terms of capability to use our keyboard between these two groups can provide us with important information about the easiness to use and the definition of the target, namely if it should be addressed only to technological-enabled people or to a more wide market.

The goal of the first experiment was to verify whether, in spite of the basic difference in technological skills between the two categories of users, no significant difference in the degree of accuracy could be detected. The experiment was carried out by subjects belonging to groups P1 and NP1. Before going on, it is important to provide more explanation about the choice of the subjects for this experiment. Indeed, the target of the keyboard are people who are in same way technologically enabled.

Thus, I formulated the

Null hypothesis, H01: There is no difference in terms of efficacy (measured by NE, the mean number of errors per task) between graduated computer professionals and non-graduated high school students.

Formally,

- H_{01} NE(P1) = NE(NP1)
- Alternative Hypothesis: H_{11}: NE(P1) ≠ NE(NP1)
- Measure Needed: graduated or not (P1 or NP1) and number of errors (NE).

Experiment 2 (E2) - my goal was to demonstrate that TaS is easy to learn. Thus, I evaluated the new approach by analyzing the subjects performance throughout a number of daily sessions. I decided to reuse results of the first experiment for the first experiment and ask the same subjects (P1 and NP1) to repeat the experiment for two weeks, five days a week.

Two pairs of hypotheses were formulated, one for accuracy and one for efficiency. These correspond to the following null hypotheses

Null hypothesis, H_{02}: *There is no difference in terms of accuracy among different experimental sessions*.

Null hypothesis, H_{03}: *There is no difference in terms of efficiency (measured by the mean Time to complete a task) among different experimental sessions*.

Given the experimental sessions $S_1, .., S_n$, formally I have:

E2 (a):

- H_{02}: NE (P1 U NP1, S_i) = NE (P1 U NP1, S_j),
- with $1 < i, j < n$
- Alternative Hypothesis:
- H_{12}: NE (P1 U NP1, S_i) ≠ NE (P1 U NP1, S_j),
- with $1 < i, j < n$
- E2 (b):
- H_{03}: Time (P1 U NP1, S_i) = Time (P1 U NP1, S_j), with $1 < i, j < n$
- Alternative Hypothesis: H_{13}: Time (P1 U NP1, S_i) ≠ Time (P1 U NP1, S_j), with $1 < i, j < n$

Experiment 3 (E3) - The most popular way to write a note or a message on a touch-screen cellular phone is by means of QWERTY soft keyboards. The goal of the last experiment was to perform a comparative usability study of the two approaches. I used the results of the first experiment on P1 and NP1 and I compared them with the results of the task execution on a QWERTY keyboard by subjects belonging to P2 and NP2, who had been expressly kept idle during the first experiment, to avoid any learning biases.

I formulated the following

Null hypothesis, H_{04}: *There is no difference in terms of accuracy (measured by the Number of Errors per task) between the TaS and the QWERTY text entry paradigms*.

Formally,

- H_{03}: NE(P1 U NP1, TaS) > NE(P2 U NP2, QWERTY)
- Alternative Hypothesis: H_{13}: NE1(P1 U NP1, TaS) ≤ NE2(P2 U NP2, QWERTY)

A summary of the groups used for each experiment is depicted in Table 1.

Table 1. Groups assigned for each experiment

	E1	**E2**	**E3**
P1	YES	YES	YES
P2	NO	NO	YES

NP1	YES	YES	YES
NP2	NO	NO	YES

Independent Variable

The independent variables were specifically designed on the basis of the experiments. In the first experiment, I wanted to compare technologically "unskilled" and "skilled" users in order to verify whether differences exist in terms of efficacy. Thus, the only independent variable I used is the capability of subjects, defined as a nominal variable C with two possible values: technologically skilled (P1) and technologically unskilled (NP1).

In the second experiment, I verified whether a sort of learning effect exists among subsequent executions of the same task throughout a given time period. In this case, the independent variable was considered to be the experimental session when people performed the experiment, namely the nominal variable S with ten levels from S_0 and S_9.

Finally, the third experiment compared the TaS keyboard with the QWERTY keyboard. In this case, the independent variable K represented the text input paradigm, with two levels corresponding to the two keyboards.

Dependent Variable

The ISO 9241-11 standard 'Ergonomic requirements for office work with visual display terminals— Guidance on usability' explains the benefits of measuring usability in terms of the user performance (effectiveness, efficiency), that is to say, the extent to which the intended goals of use are achieved (effectiveness) and the resources that have to be consumed to achieve the intended goals (efficiency) [40]. In my usability study, effectiveness of the TaS keyboard was expressed as the capability of writing text doing as few typos as possible while efficiency was represented the time required to complete the text entry task.

As for the efficacy, I considered forur types of possible errors as listed in Table 2:

Table 2. Error types

Error type	Example	Correct
Wrong character	chivarra	chitarra
Missing character	chiarra	chitarra
Missing space	chitarrasuonavo	chitarra suonavo
Added character	chitarrra	chitarra

Instrumentation

The task of the experiment was carried out on an Apple™ iPhone™ 4G, the TaS keyboard was implemented using Adobe Flash Professional CS5.5™ which supports AIR™ 1.6 SDK. Air™ is the new Adobe™ technology which allows the mobile development on Google™ Android™ 2.2 OS, BlackBerry™ Tablet OS and Apple™ IOS 4. The screen size of the device is 3.5 inch with 960 x 640 pixel resolution. The data I collected were analyzed by using the SYSTAT™ ver.12 software by SYSTAT.

4.2 - The Experiment

The experiments were conducted over two weeks but only E2 required all the days. As I stated before, in the first day I explained the experiment and the keyboards. In the second day, I let participants perform the sample text input task, then, in the following days, I asked only some of them to repeat the same task again.

The task consisted in writing the following text message:

> Se la chitarra suonavo la gatta faceva le fusa ed una stellina scendeva vicina poi mi sorrideva e se ne tornava su.<enter>
>
> Ora non abito piu la tutto e cambiato, ho una casa bellissima come vuoi tu.

The message is part of the “La gatta” Italian song by Gino Paoli. Incidentally, this implied that all the participants knew the text in advance. The text is approximately 200 characters long, spaces and <enter> included. Some words would require some accents (i.e. più, là) but I asked subjects to disregard them and write simple letters instead.

From the experimental point of view, this specific sentence represents a good example of the Italian language in terms of letter frequency distribution. Indeed, it is not distant from the distribution of average frequencies for letters in the Italian language reported in [105]. The appropriateness of the chosen text is also supported by the observation that the text is composed by 37 words whose average length is 5.4 characters per word (with spaces), quite close to the average length of the Italian words, 5.37 characters per word.

Before the task execution, I disabled the automatic spellchecker and I asked to avoid word manual corrections by using backspace.

During the initial phase, before the experiment, I noticed that the way I provided the message text affected subjects' performance. Indeed, in this phase, I asked to read the message from a sheet and write it on the device. I noticed that, in spite of the use of text drawn from a popular song, this method distracted subjects who made many more errors with respect to subjects who listened to the message. Thus, I decided to support subjects during the experiments by dictating the message.

4.3 - Analysis and Interpretation

In this section, I present the data resulting from the experiments and analyze them to derive the expected usability evaluation claims.

Table 3 shows the basic statistics relative to the first experiment. Here, I can notice that the means are very close and that there is a clear pattern that P and NP subjects had the same performances in terms of errors. It means that, I can suppose that there is no significant difference between subjects who have a deep skill in technologies and people who do not. As I can notice, both the groups have an error frequency around 6, which means people made 6 errors every 200 characters, namely, 3% errors on the average. To support the equivalence between the two groups, I also evaluate the standard deviation (SD) which shows how much variation there is from the average. In both the groups, the SD is around 4.5, namely in this round there were people who committed 10 errors as well as 2.

Table 3. E1 basic statistics

Group	No	Mean	Standard Deviation
Skilled	14	6.429	4.815
unskilled	14	6.286	4.358

This is also graphically supported by Figure 40. The figure shows that the Gaussian curves and the box plots are very similar, indicating a similarity also in terms of distribution.

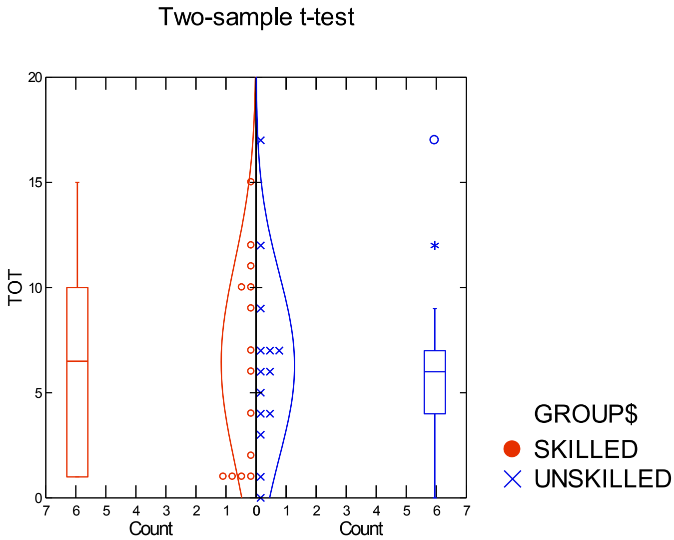


Figure 40. E1 diagram

It is also important to take a look at the outliers. I only have one for the unskilled group. However, I did not remove it since it is not an extreme value.

In order to verify whether the E1 null hypothesis H_{01} may be rejected in favor of the alternative hypothesis H_{11}, I performed a statistical analysis based on a two sample t-test. Results may be summarized in Table 4.

Table 4. Results of the two sample t-test for the E1 experiment.

t	t-crit	df	p-value
0.082	2.064	24	0,935

In order to evaluate the t-statistic, I compared the calculated t-value, with 24 degrees of freedom, to the critical t-value from the t distribution table at the chosen confidence level 0.95, and decided whether to accept or reject the null hypothesis. Generally, it is possible to reject the null hypothesis when the calculated *t*-value is greater than critical *t*-value. In my case, the calculated t-value was 0.082 while the t value of the distribution was 2.064, meaning that there is no statistical difference between the mean of the skilled group and the mean of the unskilled group.

The goal of the experiment E2 was to understand the easiness to learn of the TaS keyboard. I performed two experiments, one for evaluating the efficacy of the keyboard input paradigm and one for evaluating its efficiency. In order to assess the goals, I performed two longitudinal studies which involved repeated observations of the same subjects over ten says.

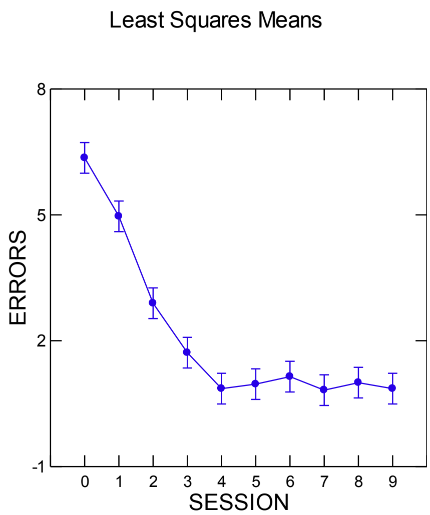


Figure 41. Error per session curve

As for the efficacy, the scatter diagram is depicted in Figure 41. It shows that a significant improvement in terms of number of errors may be obtained after five sessions. It is quite interesting that the number of errors is less than 1 on the average after very few sessions. Initially, the number of errors is around 6 on the average with a small standard deviation. Successively, it quickly decreases and reaches the mean of 1 error for the entire text input task in just a few sessions, and keeps approximately the same over the successive sessions.

In order to assess the validity of the experiment and understand whether efficacy truly depends on the repetition of the experience during subsequent sessions, I applied an ANOVA test based on repeated measures (which is especially appropriate in case of longitudinal studies). The results are shown in Table 5. I recall that if the p value is *smaller* than a given alpha level, then it is possible to *reject* the null hypothesis. The alpha level I set before conducting the experiment is 0.05.

Table 5. ANOVA test for efficacy

Source	Type III SS	df	Mean Squares	F-Ratio	p-value
SESSION	985.943	9	109.549	29.310	0.0
Error	1009.143	270	3.738		

The p-value is nearly 0 which is much smaller than the alpha level I set. Thus, I may reject the null hypothesis, where I supposed that the means NE are equal and state that the repetition of the experience in different sessions does affect the efficacy of the task execution.

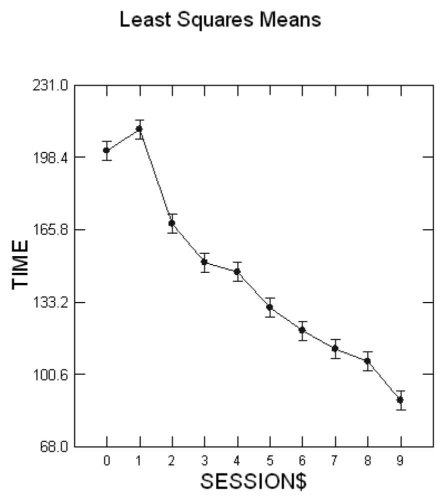


Figure 42. Time per session curve

Similarly, I evaluated the time required by subjects to perform the task. Again, I recorded that measure during the ten experimental sessions. Figure 42 shows Time evolution over the sessions.

The diagram shows that, after the first session, the time required to perform the task linearly decreases from a maximum of 200 secs to a minimum of 90 secs on the average. However, by looking into data details, I noticed that some subjects performed the experiment in 60 secs, therefore at the moment I consider this as the minimum time. Considering that the sample input text is composed by almost 200 characters and 37 words, meaning that it is possible to write nearly 3 characters per second and 37 words per minute.

Also for efficiency, I could conclude that it is affected by user's technological skills. To do that, I applied another ANOVA test for repeated measures and I got a p-value smaller than the alpha level, set to 0.05. As a result, I may reject the null hypothesis and state that the learning (session) affects efficiency with high level of significance. A summary of the ANOVA test is reported in Table 6.

Table 6. ANOVA test for efficiency

Source	Type III SS	df	Mean Squares	F-Ratio	p-value
SESSION	410153.789	9	45572.643	90.676	0.000
Error	135699.179	270	502.590		

The usability study ended with a comparative evaluation of the TaS entry paradigms against the QWERTY one. The between group approach, with a group of 28 participants (P1 U NP1) only using the TaS keyboard and the remaining group (P2 U NP2) only using the QWERTY keyboard, ensured to reduce any learning biases in the collected data. Results summarized in Figure 43 indicate that the TaS group performed better, in terms of accuracy, than the QWERTY group. As in the case of E1, the Gaussian curves and the box plots graphically highlight the improvement in terms of errors. As I can see, the distribution of the results of the QWERTY experiment (red curve) has a trend which is tendentially higher than the distribution of the TaS results. This analysis is even more encouraging, if I consider the fact that, given the popularity of QWERTY keyboards, the subjects in the second group had already some experience with it.

Table 7. E3 basic statistics

Group	N	Mean	Standard Deviation
QWERTY	28	10	5.063
TaS	28	6.346	4.681

In order to demonstrate that this outcome can be generalized and that it is not due to the chance, I do need to perform a t statistic which compares the means and provides a level of confidence for the results (see Table 8).

Table 8. Results of the two sample t-test for the E3 experiment.

t	**t-crit**	**df**	**p-value**
2.00	2.844	54	0,006

In this case, the p-value is under the threshold indicated by alpha. It means that the null hypothesis should be rejected in favor of the alternative hypothesis so highlighting a difference in terms of efficacy of the two methods.

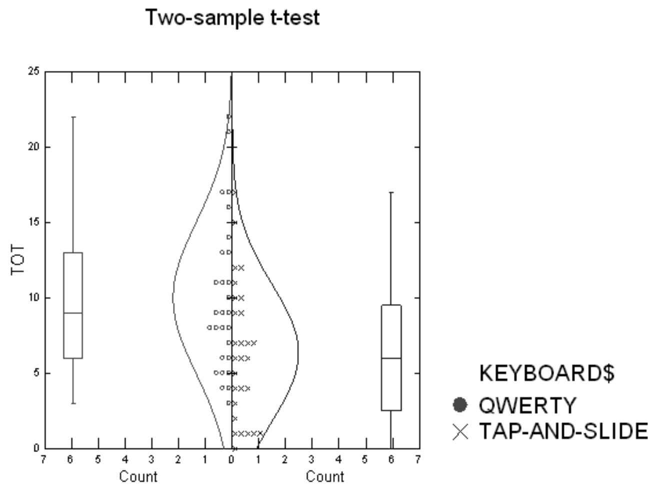


Figure 43. E3 diagram

5 - SUMMARY

In this chapter I have presented the Tap-and-Slide interface which is a new soft keyboard developed for mobile devices which uses a new interaction method.

I presented two different implementations which are devoted to two different platforms: smartphones and tablets. In both the case, the most evident advantage is the minor size of the keyboard with respect to the existing ones. As described, the two implementations are slightly different because the specific target device interactions. Indeed, the buttons of the smartphone keyboard are very close to each other because smartphones are usually managed by one hand and it is necessary to minimize the distance that the finger has to cover, while buttons on the tablet implementation are divided into two groups located in the bottom corners in order to allow multi-touch by the two inches.

In the second part of the paper I have described the experimental usability evaluation I have performed involving two groups of users who use mobile devices and technology but have different technological background. The analysis of the experimental results, allowed me to draw three major claims:

- accuracy in performing text input tasks with the TaS soft keyboard is independent from user's technological skills
- user's behavior with the TaS soft keyboard improves, both in terms of number of errors and of task execution time, with the replicated usage of this paradigm.
- a higher level of accuracy is achieved with TaS keyboard with respect to the QWERTY soft keyboard.

Chap 6 - Discussion and Conclusions

This concluding chapter presents a generalization of the solutions so far carried out and reviews the findings and the contributions of the research based on the original objectives. The research ends with some highlights of possible future developments.

1 - INTRODUCTION

This concluding chapter presents a summary of the whole thesis and briefly discusses the major outcomes of the research project; the Framy technique and the TaS Virtual Keyboard. It then generalises the principles underling the above outcomes in the form of an interaction design pattern for the former and a potential interaction design pattern for the latter.

Next the answers to the eight questions of the Design Science approach are presented in a tabular form describing in which chapters the questions were answered together with a brief explanation. Finally conclusions and potential extensions to this work are described.

2 – SUMMARY

Chapter 1 has introduced the broader context and the research question of this thesis. The broader context is related to the area of mobile devices and underlines the relevance of the research in this field. From the analysis of the context, usability comes out as the main issues on which the research should investigate. These issues are related to the limits and to the opportunities that new mobile devices hardware brings out. In particular, this thesis focuses on the visualization of spatial data. Spatial data are paramount in the mobile context insofar as they are present in almost all the mobile applications. Therefore the research question is "**How to enhance the usability of mobile users interfaces for spatial data**". In In particular, my research investigation has been focusing on two main problems: "*How to display spatial data on small-sized screens*" and "*How to enhance text input methods*". After that I introduced the scientific research approach; Design ***Science Research*** used during the investigation.

In Chapter 2 I investigated a particular case of the first part of the research question that is the visualization of geographical data with mobile map based applications. A new visual technique called Framy has been introduced and proposed as an effective solution to the issue. The comparative analysis of existing visualization techniques that address similar issues shows that Framy is far more flexible and domain independent. Applications embedding Framy may be configured to work with different modalities and different kinds of aggregates, including, e,g. those conveying temporal information.

Finally, a comparative usability evaluation process between a traditional map application and Framy has been presented together with related results which demonstrate the validity of the technique.

Chapter 3 has presented a Framy interface enhanced with multimodality in order to improve its usability. Moreover, the chapter describes the evolutionary process that transformed the multimodal interface into an interface able to support both able-bodied users and visually impaired users. Although the first interface was equipped with many features which should allow visually impaired users to use Framy without particular problems I had to recognize that the solutions I adopted were not always the most suitable for visually impaired users and in many case I had to re-design the interaction on the basis of the user’s suggestions. From the pilot tests and the interviews, I got enough information to devise some useful guidelines to re-design the multimodal interface, taking into account the different abilities of visually impaired users.

Chapter 4 has shown the applicability of the Framy principles in different research fields that involve spatial data demonstrating their effectiveness in overcoming repetitive problems related to this kind of data.

It includes the presentation of four applications related to the visualization of spatial data developed using Framy technique. The first application is related to the crisis management field and exploits the visual analytical power of Framy to support decision-makers during the operations directly on the disaster sites.

The second application is a new system that supports users during the exploration activities through an interface based on augmented reality. A visual technique is used to orient users towards POIs that are located out of the visual cone of the camera phone. The visualization technique represents a significant variation of the original Framy technique but all the fundamental principles remain unchanged.

The third application addresses the issues related to the geo-visualization of users of a web community. Two different modalities are utilized: on map modality and on augmented reality modality. In this case the Framy principles are used to design visual metaphors that support the users' orientation and avoid the visual information overcrowding on the screen.

The last application is related to the area of collaborative systems. The work provides users with solutions for traditional web interfaces and mobile interfaces. The mobile interface presents a problem related to the users perception of the modifications of the cells contents. A variation of Framy has been used to overcome it.

In chapter 5 I investigate the second part of the research question, that is how to enhance the text-input methods. A new virtual keyboard called TaS is presented. This new keyboard is based on gesture interactions. The layout is simplified by arranging groups of letters on the same button. These allow on the one hand to reduce the size of the keyboard and on the other hand to increase the size of the buttons. A comparative study has been performed taking into account the TaS VK and a traditional QWERTY VK. Results have demonstrated that users that interact with TaS VK make less mistakes and spend less time to write text than with the traditional VK.

In this chapter I am highlighting the major contributions to the scientific knowledge:

1. Framy technique has been widely applied in several applications demonstrating that its principles are able to overcome a general repetitive problem related to the visualization of spatial data. In this chapter these principles are synthesised into an interaction design pattern.
2. The TaS keyboard has demonstrated through usability tests that users today are ready to change the text input methodology and to use gestures interactions instead of the traditional VK interactions. This improves the usability of text input interfaces. The idea behind TaS has been presented in the form of a potential pattern.

3 - A New interaction design pattern to visualize Spatial Data

In chapter 4 I have shown how the Framy techniques can be exploited in order to overcome the problems related to the visualization of spatial data in different research fields. Although I have modified the technique to fit each different problem, the principles underlying the original technique have been maintained.

The famous principle focus plus context, from the field of information visualization, asserts that a good design should support user's focus on a specific point of interest while providing some useful information about the surrounding context. The described spatial data visualization technique follows this principle taking into account the limited size of mobile interfaces, hence in a way quite different from traditional desktop approaches, such as the 'overview plus detail' or the 'fisheye view' design strategies. Therefore, such techniques form a new body of knowledge for information visualization on mobile interfaces, with common principles applied to different domains. The derived design guidelines can be formalized in terms of two interaction design patterns, specific for mobile interfaces managing spatial data. This is one of the contributions of my investigation to the scientific knowledge.

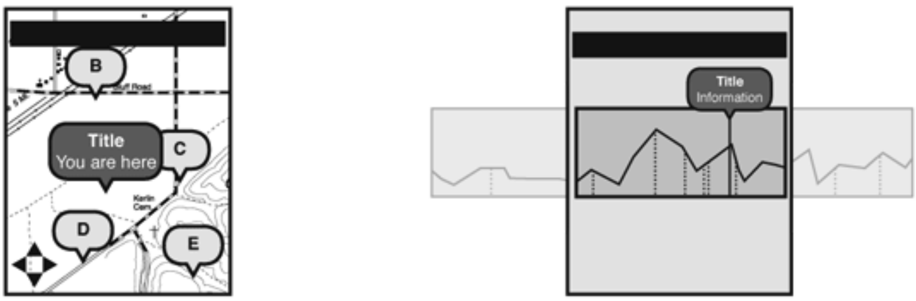
I have formalized this technique as extensions to a design pattern in order to help designers to display spatial data on limited sized screens.

A design pattern is a generic solution to a repetitive problem in the area of the software design. In the late 1970s the architect Christopher Alexander carried out the concept of pattern [3]. Alexander states that patterns are elements of a language which can be exploited in order to lead a discussion *about building and the nature of human existence in space.* Successively, the pattern concepts were translated from the architecture and engineering fields to the software and interactive design fields. Object oriented software development acquired the concept directly from Alexander's idea in the late 1995, as showed in the book *Design Patterns [42]*.

Patterns for interactive design are quite similar to the ones applied in software development. A first significant work in this area was presented by J*enifer Tidwell in* A Pattern Language for Human-Computer Interface Design in 1999 [67].

Tidwell states that nowadays scientific literature about high-level principles of good interface design is mature. Designers knew that they have to use direct manipulation style and intuitive feedback, that they do not have to use too many sounds and animations, that they have to deal with accidental mistakes, that they have to use gentle error messages, etc. However, for novice designers it is hard to remember all these principles. All this created the need for a pattern language for HCI.

In spite of the great number of pattern languages proposed in different sectors of HCI, very few of them can be successfully adapted to the context of mobile interface design. As a matter of fact, only recently this approach has attracted the interest of scientists working in the area of mobile user interfaces. Apart from some useful collections issued as supporting documentation of commercial development environments for mobile platforms, such as Android [7] and Nokia [83], a valuable work has been done by Steven Hoober and Eric Berkman, who have introduced a new interaction design pattern language dedicated to the design of generic mobile interfaces. In Designing Mobile Interfaces [108] the core principles of mobile interactive design are summarized as “user centred design”, context and other principles. According to the authors, designers should always take into account those principles to determine the appropriate pattern for the current situation and to integrate the elaborated solution into the system. Studying their pattern language I found out the pattern 'Infinitive Area', which is used to represent information that is potentially infinite such as maps, big detailed images or complex charts as shown in figure 44.



(a) (b)

Figure 44 – examples of infinite information: a map of the whole world (a) and a complex chart (b)

Infinitive Area manages the whole data set as a large, two-dimensional graphic, whereas smaller subsets can be viewed as they were "zoomed in" portions of the larger image. Users can navigate the image by scrolling it in each direction. Zooming shows further details, generally with updated images that constitute additional information layers. For example, on the city level of a map only highways are labelled, whereas the names of the streets appear only when they are really useful without overcrowding the screen.

I realized that this pattern could well represent the basis upon which a new pattern (together with its multimodal extension) could be built as a general solution supporting the *focus plus context* principle in the design of mobile interfaces.

Table 1 describes the internal structure of the pattern.

Name	Names are as short as practical while still being clear, and whenever possible do not conflict with an existing concept. Some end up being a bit of a mouthful as a result, but we do our best. In far more cases than expected, there was no name at all for a well-used design element, and we had to make something up.
Problem	This is just a summary of why you'd want to use this pattern. Ideally, patterns are grouped with similar problems, and you can get to the right section, then compare the problem statements as a way to help identify which one you really have.
Solution	A definition of what the pattern involves, which other patterns are key overlaps or provide key components and when relevant the important technologies required to make it operate.
Variations	The patterns aren't stencils, so aren't restrictive. All of these have variations that can not only be chosen from, but which are defined so that the correct one can be chosen based on the content to be delivered and the context in which the pattern will be used.
Interaction Details	How the user interacts with the item being described, both the physical pressing of buttons (or swiping the screen) and what the screen displays that the user can click on or type inside.
Presentation Details	Things on the screen, which you cannot click on, or details about the manner in which displayable items are presented, which do not directly influence the interaction. A shadow on an interactive item might help visibility, so matters, but does not directly influence interaction, for example.
Antipatterns	Specifics of the implementation you should watch out for are always listed. These cover both "anti-variations" (methods that should never be used at all) and more minor pitfalls or edge case uses of proper variations to watch out for. These are not speculative, but are known to be bad by violating heuristics, and often are verified by research.

Table 1 - internal structure of the interaction design pattern

In table 2 I describe only the extension of the *Infinitive Area Pattern*, to read the detailed description of the original pattern visit the following link http://4ourth.com/wiki/Infinite%20Area.

Name	Infinitive Area + Context. *This pattern extends the Infinitive Area*.
Problem	A complex and/or interactive visual information that should be presented as a single image. Consider the need to convey a lot of specific spatial information - either of homogeneous or heterogeneous type but interconnected in some way – that are located in off-screen space.
Solution	The solution is to display coloured visual metaphors, which provide information clues about different sectors of the off-screen space. Use different colour intensities or dimensions to give qualitative and quantitative information about objects located in the corresponding off-screen sector.
Variations	1. Multimodal Infinitive Area + Context 2. Infinitive Area
Interaction Details	When users change the spatial focus the information represented by the visual metaphors are automatically updated.
Presentation Details	The visual metaphors position must be significant. It gives intuitive information about directions. In a general way they can be inscribed along the borders of the view of the application that in many cases corresponds to the whole screen of the device.
Antipatterns	Use caution with the size of the metaphors. Graphic objects which are too small may be misunderstood by users. Be careful with the number of the graphic objects. A large number may reduce the usability of the ordinary user interface. Use Itten's theory to choose the right colour combination of the contiguous graphic objects. A wrong combination may make users confused.
Examples and figures	**Consider** a high resolution image where the subjects are human faces. Supposing that the software automatically recognizes the faces as points of interest, the frame can guide users towards them. (fig 45) **Consider** a spread text like the web page of a newspaper wherein users look for a particular word through the appropriate search tool. A frame can guide users to find the word in the text, the colour intensities could give information about the number of the words in the given direction or the distance from the current view. (fig 46) **Consider** the case when people use a map application to find restaurants and bus stops around them in a range of 3 km. Restaurants and bus stops are two different categories of POIs. Two nested frames – each one related to a specific category of POIs – provide users with information about the directions to take. (fig 47) In each case the colour intensities of a given portion of the adopted visual metaphor can give information about different qualitative elements such as the distance from the current focus, the number of elements located outside the screen or a combination of them.

Tablet 2 – Infinitive Area + Context pattern

Figure 45. Example of exploration of a high resolution image

Figure 46. Example of research of words in a web site

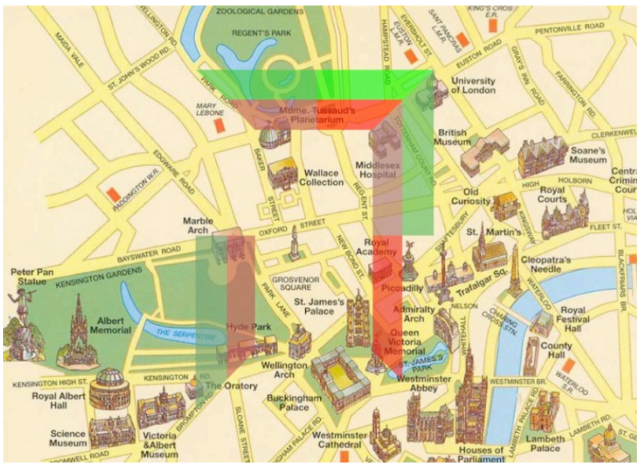


Figure 47. Example of exploration of POIs on a map

The next pattern is a further extension of the Infinitive Area. The pattern synthesizes the multimodal principles and should be used when the interface has to deal with particular situations of low visibility and multimodal interaction modes should be devised to convey relevant clues about the context.

Name	Multimodal Infinitive Area + Context. *This pattern extends the Infinitive Area + Context*.
Problem	Consider the need to support users through different senses (to deal with diverse users capabilities or with extraordinary environmental situations).
Solution	The visual metaphors are associated with auditory or vibro-tactile feedback. Use different sound sources for each metaphor or modulate tactile vibration.
Variations	Infinitive Area Infinitive Area + Context
Interaction Details	When users change the spatial focus the information perceived changes accordingly. Users interact with the multimodal interface either performing gestures on the screen, or triggering the movement sensors off or through the GPS module.
Presentation Details	Different sound sources must be clearly discernible as well as vibro-tactile modulation.
Antipatterns	Use caution with the usage of vibration, it may annoy users.
Examples and figures	**Consider** the case when a visually impaired user needs to orient himself while walking. He can use a mobile map application assisting his impaired sight with sounds and vibrations triggered off by his touch on the screen or his movements.

Table 3. Infinitive Area + Context pattern

4 - A NEW INTERACTION DESIGN PATTERN FOR VIRTUAL KEYBOARDS

In chapter 5 I have shown a new advanced gesture-based keyboard called TaS. The purpose of the TaS VK is to provide mobile users with a powerful text input method that can work effectively on small screens. I also showed a variation of the keyboard adapted for tablet screens. In this case the goal is to provide users with a simple text input method that allows them to write and hold the device in a comfortable way.

Today users are familiar with gestures-based interactions because of the large diffusion of touch-screens technologies and they are not confused by using advanced virtual keyboards exploiting this modern characteristic. Indeed tests on the TaS VK have demonstrated users' capability to learn how to use this kind of keyboard very quickly. So that, solutions based on gestures should be further investigated and applied to the real world.

In the current section I generalize my text-entry solution in order to support designers to develop alternative gesture-based keyboard. I present the idea underlining the TaS keyboard in form of a proposed pattern. Once it’s wider applicability gets established this proposed pattern can become an accepted pattern.

In table 4 I describe the proposed pattern *Gestures-based Keyboard.*

Name	*Gestures-based Keyboard*
Problem	You must provide a method of text and numeric entry that is simple, easy, and should be so predictable in behavior it may be performed by any likely user with little or no instruction. Letters should be easy to recognize and to select. The keyboard should not crush the screen.
Solution	The solution is to group into a single button different letters and exploit gestures to allow people to select them from the button.
Variations	The shape of the buttons can be quadratic, triangular or of any other polygon and can contain a variable number of letters.
Interaction Details	The interaction with a button is performed by gestures that are simple to memorize. Use the tap to select the letter in the middle of the button and a slide to select the other letters.
Presentation Details	Key labels must be clear, large enough for users to read, and easy to read in all lighting conditions. Button on the keyboard can be contiguous in order to save space on the screen but they have to be plainly discernible
Antipatterns	Avoid accidental input: when users touch a button lock the other ones. Do not confuse users by positioning to many letters into a single button.

Tablet 4 – Gestures-based Keyboard pattern

5 - Design science checklist

In this section I am providing answers to the eight questions of the Design Science approach. The following table associates each question to the chapters where they are satisfied and a short description.

Questions	Chapters	Short Description
1. What is the research question (design requirements)?	Chapter 1	The research question "**How to enhance the usability of mobile users interfaces for spatial data**" is introduced in the first chapter of the thesis. This main research question is further divided into two parts: 1. "How to display spatial data on small-sized screens" 2. "How to enhance text input methods"
2. What is the artifact? How is the artifact represented?	Chapters 2, 3, 4, 5	The artifacts, which addresses the first research issue, are the interfaces adopting the Framy technique. Using this technique many applications that use multimodal interfaces were in fact developed. The artifact developed to address the second research issue is the gesture-based virtual keyboard for mobile devices called TaS .
3. What design processes (search heuristics) will be used to build the artifact?	Chapters 2, 3, 5	The design process followed a user-centered design approach. This approach starts by studying potential users and existing solutions giving attention to the needs of users at each stage of the design process. To cater for visually impaired users universal design principles were also used.
4. How are the artifact and the design processes grounded by the knowledge base? What, if any, theories support the artifact design and the design process?	Chapters 2, 3, 4, 5	The artifacts were grounded on the following; the color theory, user-centered, scenario-based design approaches, well settled techniques for empirical usability evaluation and the state of the art, also on existing relevant design patterns.
5. What evaluations are performed during the internal design cycles? What design	Chapters 2, 3, 4, 5	Evaluation tests have been performed. Comparative usability tests have demonstrated that the new artifacts give significant advantages in terms of efficiency and effectiveness with respect to existing

improvements are identified during each design cycle?		common solutions. Moreover, as a result of the empirical study performed on the Framy multimodal interface, which promoted a participatory design approach, the interface has been re-designed to support both normal-bodied users and visually impaired users.
6. How is the artifact introduced into the application environment and how is it field tested? What metrics are used to demonstrate artifact utility and improvement over previous artifacts?	Chapters 4, 5	Framy was tested in different contexts by developing applications using this technique for these environments. Moreover comparative tests have been performed to demonstrate the advantages in terms of effectiveness and efficiency of the new artifacts in respect to the current solutions.
7. What new knowledge is added to the knowledge base and in what form (e.g., peer-reviewed literature, meta-artifacts, new theory, new method)?	Chapter 6	The knowledge base has been expanded by the extensions of an existing pattern for the visualization of spatial data on mobile devices and a proposed pattern for the design of gesture-based keyboards. Based on this work 10 papers have been published.
8. Has the research question been satisfactorily addressed?	Chapter 6	The research question has been satisfactorily addressed. The performed tests have shown the usability improvements of my solutions and the international scientific community has recognized their value as shown by the publications in book chapters, journals and conference proceedings. ([34][35][36][37][39][48][86][87][88][89])

Table 4 - checklist for the design science research approach

6– Conclusions and future works

In this thesis I have investigated the research question "**How to enhance the usability of mobile user interfaces for spatial data**". This question is divided into two parts: "How to display spatial data on small-sized screens" and "How to enhance text input methods".

During the investigation of the first part of the research question I was able to come up with the Framy technique to visualize large amount of Spatial Data on mobile interfaces. The successful application of this technique in different fields to solve repetitive problems has demonstrated the effectiveness of the Framy principles so that I was able to synthesize them into two patterns.

During the investigation of the second part of the research question I have also developed a new virtual keyboard called TaS. My keyboard has proved to be more efficient and effective than the QWERTY virtual keyboard, that is the most common virtual keyboard. I formalized the gesture-based methodology underlying TaS in the form of a potential pattern.

Therefore, in this thesis I have successfully investigated the two parts composing the research question. The hardware constrain related to the screen dimensions has been overcome by introducing new multimodal techniques which are applicable to the real-world context of mobile devices.

Framy technique has been applied to enhance the interface usability for spatial data in 2D environments in the mobile context. The next challenge is to use Framy in a 3D environment and to study the impact that could have in contexts different from the mobile. For example the area of the bioinformatics could benefit from visual techniques that allow experts to seamlessly navigate complex structures of molecules in 3D environments. New patterns may be formalized in order to support designers during the implementation of solutions aimed to visualize complex spatial data on large screens and in multidimensional environments.

Although the comparative tests on the TaS VK have demonstrated the effectiveness and the efficiency of the technique, a new challenge would be the choice of a layout that can further improve the writing speed. So the next step in a new investigation will be a study on the modern keyboard layouts aimed to elaborate the best layout for the users.

Finally I am planning to carry on the study of multimodal interfaces as support for visually impaired users in particular in the field of mobile devices. The goal is to formalize a set of guidelines to develop universal mobile user interfaces. Once their wider applicability gets established these guidelines will be formalized in the form of new interaction design patterns for the accessibility issues.

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