Mobile Interaction with Static and Dynamic NFC-based Displays

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ABSTRACT
This paper reports on a development framework, two prototypes, and a comparative study in the area of multi-tag Near-Field Communication (NFC) interaction. By combining NFC with static and dynamic displays, such as posters and projections, services are made more visible and allow users to interact with them easily by interacting directly with the display with their phone. In this paper, we explore such interactions, in particular, the combination of the phone display and large NFC displays. We also compare static displays and dynamic displays, and present a list of deciding factors for a particular deployment situation. We discuss one prototype for each display type and developed a corresponding framework which can be used to accelerate the development of such prototypes whilst supporting a high level of versatility. The findings of a controlled comparative study indicate, among other things, that all participants preferred the dynamic display, although the static display has advantages, e.g. with respect to privacy and portability.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – Input devices and strategies; Prototyping. H.1.2 [Models and Principles]: User/Machine Systems – Human Factors.

General Terms
Measurement, Design, Experimentation, Human Factors.

Keywords
Near Field Communication, mobile interaction, dynamic display, static display.

1. INTRODUCTION
Mobile phones are the first truly pervasively available interaction devices that are increasingly used for interactions with people, places and things in the real world. Examples for this are location-based services, Bluetooth-based interactions, camera-based applications and, more recently, tag-based interactions. The last enables NFC (Near Field Communication) or RFID (Radio Frequency Identification) supported mobile phones to interact with tags simply by touching them. This paper focuses on NFC technology: an emerging feature in mobile phones that allows, for example, touch-based interactions with advertisement posters, turnstiles or other mobile phones. In the context of this paper, we refer to passive NFC tags; these tags require no power source as they are powered by the NFC chip in the mobile phone. The communication range can be up to ten centimeters though it is normally most intuitive to simply directly touch the tags.

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A typical usage example is attaching an NFC tag that stores a link to a related web page to an advertisement poster. Once users touch the tag on the poster with their NFC phone, the corresponding web page is opened. These are called single-tag interfaces, as just one NFC tag is attached to the physical interface. In recent years, we have seen the trend of augmenting physical objects, such as maps, posters, information boards, menus or interactive displays, with one or more tags. Tagging objects enables the user interface on the phone to be extended to the physical world; thus, making mobile services more visible whilst potentially combining two displays: the mobile phone display and the physical display. In addition to making services more visible, using the phone as an interaction device enables the features of the phone to be utilized. Such features include using the phone's display (e.g. for displaying sensitive information), keypad (e.g. for password input), and using vibration and audio for more assertive feedback.

In contrast to visual markers, NFC tags have several advantages including a faster read time, larger amount of storage, and easier interaction (no need to aim and focus the camera). In addition, they allow an unobtrusive integration into posters, objects, and displays as they can be embedded behind or under the surface. This also means that multi-tag interfaces can easily be created. These can support a number of options and sequences of tag reads in order to achieve a goal. In this paper, we will focus on multi-tag interfaces as these vastly increase the number of applications that can be supported with NFC technology. Examples are augmented maps, games, multimedia, and web browsing. However, a number of these more sophisticated applications require dynamic feedback. Therefore, as well as exploring static displays such as printed posters, we propose and include the use of dynamic displays.

We developed two NFC prototypes that are centered on the tourist information domain and allow users quick access to information about the area they are visiting. The prototypes have been developed in order to demonstrate and evaluate multi-tag applications with different display types. They also served as a basis for generating a set of requirements, an architecture, and an implementation of a framework that is able to accelerate the development of such solutions, encapsulating design practices we found to be important.

The next section of this paper will cover related work in the area of tag-based interaction. This is followed by a section describing the two prototypes. This includes the characteristics common to both of them and a description of the features of each. In the second part of the paper, the proposed development framework is described, beginning with a list of requirements and leading to a more thorough treatment of some important details. The third part reports on the setup and detailed findings of a user study conducted using both prototypes. A concluding section summarizes and discusses the findings in the paper.

2. RELATED WORK

The momentum behind current NFC emergence is driven mainly by payment and ticketing [1]. The potential of this technology is suggested by ABI Research who forecast that, by 2012, more than 400 million NFC chipsets will be shipped that will be used not only for payments at points of sale, but also to access information from smart objects [2]. Proposed applications based on NFC or passive RFID tags read by mobile phones are usually single-tag as just one tag is attached to an object.

In order to classify the related work, Figure 1 illustrates the various configurations of NFC user interfaces based on two factors: visual feedback type and NFC tag coverage. An example of a static feedback type (Figure 1: a/b/c) is a paper poster. This relies on the phone screen to provide dynamic information. An example of a dynamic feedback type (Figure 1: d/e/f) is a direct-view display, which could be provided by a projection or an LCD screen. In Figure 1, each colored square visually represents an NFC tag (where the physical tag is placed behind the representation). The lighter colored squares represent visual feedback from a tag read and are relevant only to dynamic displays.

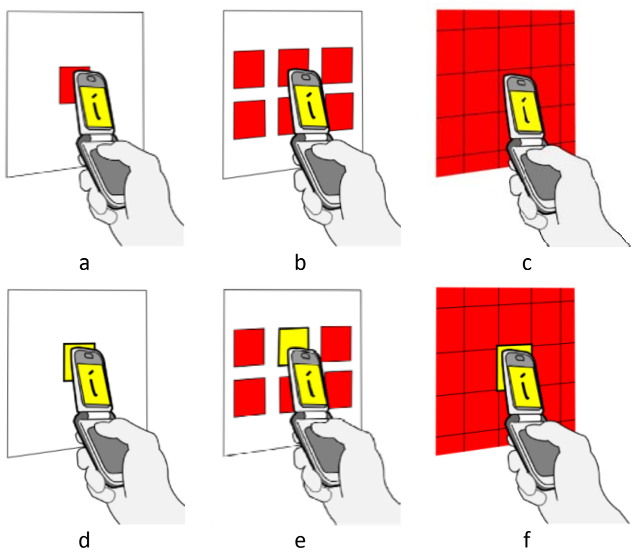

Figure 1: Various configurations of feedback type (top row static, bottom row dynamic) and NFC tag coverage (from left to right column: one, several, and complete coverage)

Want et al. were among the first who augmented objects such as books, documents or business cards with a single RFID tag [3] (Figure 1a). An RFID reader was connected to a mobile device and used to read the links to corresponding services, such as ordering the book, getting the electronic version of the document or picking up the email address from a business card. Such single-tag interactions are now widely used in Japan via the i-mode FeliCa service offered by NTT DOCOMO [4]. Here, Felica enabled handsets can be used for electronic payments, access control, and as a commuter pass just by touching corresponding readers.

Currently, we see the trend towards multi-tag interfaces in which physical objects are augmented with many NFC tags that represent different actions or parameters related to the object. Examples are posters augmented with RFID/NFC tags that provide several services, such as getting additional information, downloading media content, and ordering movie tickets [6, 7]. Such configurations can be seen in (Figure 1b). Augmenting menus with RFID technology for ordering food has been trialed by McDonalds in Korea [8], by Häikiö et al. for a touch-based user interface for elderly people [9], and by VTT for a restaurant in Oulu, Finland [10]. In those examples, a menu was used in which each item (e.g. burger, salad or drink) was touch-enabled through a corresponding NFC tag on the back. Further examples for multi-tag interfaces are "infotags" 1500 of which were deployed in Oulu Finland [10] providing different hyperlinks, and posters trialed by Vodafone providing local traffic news [11]. A further example is given by Reilly et al. who augmented a paper map with a number of RFID tags beneath points of interest [5]. This configuration is shown in (Figure 1c). A mobile device, connected to an RFID reader, was able to read those tags and provided information about the touched sights.

The multi-tag interfaces discussed so far focus on static physical interfaces, such as maps, posters or menus. Though there is no work yet which coincides with (Figure 1d) and (Figure 1e), the Touch & Interact [12] and Touch & Select [13] systems show the usage of dynamic physical interfaces with projections or LCD displays augmented with NFC tags. These configurations can be seen in (Figure 1f). Here, the dynamic physical interface turns into an interactive screen, which reacts to the interactions of the user. The Touch & Interact system supports the interaction with an interactive display in a tourist office using maps, points of interests and routes [12]. The Touch & Select system uses an NFC equipped display of a laptop supporting the rapid initiation of uploading and downloading pictures between the phone and the laptop [13].

Many of the previously mentioned examples for multi-tag applications have been evaluated in user studies or have been trialed. Although this previous research shows the usefulness and the advantages of multi-tag interfaces, all of them have been developed from scratch. These lead to time consuming and expensive prototypes or systems which had often also serious user interface problems. One of the first frameworks supporting different kinds of mobile interactions with smart objects is the Physical Mobile Interaction (PMIF) Framework, which addresses also RFID/NFC-based interactions [14]. This framework focused primarily on technical aspects needed to establish a connection between mobile phone and augmented object. Furthermore, it did not focus on multi-tag applications at all. This framework was extended to the Pervasive Service Interaction (Perci) framework which focused primarily on the automatic generation of mobile user interfaces for physical mobile interactions based on semantically enriched service descriptions [14]. Again, no support for multi-tag user interfaces was provided. Further frameworks, which focus rather on the technical aspects of single-tag NFC applications than on user interface aspects, were developed by Koskela et al. [15], Guinard at al [16] and Sanchez et al. [17].

Almost all graphical user interfaces are built using existing user interface widgets such as buttons, sliders or menus (provided by user interface frameworks). These are usually targeted at device classes such as desktop systems (Java Swing, Macintosh Cocoa and Windows MFC) or mobile devices (Symbian UIQ, Android View System und iPhone UIKit). Developing a system with a distributed user interfaces – as is the case for multi-tag applications – currently means that two different user interfaces and a corresponding application logic which combines them have to be developed. Systems in which the user interface spans several devices are, for example, the Pebbles system focusing on indirect interactions of mobile devices with remote screens [18], the Stitching interaction technique that supports pen gestures that span multiple displays [19] or Pick & Drop for data transfer between different devices [20].

The related work shows the emergence of combining NFC with dynamic displays in order to increase the utility of such interfaces. However, there has been no work comparing static and dynamic NFC displays with a user study. The results we discuss from our comparisons can be used to help evaluate which type of display addresses aspects such as the needs of the application, deployment constraints (e.g. power and weather), and monetary cost.

The related work also shows the trend towards multi-tag applications, but also the lack of a corresponding framework that addresses the special requirements particular to NFC user interfaces, such as the support of user interfaces spanning mobile device and physical interface, and cases where there may be multiple selectable items that can only be selected by a single NFC tag (e.g. in a map application). We describe such a framework which addresses these issues whilst supporting both static and dynamic displays. In addition, ours is the only framework that focuses on user interfaces for touch-based interactions with physical objects.

3. STATIC AND DYNAMIC PROTOTYPES

Two prototypes were developed to explore multi-tag interaction with varying display types. They are used to demonstrate the feasibility of both static and dynamic concepts, and the perceptions of users in a corresponding user study. The first prototype developed is a static NFC display: a paper poster. The second prototype is a dynamic NFC display with a projected screen providing the feedback. It should be stressed that projection is not the only option to provide dynamic feedback. An alternate option is to use an LCD screen which will eliminate occlusion of the projection caused by the user as demonstrated in [13]. Both prototypes share the same tourist guide functionality and the same interaction concept. The next section will distinguish visual displays pertaining to multi-tag interaction.

3.1 Visual Feedback: Static versus Dynamic

Static physical displays show an initial visual representation of the application. For example, a poster can conveniently display a map as the components of the map (e.g. points of interest) are not likely to change very frequently. However, if an application was to show several consumer products along with the number of each product currently in stock, this would not be feasible due to the potentially high frequency of required updates. The multi-tag interaction technique permits the phone to interact with the display through NFC-based interactions. As part of this interaction, the phone's display can be used to overcome the inability of the physical display to provide visual feedback. Given the product stock scenario, the phone could be used to touch the product on the physical display in order to trigger the phone display to show the number of that item in stock.

A dynamic display is able to directly provide visual feedback and does not depend on the phone display. This is advantageous for two reasons: firstly, the spatial awareness provided by the physical display is not lost when visual feedback is required (as an attention shift to the phone display can be avoided). Secondly, the dynamic display does not require user interaction before it can reveal up-to-date information.

3.2 Shared Interaction Concept

The fundamental configuration remains the same for both prototypes (Figure 2). One or many NFC tags are attached to the back of a display layer. The configuration takes advantage of the fact that NFC tags have a transmission distance of a few centimeters and can transmit through a variety of materials. The display layer hides the tags from the view of user, although they may of course be visualized by the display layer on top of them. The tags may come in the form of a paper sheet (e.g. for posters, labels, or a sheet used as a projection canvas) or a direct-view screen (e.g. an LCD or TFT screen). With this configuration, the phone reads through the display layer, which, in turn, provides a representation of the role of the tag.

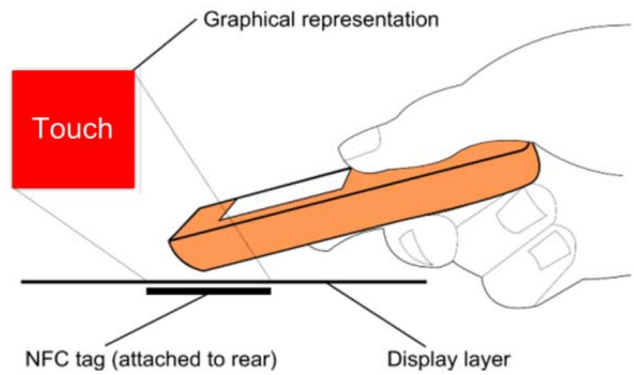

Figure 2: The basic configuration shared between prototypes. A tag-based input layer is stored behind a display layer.

Both our prototypes are based around tourist information services. As part of this role, they both feature maps. Maps are used primarily for two reasons: firstly, they show the potential of large NFC-based user interfaces with regard to spatial awareness. Secondly, they can be used to explore the mismatch in resolution between the tag matrix used for input and the pixels used for output. There are cases when the graphical representation may have a higher output resolution than the input resolution that is dictated by the physical dimensions of the NFC tag and phone. For example, there may be four selectable options inside the physical dimensions of only a single tag. The work carried out by Hardy and Rukzio [12] shows several ways the phone can be used to overcome this issue and allow the user to select a specific option.

3.3 The Static Prototype: NFC Poster

The first prototype consists of a static tourist guide poster (Figure 3), which has no ability to provide visual feedback other than on the phone. The poster's back is completely covered with a mesh of tags that provides extra functionality, yet leaves the traditional use of the map unchanged. One deployment scenario is that many posters can be created and installed at various bus shelters around the city.

The poster features a map of POIs (points of interest) specific to its deployment location. Located on this particular map are various nearby restaurants. The poster also provides a method of querying the restaurants based on a set of criteria. This can be seen on the left-hand side of the poster. There are radio button options that enable the user to specify a particular type of restaurant (e.g. Italian). There are also checkboxes used to specify one or more desired restaurant ratings. Note that, of course, the poster cannot show the selections; this has to be done on the phone. Once the criteria have been set, the user can select the "Query" action which returns the corresponding restaurant matches to the phone along with their gird references so they can be located on the map.

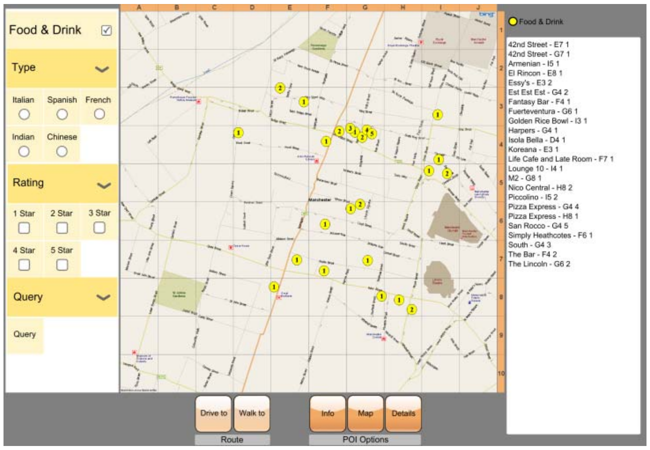

Figure 3: The UI of the static, printed poster prototype.

In order to get more information about a specific POI, the user simply touches the corresponding grid area with the phone. When there are multiple POIs in a grid area, the POI can be selected using the phone's number pad. POIs are identified locally within the bounds of the tag (e.g. if there are three POIs in one grid area, their identifiers will be 1, 2 and 3). Global identification is thus achieved by combining the local identifier with the map grid reference (e.g. A7-1).

Once a POI has been selected, the user is able to find out more information about it through the options provided (Figure 4).

Figure 4: A list of POIs in a map grid area (*left*), options for a POI (*centre*), information about a POI (*right*).

The options can be accessed through both tag interactions on the poster and tab interactions via the left and right directional keys on the phone interface. Once users have an idea of the POIs they wish to visit, route functionality provides them with navigation information which is subsequently automatically available on the phone when navigating to the selected POIs. The various route options are shown in Figure 5.

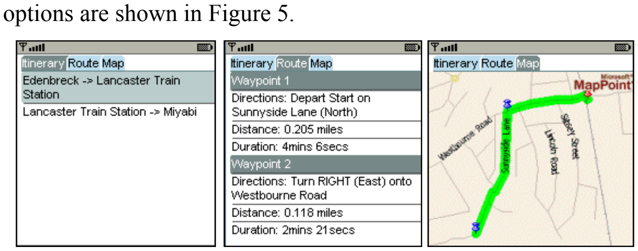

Figure 5: A route itinerary (*left*), tabular directions for a route (*centre*), map visualization of a route (*right*).

To create a whole itinerary, the user can switch to "route mode." In this mode, POIs are aggregated to a list rather than replacing one another during selection. Route mode is enabled by selecting either a "Drive to" or a "Walk to" tag on the poster. Subsequent POI selections build the itinerary. Each item in the itinerary list represents a route between two POIs. A route can be selected in the itinerary and options, such as directions and a map, can be accessed for that route.

3.4 The Dynamic Prototype: NFC Display

The second prototype is the dynamic prototype, which shares a similar appearance with the static example (Figure 6). However, the printed poster is replaced by a projector and thus a change of content and direct visual feedback is possible.

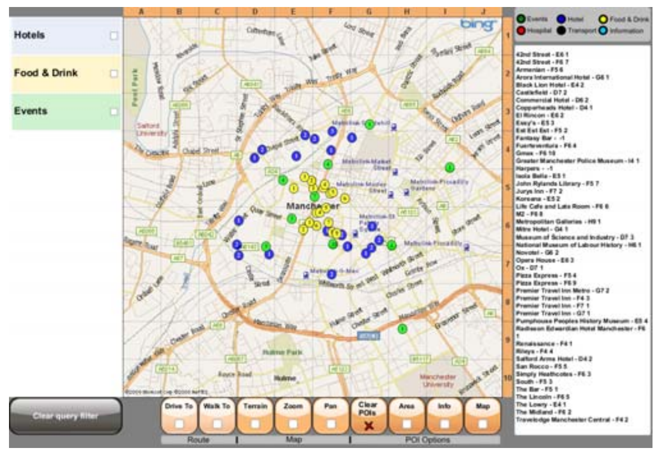

Figure 6: The UI of the dynamic, projected display prototype.

The goal of this prototype is to extend the features of the static poster by taking advantage of a large dynamic display. Further capabilities of the dynamic display are map panning and zooming. There are also navigational route overlays used to show a particular route directly on the map (Figure 7, left).

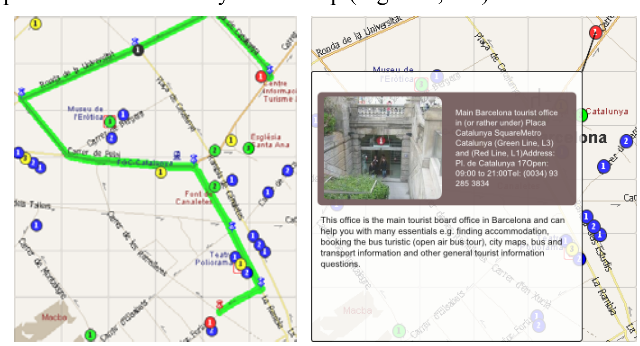

Figure 7: A route overlay (*left*) and a detailed information popup about a POI (*right*).

Information overlays display a large popup with information about a POI such as a picture and description (Figure 7, right). Moreover, there is a dynamic rollout menu widget (Figure 8, left) used to access POI querying controls, not only for restaurants, but also for other categories such as hotels and events.

In addition, visual enlargement of tag areas can used as an additional alternative for selection disambiguation (e.g. if there are several POIs displayed on the area of one tag, see Figure 8, right). There is also the ability to toggle the display of terrain information – a further demonstration of the dynamic map capabilities.

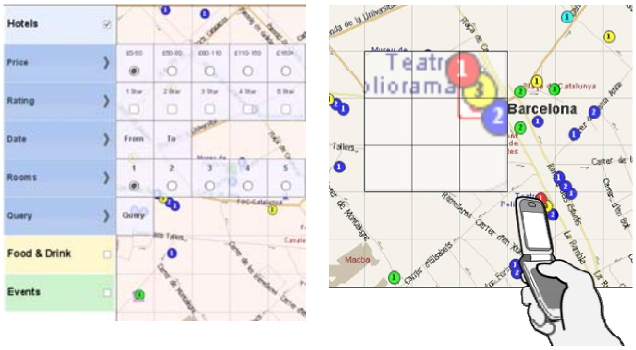

Figure 8. The rollout menu (*left*) and tag enlargement (*right*).

The features take advantage of the fact that the combination of spatial awareness (provided by the large display) and dynamic feedback allows the application state to be displayed in a much more manageable way than possible in the static version. For example, a polygon can be drawn by touching several tags (which coincide with the polygon points) in a sequence. All POIs within this polygon area are then selected. Both the polygon and the POI selection would be quite difficult to show on a mobile phone using the static poster version.

When considering both prototypes, one can imagine utilizing the advantages of both. The dynamic display has the advantage that it can abstract data (e.g. in the rollout menu), and thus provide a great deal of functionality to its users. The static poster is cheap to produce and potentially portable. Therefore, it could be produced as a snapshot of one state of the dynamic version; for example, a provider might want to offer a view tailored to hotel POIs for a specific area, or to only relevant POI search results. A more detailed comparison of each display type is given in Section 6.

3.5 Prototype Architecture

Both prototypes share a similar architecture. This can be seen in Figure 9. There are three main components: the Java ME client on the NFC phone, a Java SE application, and a C# application.

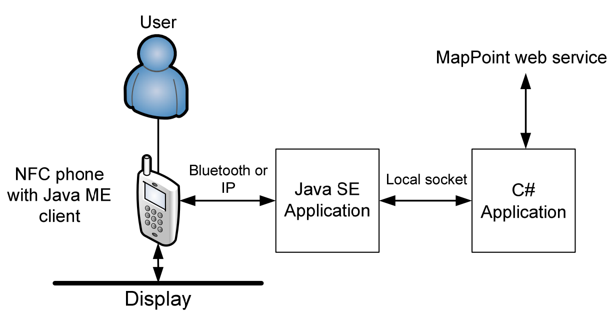

Figure 9: The prototype architecture

The Java ME client sends requests to the Java SE application via NFC reads. There may also be key presses on the phone in conjunction with tag reads. These may be used to select further options or simply to confirm the tag read. The requests can be sent over Bluetooth or via a mobile internet protocol. The client is also responsible for rendering server responses on the phone display (e.g. a set of directions for a route). On initialization, the Java SE application requests a map and set of associated POIs for a defined area from the C# application. This information is then adapted for use with the NFC grid (reassigning the POIs to NFC tag locations). Once this is done, the Java SE application listens for the phone client's requests and sends further requests to the C# application when it requires MapPoint data. This data is sent back to the phone, including a description of how the client should render each response.

The C# application serves location data requests from the Java SE application by communicating with the MapPoint web service. These requests involve:

1. Fetching a map image for a particular area including associated POIs in that area
2. Fetching 'POI nearby' area maps
3. Fetching directions between two POIs
4. Fetching a route map

The C# application performs several additional operations for the convenience of the Java SE application. These include converting search areas from a circular radius to a bounded-box area, and converting from geographical coordinates to pixel coordinates. This design served as a starting point for the development of an architecture and framework that spans the creation of both, static and dynamic, NFC-based multi-tag applications which is described in the following section.

4. THE MULTITAG FRAMEWORK

A theme connecting both prototypes is the spanning of the user interfaces across the phone and physical displays; however, the roles are different: with the static display system, the interface depends on the phone interface, whereas the phone user interface takes on a complementary role with the dynamic display system.

However, there are also major differences between the two systems. There are two main causes for this; firstly, the display types are different, and secondly, the networking support is different. The static system uses a paper poster display. As there is likely no nearby server driving the interface, the server most probably needs to be remotely accessed over a mobile internet protocol (incurring significant round-trip times and potential monetary cost to the user). Alternately, the dynamic system needs some component that drives the display. Thus, a Bluetooth connection is probably available.

When considering a framework capable of supporting varying types of multi-tag applications, the framework should fulfill several requirements. We have collected requirements from the lessons learnt during the development and usage of the prototypes described in Sections 3.3 and 3.4. Therefore, the toolkit succeeds the prototypes and provides an architecture that is based on comprehensiveness, reusability and versatility (rather than being tied to a specific application as with the previous prototypes). The requirements are as follows:

1. Abstract from communication protocols and support.
2. Support user interface sharing between the phone and physical displays.
3. Provide a thin mobile phone client that can work with all types of prototypes and applications.
4. Support physical NFC interfaces of varying visual feedback types (i.e. adapt the previous two requirements based on feedback type).
5. Provide GUI creation that suits the NFC tag geometry rather than an adaptation of an existing desktop GUI framework.

4.1 Architecture Overview

The framework provides support for the developments of NFC solutions with particular focus on multi-tag interaction. At the hardware level, there are three main components: NFC tags, phone and server (Figure 10). The NFC tags are attached to a display in order to convert it into a physical user interface. The phone is the "smart stylus" used to interact with the physical interface. The server takes the role of the back-end for the physical interface (providing services and application logic) and is also used to generate the physical interface.

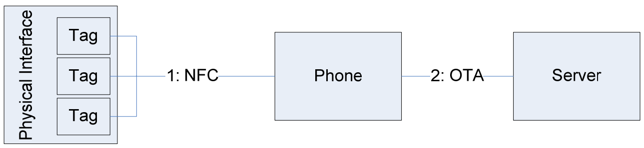

Figure 10: Hardware components: a phone reads/writes to NFC tags (1) and communicates over-the-air with a server (2).

The data flow between the three hardware components differs depending on whether the tags are written to (for setup purposes) or read from (at runtime). Typically, when a physical interface is read, communication flows from the tags to the phone and onwards to the server. The flow between is phone and server abstracts from various networking protocols in keeping with *requirement 1*. Subsequent flow may take place between the phone and server using the various input modalities of the phone, for example, if the user had to confirm a tag read with a key press. The process of data flow over all three components holds for every tag on a dynamic physical interface (Figure 11a) as there is no strict mapping between the tags and the corresponding data. However, when a static physical interface is used the data shown on the representative tags will be fixed in most cases. In these situations, the server needs not be contacted as the tags can store the data itself ('absolute data') rather than a link to the data on a server ('relative data', Figure 11c). When this is not possible, i.e. when the data is dynamic, the widget must consult application logic or state on the server. Therefore, an ID-based widget link can be established to the server widget representation (Figure 11b). Using the configurations in Figure 11, both dynamic and static displays types can be supported (as specified in *requirement 2*).

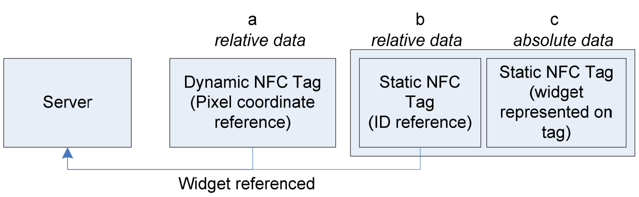

Figure 11: Various tag configurations showing how data is retrieved by the corresponding tags.

As the phone sits between the server and physical interfaces, it can receive commands in data received from either component. The ability to control the phone results in less application logic and state on the phone client and so it to becomes as lightweight as possible (in keeping with *requirement 3*) with only a few general functions that can be called. These include commands to store/retrieve or display information from either the server or tags. Also, general user interface commands such as "undo", "back", "vibrate", and "beep" are supported.

To summarize, the framework is designed to support various types of interface and network solutions. For example, with a static poster, it is likely that the poster must be supported by mobile internet protocols (rather than short-range protocols such as Bluetooth). By reducing server connectivity as much as possible, one can alleviate round-trip-times, and consequently, an undesirable delay in interaction feedback timeliness.

4.2 The Multi-tag Widgets

The core software components of the framework are focused around a reusable collection of multi-tag UI widgets. The majority of multi-tag widgets are synonymous with those used in desktop widget libraries (e.g. radio buttons, drop-down boxes, etc.). However, the distinctions with multi-tag widgets are that

1. they suit a variety of display types (e.g. projection, direct-view, and posters) and
2. the widgets are distributed over the three hardware components shown in Figure 10. Widgets reside on a static physical interface (*Static Widgets*), the phone interface *(Phone-only Widgets),* and the server (*Server Widgets*).

Static Widgets reside on the NFC tags as, typically, the tags have sufficient storage to store a description of the tag (Figure 11c). For example, a description might be a radio button on a paper poster which is labeled "price" and is initially deselected. The phone user interface uses a collection of *Phone-only Widgets* that are provided by the Light Weight User Interface Toolkit (LWUIT) [23]: an API for creating mobile device application user interfaces. If the user selects the abovementioned radio button, then the poster is unable to convey this, so the LWUIT radio button on the phone display must provide the appropriate feedback. *Server Widgets* reside on a nearby server. With these widgets, the NFC tags simply provide an ID or pixel coordinate in order to reference a particular widget (Figure 11a/b).

To support the *Server Widgets*, the well-known model-view-controller (MVC) pattern is exploited and applied to each widget. By separating the model (state and logic) from the views (rendering) and controllers (user event handling), multiple views and controllers can look onto a single model. Therefore, the phone and physical interface can run in parallel for dynamic physical interfaces in accordance with *requirement 4*. Moreover, another reason for the separation is so that the views and controllers can be replaced with no dependencies on one another or effect on the model. For example, the phone widgets could be controlled using different *phone-only* views and controllers on the server. Here, the view would control what is being displayed on the phone display via user interface descriptions that organize the *Phone-only Widgets*. Also, the controller would respond to, for example, events from the phone's key-pad, rather than NFC events from the physical display.

Figure 12 shows the multi-tag widget hierarchy. The patterned widgets are currently supported by LWUIT (i.e. *Phone-only Widgets*). Alternate widgets can be substituted for widgets that are not natively supported (e.g. a ChoiceItem for a ToggleButton). The *Server Widgets* can also be broken down into *Widget Components*. These are icons and text which can be reused and painted separately on rendering updates. We focus on using SVG (Scalable Vector Graphics) capability for the physical interface, so that by using SVG, the interfaces have lossless rescaling capabilities, dynamic transformation, and animations. This gives the developer a great deal of freedom when creating the graphics using a visual graphics editor (in accordance with *requirement 5*).

Finally, a look-and-feel paradigm is used to dictate the mappings between the models, views and controllers. The look-and-feel is used in the same way as in many traditional desktop operating systems (e.g. Microsoft Vista). However, with traditional examples, there is a greater weighting towards the *look* (cf. skinning), whereas with the multi-tag look-and-feel, the *feel* can also be radically changed.

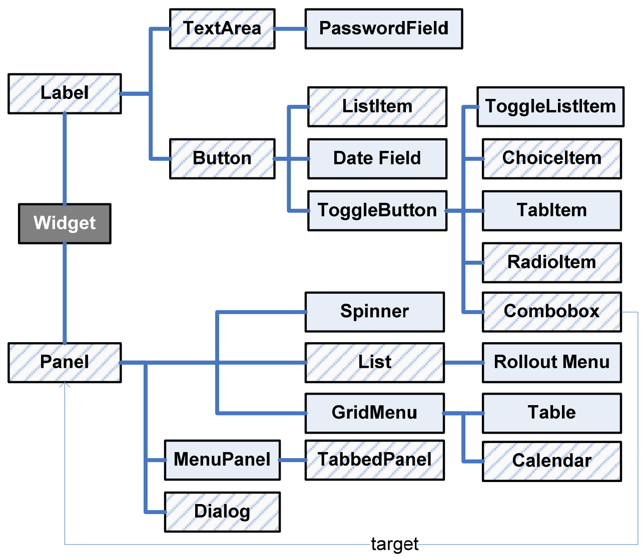

Figure 12: The multi-tag widget hierarchy. The patterned widgets are supported by the used LWUIT toolkit.

5. SYSTEM EVALUATION

We conducted a user study in order to evaluate participants' perceptions on both user interface types. As well as evaluating each from a comparative point of view, we also investigate participants' perceptions with regard to the overall concept regardless of display type. The primary goals of the study were the following: firstly, we wanted to find out the pros and cons of both display types when using the same tourist guide scenario. Secondly, we wished to gather understandings on the potential of such sophisticated NFC user interfaces from a conceptual and usability point of view. We also strived to understand the barriers to entry for the initial use of these interfaces, how easy to learn they are, and how productive users can become. Further desired findings that are common to both versions were specific issues and comments for a particular version and the users' impressions towards perceived benefits and desired additional features.

5.1 Study Setup

A cooperative evaluation technique was used to encourage a relaxed dialog between the 12 participants and the evaluator. The participants consisted of 6 males, 6 females, with a mean age of 22.8 years. The tasks for each participant were conducted in accordance with a repeated measures design. Figure 13 shows the two prototypes used in the study. Initially, the participants' demographics and mobile phone comfort levels were collected. This was followed by an introduction of the features for both prototypes. Then untrained POI selection was used to observe how the participants approach the prototypes. Finally, they had to execute the following tasks:

1. Perform 5 random hotel/restaurant/event queries.

   For example, find a hotel today between £50-80/night, which is a 3 or 4 star rating. The matching hotels are then highlighted on the NFC display and a corresponding list of matches shown on the phone display.
2. Select 10 random POIs.
3. Create 3 routes made up of 4 POIs per route.
4. Get the 'nearby map' for 3 POIs.

   This option can be accessed when a POI has been selected. It shows a small map of the area surrounding the POI on the phone.

In addition, for the dynamic prototype only:

5. Zoom into the map and select a route of three POIs.
6. Use the polygon select (from section 3.4) to select a group of tags.

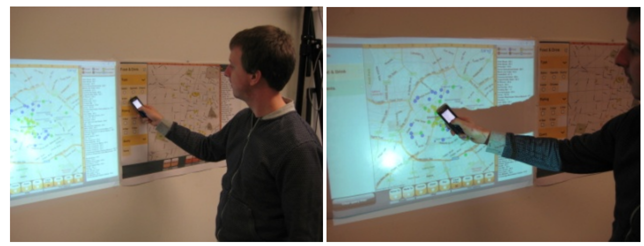

Figure 13: (left) interaction with the static display and (right) interaction with the dynamic display

Feedback was gathered for the features shared by the prototypes (querying POIs, POI selection, and route selection) using a NASA task load index survey [21]. Once both prototypes have been used, a subset of IBM CSUQ (Computer Systems Usability Questionnaire) [22] questions was used to gather feedback on overall usability (taking into account both prototypes). The ordering of the set of prototype tasks was counterbalanced in order to reduce learning effects caused by one version or the other.

5.2 Investigating the Barriers to Entry

The study had two phases with the first one aimed at observing the barriers to entry for such an interaction. This is expected to be quite high as the action of touching a display with a phone will seem very unfamiliar to users. Initially, participants were told about the purpose of the prototypes, but not about the technology that drives them, or the way they are used. Given the task to select a particular POI, the following interaction attempts were observed. In many cases, participants were given the phone, yet still touched the POIs (on both prototypes) with their fingers (possibly due to familiarity with touch screens). In other cases, participants interacted with the phone only, neglecting the NFC-interface (possibly due to familiarity with Bluetooth connectivity). In addition, nearly all participants aimed directly for the POI rather than the map grid segment to which it belongs. Due to the size of the NFC tags, there may be several POIs contained in a single selectable grid segment. Though this works in most situations, there is a greater likelihood of interference from adjacent tags. However, such barriers will ultimately be lowered by a wide user base awareness of the technology, and the focus is targeted more towards the potential of such systems once the barriers to entry have been crossed. Figure 14 shows that the majority of the users were very comfortable with computers and mobile phones. In addition, the majority of users had at least some experience with mobile internet.

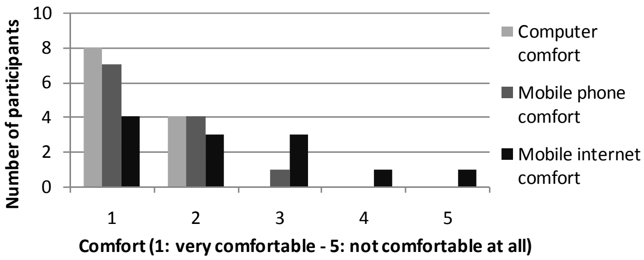

Figure 14: Participants comfort with (mobile) technologies.

5.3 Subjective Workload Results

The results of the NASA TLX survey for the dynamic prototype can be seen in Figure 15. The Y-axis shows the raw ratings out of 100 for each of the six scales: mental demand (MD), physical demand (PD), temporal demand (TD), performance (OP), effort (EF), and frustration (FR). To avoid confusion, it should be stressed that performance is a measure of the success of the tasks and a lower raw rating leans towards perfect performance, whilst higher values lean towards failure. Along the X-axis are the weights: these indicate the participant's suggested importance of each of the six scales in relation to one another. The multiplication of raw ratings and weights provides the adjusted rating. This rating gives an insight into the workload for each scale.

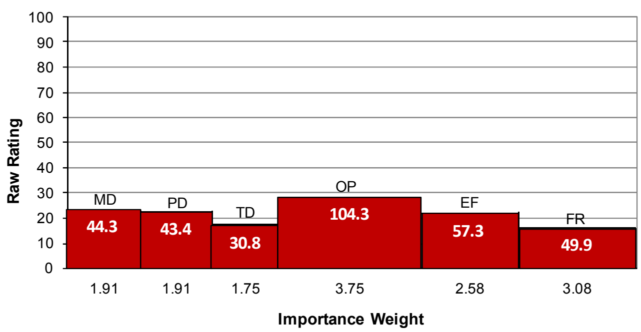

Figure 15: Graph showing the adjusted task load ratings for the *dynamic* display.

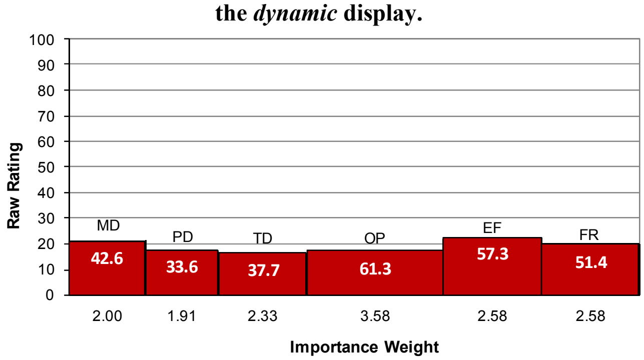

Figure 16: Graph showing the adjusted task load ratings for the *static* display.

From Figure 15 and Figure 16, the greater the area for each scale, the greater the workload. Figure 15 shows that all ratings are low (pointing to little workload on the user). However, the area of the scale for performance is considerably greater than the other scales with an adjusted rating of 104.3 compared to the others which are between 30.8 and 57.3. However, the performance adjusted ratings are not so substantial with the static prototype.

So what are the reasons for the substantial adjusted ratings with respect to the performance scale in Figure 15? For both versions, the sensitivity of the performance ratings are increased due to the level of the weightings (3.75 and 3.58). However, even still, the raw rating for the dynamic performance value is ~10% greater than those of the static version which is statistically significant ($Z = 1.96, p = .05$) using a Wilcoxon signed-rank test. This difference is due to two reasons: the complexity of holding the phone in range of a tag until a selection can be confirmed with a key press on the phone (an action exclusive to the dynamic prototype), and due to occlusion of the screen. In particular, the selection technique in which the phone needed to be held in tag range of a tag led to a higher error rate; thus, hindering the success of the task. Nevertheless, all users still prefered the dynamic display protoype overall – an interesting result that indicates the value of dynamic feedback for such systems over hindered user interaction (whether this effect holds over time would have to be evaluated in further longitudinal studies). The frustration ratings for the dynamic prototype help to validate this point as they are slightly lower for the dynamic prototype due to people's feelings that the dynamic version is more impressive and, consequently, enjoyable. Figure 17 shows that the overall workload summarizing all six ratings indicates less workload in favor of the static version: a result of the high raw performance ratings for the dynamic version. In keeping with the bipolar scales (0-100) from very low to very high, the overall workload for both versions seems very positive.

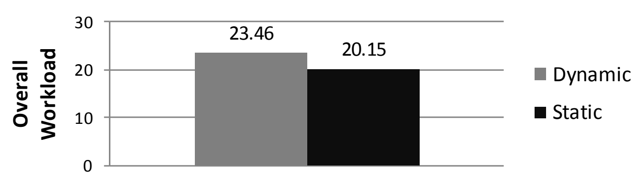

Figure 17: Overall workload for each prototype.

5.4 Usability and Focused Questions Results

The results of the CSUQ survey are relevant to both prototypes. Therefore, the survey is eliciting feedback concerning the fundamental interaction technique, shared functionality, and design. As seen in Figure 18, the results are overall very positive (items were 7-point scales ranging from "strongly disagree" at 1 to "strongly agree" at 7). Most importantly, the users considered the prototypes easy to learn and saw themselves quickly becoming comfortable and productive with the interface.

With regard to privacy issues, 42% of users did not feel that they would be concerned about using such a system in a public setting. The other 33% and 25% represent indifferent and concerned opinions respectively. Interesting comments on the subject of privacy revealed that participants felt that the static poster is a more suitable prototype with regard to privacy as all feedback takes place on the phone's private display. Another question put to the users was whether they were worried if the static poster was up-to-date. 42% of the users would have concerns about the poster not showing the most current information, not particularly relating to the POIs already present on the poster, but more that it may be missing the latest POIs. Yet, all agreed that they would have the same amount of trust as with all non-interactive posters currently deployed and 25% of the users were not concerned with this issue. The remaining 33% of users were indifferent to this aspect.

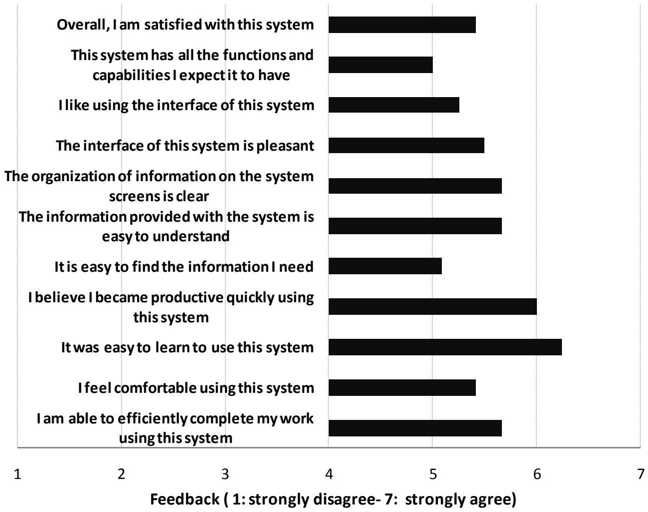

Figure 18: CSUQ results for the overall concept (The results from all questions are greater than the mid-point of 4)

The users were also asked whether they agreed that the static poster was a suitable replacement for a dynamic installation. This situation may occur for monetary reasons or deployment constraints (such as lack of power supply). 75% of users agreed that a static poster could be a replacement for the features it shares with the dynamic counterpart. Those who disagreed argued that the inability to pan the map might be too critical a feature. As a side result, 83% of users preferred the option of using one potentially larger poster encapsulating all POI types and less focused in a specific area to separate posters with a more specific focus. Regarding the advantages for the dynamic version, most users found it easier to use, despite the more advanced interaction techniques used. One reason is that the increased amount of feedback provided required the users to concentrate less. In addition, more information could be displayed in an organized manner.

However, the major drawback of the dynamic prototype was occlusion caused by the projection. As participants tried to keep their body out of the projection beam, they needed to stretch their arms which makes reading the information on the phone screen more difficult and people often ignored it as a consequence. However, it is important to stress that this is only an issue with our current prototype and not concept of the dynamic display as such. Occlusion can be avoided by using an LCD display augmented with NFC tags as done in [13]. We also recently switched our installation to use a short-throw projector mounted on the ceiling which already considerably improves the situation. Also, big advantage with the static version is its portability. The map could be folded up and carried by users for later reference (in the same manner traditional maps are used). When asked if users would carry an NFC enabled map (without taking into account cost), 92% agreed that they would. The one user who would not said they would prefer to use their phone.

After investigating the participants' choices for making a basic selection, 75% of the participants preferred simply touching the option with the phone. There were two further methods of selection which force the participants to confirm the NFC read with a key press on the phone. The first method supports the phone to be away from the NFC tags before a confirming the NFC read with a key press. Here, 25% preferred this method explaining that this gave them greater control over their selections and avoided accidental selections which may occur by reading an incorrect nearby tag. The second method forced the user to hold the phone within range of the tags until the tag read is confirmed with a key press; no participants preferred this option. For POI selection (and route selection accordingly), a confirm selection was mandatory. Here, no participants were in favour of this second method as they found it difficult to hold the phone within reading range for some time whilst maintaining a view on the phone screen. Also, on many occasions, the participants had to change their grip on the phone in order to position their thumb/finger on the number-pad to make a selection. In the process of changing their grip whilst holding the phone within range of a tag, the phone would occasionally move out of range and would require repositioning on the tag.

When observing the participants' posture whilst using the system, the height of the user interfaces was a particular problem. The height did not affect their ability to select the options on the prototypes. However, a couple of participants had problems seeing the phone screen whilst selecting. This is because the phone is normally held in a slightly tilted position when reading a tag.

6. SUMMARY AND DISCUSSION

In this paper, we proposed: two sophisticated NFC-based application prototypes, a framework supporting developers with the creation of such systems, and a user study targeted at both prototypes to understand users' perceptions on dynamic and static NFC displays. The prototypes demonstrate that NFC-based interfaces can accommodate rich user interactions and large amounts of information. They also show that such interfaces can potentially come in many different forms, which depend on various constraints, such as deployment restrictions, monetary limitations and available types of connectivity. The multi-tag framework has been succinctly described and is designed to meet these demands and lower the effort in creating tailored NFC-based solutions. As well as providing developer support, the framework can support a diverse range of NFC applications. The development of the framework is driven by the complexities of sharing the user interface between the phone and physical interface as well as to avoid the complexities of adapting a GUI that is intended for desktop use (e.g. SWING) to an interface that suits the geometry of the tags.

We have also discussed the salient findings of a user study that focused on a comparison of prototypes that use static and dynamic visual feedback, respectively, and elicits preliminary thoughts with regard to the potential of the overall interaction technique. The dynamic display was the preferred choice from the participants' perspective due to the value of dynamic feedback. For instance, it supports map manipulation and selection feedback that is in keeping with the spatial awareness provided by the large display size. However, posters can be thought as complementary rather than a substitute, even though 75% of users agreed that they would also consider the static version as a substitute. Pertaining to selections, our findings have pointed to the preference of the simply touching NFC tags to make a selection. When this is not possible (e.g. if the input resolution of the tags is not sufficient) confirming using a key press without having to hold the phone in tag range is the preferred option.

To summarize, Table 1 contrasts static and dynamic NFC displays for a set of aspects. Dynamic displays are generally less privacy preserving than static displays as a user's actions can be visualized by the display. However, both versions could take care to show more sensitive information on the phone display only. Dynamic displays are perceived to be more up-to-date than static displays due to the fact that posters must either be reprinted or rely on the phone display for up-to-date information. The monetary cost of the display is obviously higher with dynamic displays as posters are cheaper to produce and replace. Static displays can also be folded for portability and are simpler to deploy as they require no power and are less susceptible to light conditions, weather and vandalism. Perceived usability is in favor of the dynamic displays as people value the direct dynamic feedback while the phone display was in many cases ignored. The phone display is used with both types of display to show sensitive information; however, the static display has to rely more on it for displaying dynamic content. Regarding network options, static displays are likely to depend on a mobile phone network. One the one hand, this may result in slower responses to interactions, on the other hand, though, deployment is made much easier and network coverage is generally high. Thus, static posters may become more (easily) ubiquitous.

Table 1: Comparison of dynamic and static NFC displays.

Aspect	Dynamic	Static
1.Privacy	Medium	High
2.Up-to-date information	High	Low
3.Production cost	High	Low
4.Portability	Low	High
5.Deployment procedure	Complex	Simple
6.Environment susceptibility	High	Low
7.Usability	High	Medium
8.Novelty	High	Medium
9.Phone display usage	Complementary	Necessary
10.Network	Bluetooth	Mobile IP
11.Ubiquity	Medium	High

Future work will focus around forming a collection of design guidelines that can be used to complement the widgets in the framework. Such guidelines can be found through a collection of focused studies on aspects such as widget selection, Gestalt Principles, and the creation of KLM (Keystroke-Level Model) extensions for multi-tag user interfaces. Further, longitudinal studies could reveal interesting information about the long-term usability of advanced NFC-based interfaces and the effect of novelty on the users.

7. ACKNOWLEDGMENTS

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