Musing: A Mobile Client and Web Server Augmented Reality Application for Museum Visitors and Curators

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***Abstract*—Textual didactics, used in museums and galleries provide access to historical, socio-political, technical, and biographic information about the artworks and artists. These types of didactics are considered to be cost-effective. However, they do not enable the use of audio, video, and Web interface that allows for multiple forms of usage for the museum visitors. We have developed a smartphone application, called *Musing*, for interaction of museum visitors with informational content and enhancement of their museum experience. *Musing* is an augmented reality (AR) application that enables the visitor to capture an artwork with a smartphone camera. Using image processing, the application recognizes the artwork and places graphical user interface objects in the form of Points of Interest (POIs) onto the image of the artwork displayed on-screen. These POIs provide the visitor with additional didactic information in the form of text overlays, audio, video, and Web sites. The *Musing* application and administrator Web site, described in this paper, is designed with several performance and efficiency goals, including high reliability and recognition rate, high usability, and significant flexibility. The application is designed to be adaptable to a variety of museums and galleries without requiring special hardware or software. Furthermore, the administrative interface enables museum staff to provide content for the didactics without requiring software development skills.**

Keywords—interactive didactic; museum didactic; virtual museum; image recognition; augmented reality

I. Introduction

Museums have historically been tasked with providing access to, and educating visitors about artworks. Museum didactics attempt to clarify artworks' meanings by addressing concepts of art, history, politics, construction techniques, as well as the lives of artists. For many visitors, however, museum and gallery exhibitions may lack the proper context to allow access points for exhibited works and can leave the "uninitiated viewer" intimidated, "particularly when it comes to interpretation" [1][2].

In many ways, mobile technologies, such as responsive Web sites and AR, present an ideal opportunity to make those personal connections with the visitor, as well as help the visitor make connections to the exhibited objects and/or works of art. As such, the context for the artwork is broadened via interviews, videos, Web sites, source material, art historical influences, and other artworks with shared conceptual frameworks, all of which can be integrated into a mobile application for the museum. Such a personalization of experience through narrative is a highly effective way to expand the context for the work and deepen viewers' connections as they process and integrate the information into their existing world-view [3].

Nevertheless, under the current paradigm, in order to add audio and video to exhibits, museums must rely on proprietary hardware and software. The hardware must be provided by the institution at significant cost both in capital investment and in maintenance. The software used on these devices is often proprietary for the exhibition, reliant on external hardware installed in the gallery, and must be reprogrammed for new exhibitions. While large museums have the resources to purchase and maintain these systems, small community-based museums often do not.

Pedagogical shifts away from passive museum participation to active participation are occurring in higher education, as well as in museological practices, and reflect the changing needs of the visitor [4]. An enriched learning environment requires incorporating diverse learning styles, which include visual/print, visual/picture, auditory, kinesthetic, and verbal/kinesthetic modalities [4].

A. Problem Statement

In order for museums and galleries to fully meet the needs of their visitors, they must incorporate didactic information that embraces diverse learning styles and present multiple types of didactic information.

An interactive didactic system should be designed to reach the highest number of museums and their visitors, which does not rely on proprietary hardware, the installation of external devices in the gallery, or the need to reprogram the system when exhibits are modified or added.

In order to create a system that does not require proprietary hardware, the system should be developed on mobile hardware that many of the museum visitors already possess. This hardware would include classes of smartphones and tablets running on iOS or Android operating systems.

To minimize the technical burden on institutions, the system should not rely on extra hardware such as Bluetooth or Near Field Communication (NFC) devices.

An administrator panel should be designed to facilitate ease of editing—addition and deletion of content in such a way as to give museologists these abilities without the requirement of software development skills.

Finally, image processing and image recognition algorithms should be used in order to provide the opportunity for the viewers to deepen their connections to artworks by scanning artworks directly, removing the need for external tokens such as Quick Response codes (QR) or number codes to be entered by users.

B. Hypothesis

By using a combination of off-the-shelf image recognition algorithms and unmodified consumer-level hardware, the research team will be able to create a client application that is fast and accurate enough to be usable in a museum, without the need for proprietary hardware, or external tokens. In addition, retrieving exhibition data via a database will allow for a client program that is sufficiently flexible and does not require reprogramming when exhibitions are added or modified.

The proposed interactive didactic system will be designed with a client-server architecture. A database, administered by a Web site, will provide the client application with access to didactic information without the need to permanently store that information on the device. The client application will be programmed for current popular hardware such as a smartphone or a tablet, either owned by the museum visitor or provided in the form of loaners.

Providing museologists with an efficient and usable software tool that facilitates generating new AR exhibitions and editing / modifying existing AR exhibitions (i.e., editing the Musing server) without requiring software development skills will enable widespread usage of the client part of *Musing*.

In order to test the relative success of the application and its acceptance by museum visitors, *Musing* will be deployed in three exhibitions at The University Galleries at Texas State University, a three thousand square foot, university-based, contemporary art exhibition venue. Benchmark testing of the application will be conducted in order to determine recognition accuracy rate and speed. Post-exhibit, exit questionnaires will be given to visitors in order to determine their acceptance of the client application and perceptions of system performance and usability.

C. Proposed Solution

The research team has developed *Musing*, a mobile, image recognition and AR application that runs on consumer-based iOS systems, requires no external tokens or hardware, and does not require reprogramming between exhibits. The application has passed the Apple approval process and is available at [5].

The main contributions of this research is the design, development, and deployment of an end-to-end reliable, usable, and effective AR system that provides a museum visitor with virtual information and provides museum staff with adaptable, cost effective, and easy to maintain virtual museum utility. To date and to the best of our knowledge, this is the only fully functional system that integrates custom-hardware agnostic and custom-software agnostic virtual museum content delivery and administrative support, which does not require hardware to be installed in the exhibition space, and is freely available to consumers.

This paper, which is an expanded version of [1], is organized in the following way: Section II provides background in the form of relevant past research performed by this team, with Section III containing a Literature review. The application deployment of the *Musing* client application, as well as its associated administration back-end is outlined in Section IV, followed by deployment results showcased in Section V. Section VI explains the evaluation of results from both benchmark testing and exit questionnaires given to the museum visitors. Lastly, Section VII outlines the conclusions and future research objectives for *Musing*.

II. BACKGROUND

A. Previous Research

In 2012, the research team developed a series of responsive Web pages triggered by QR codes used in an exhibition at The University Galleries at the Texas State University [6].

In this pilot program, QR codes were included in the tombstone wall labels placed next to artworks in the gallery. These codes, when scanned with reader software on the user's smartphone, presented the visitor with a custom-built Web responsive page for each artwork (Figure 1). These pages provided supplemental didactic information via news articles that pertained to the artwork's subject matter, full artist biographies, video interviews with the artist, photos of the artist's workspace, and links to external Web sites.

Figure 1. Example QR-triggered Web page with artist interview (http://www.txstgalleries.org/michael-henderson)

During the pilot exhibition, the gallery Web site recorded 23 unique visitors per day with an average time on-page of 3 minutes and 37 seconds. The Web pages that were only accessible by the QR codes were responsible for 16 of the 23 unique daily visitors (69%) and the majority of the time on-page (3 minutes and 33 seconds). For comparison, exhibits installed after the pilot test did not include QR codes. The subsequent exhibit showed a decline in both the number of online visitors (-26%) and the amount of time visitors spent on the gallery Web site (-42.5%). This data indicates that when QR codes and their associated didactic information are included with the artworks in the gallery, there is an increase in online interaction with the visitor.

The experiment with QR codes in the gallery indicated that visitors would use interactive technologies in the gallery and that they would spend the time necessary to consume the extra content. However, a major drawback of the QR codes was the inability for the museum professional to contextually place information within an artwork's representation. The newer AR technology would allow the administrator to place content exactly where it would be most pertinent to the visitor's view of the artwork. For example, a POI could be placed over a specific person or place in an artwork to provide information about the historical or social significance. Lastly, QR code reader software is not created specifically for the needs of museums and galleries, as they are designed to work for a wide variety of applications, from advertising to stock keeping.

Following the positive response to the QR code project, it was decided that the next step in the research should be to create an AR system allowing for information placement within an artwork, and which could be designed specifically for the needs of museums and galleries.

Several aspects of the *Musing* system, such as the pedagogical and art design characteristics are covered in [7][8]. The current paper, as well as [1], concentrate on the user experience and the technological innovation which enables this experience.

III. Literature Review

The literature review is addressing two areas of interest: 1) The relevance and potential for a positive influence of technology in an exhibition setting on the visitor experience, and 2) current use and applications of AR and mobile applications within an exhibition setting.

In his article, "Designing Mobile Digital Experiences," Tallon talks about the "potential of digital technology" as it surpasses its own hype to become a source of enrichment for visitors' learning [9]. This positions the visitor as a collaborator in the process of making meaning by gathering information and connecting them through their personal frame of reference.

Stephen Weil, author of *Making Museums Matter*, advocates for museums to "be more than merely a communicator or a stimulant" [10]. Moving from the traditional (and outmoded) linear model of communication that provides didactic information in an institutional voice via wall labels and gallery talks, to a circular model that promotes—by incorporating technology into the exhibition materials—an enriched environment in which the visitors can partner in the making of meaning by aggregating a variety of information types as well as voices within the information dissemination. Learning environments that qualify as enriched are reflective of a variety of learning modalities: visual, auditory, and kinesthetic [11], which are comprised of seeing, hearing, and interaction. This is imperative if museums visitors are to move toward relating to art in a non-linear manner.

Another influential theory can be found in John Falk's book, "Identity and the Museum Visitor Experience" [12], wherein Falk identifies five key types of visitors who attend museums while also defining visitor motivation. These five key user types fall within the definitions of human need, rather than that of demographics and are characterized in the following ways relative to basic human needs. They are: 1) Explorers–motivated by personal curiosity (i.e., browsers); 2) Facilitators–motivated by other people and their needs (i.e., a parent bringing a child); 3) Experience-Seekers–motivated by the desire to see and experience a place (i.e., tourists); 4) Professional/Hobbyists–motivated by specific knowledge-related goals (i.e., a scholar researching a specific topic); 5) Rechargers–motivated by a desire for a contemplative or restorative experience.

It is through this research and literature review that the research team gained a clearer picture as to the need for, as well as potential ways to make connections and meaning, in assessing audiences based on their desired experience rather than outmoded demographic considerations. As such, learning typologies, alongside Falk's research on the five types of user experiences seen in museums, provides an emerging picture of the important role that technology can play in facilitating a variety of learning styles, as well as, the diversity of user types are found in exhibition settings.

Addressing the second area of interest, a review of existing literature showed a number of teams researching the possibility of using AR to augment the information provided by museum didactics. In most of the cases, however, these didactics rely on proprietary hardware, require reprogramming between exhibitions, or installation of external tokens (e.g., Bluetooth, RFID, and QR) within the museum space. Some work has been done with respect to the challenges of image recognition, but little attention has been paid with regard to integrating custom-hardware/software agnostic image based picture recognition with content delivery.

Bimber et al. have developed a mobile system, named, *PhoneGuide* allowing museum visitors to use mobile phones to detect artworks in a physical museum space [13]. Their method includes image recognition, using the phone's camera, as well as pervasive tracking techniques using a grid of Bluetooth emitters distributed in the space [13]. The reliance on external tokens (e.g., Bluetooth) to assist in the object recognition would require the museum to install new hardware and provide for updates in each gallery space.

Hatala et al. describe a prototype system, called Ec(h)o, developed to provide "spatialized soundscapes" for museum visitors [14]. That is, specialized audio is played for the listeners depending on their position within the museum. The supplied audio is meant to augment the overall experience of the exhibit rather than providing information about artwork.

Jing et al. have developed a mobile augmented reality prototype system which uses image recognition running on specialized hardware to provide additional information on physical images displayed in museums for Personal Museum Tour Guide Applications [15]. The system uses the SIFT recognition algorithm that employs “coarse to fine” recognition to improve the speed of the process [16]. Nevertheless, some users complained of slow processing speed.

Blockner et al. developed a prototype system which allows users to create virtual museum tours on a mobile app. The mobile device uses NFC to transmit these tours to projectors positioned within the gallery which display the desired information [17].

Miyashitat et al. have developed an interactive device at the Dai Nippon Printing (DNP) Museum Lab at the Louvre Museum (Paris) for use with an exhibition on Islamic Art. This device used a neural network based system to map content of exhibits and was able to recognize three dimensional objects from a single viewpoint, but also relies on purpose specific hardware which is not available outside the Louvre and requires that Bluetooth enabled hardware be installed in the gallery [18].

Klopfer et al. proposed a “location aware field guide” which operated in a manner similar to *Musing* but it was not adapted to use in a museum [19].

Lee et al. used an ultra-mobile PC, inertia tracker and camera for object recognition [20]. This system did not rely on external devices; instead, it relied on template matching. In this case, a translucent image of the next artwork is placed on the screen, guiding the user to the next artwork to be matched and used to locate the user within the museum space, attempting to estimate the user’s location by the last artwork scanned. However, this approach does not provide for an accurate location estimate. Furthermore, this project relied on proprietary hardware supplied by the institution.

Another system that used specialized hardware to provide an augmented reality experience is described in [21]. The system overlays the picture of a physical image displayed on a custom hardware with pertinent information in real-time. The detection of the artwork is accomplished using ultrasound sensors and gyros for pose tracking. The information is then matched to the image using an edge-detection algorithm.

Explora-Museum-EXMU ([22]) is a tablet application that shares several features with Musing. It has a similar look and feel and similar client/server design approach[1]. Nevertheless, two key features distinguish the EXMU app from Musing. First, the app is currently available only on tablets. Second, and more important, the app requires special hardware in the form of blue tooth transmitters.

This might impose limitations on the flexibility of placement of artwork and rearrangement of the app upon changes in gallery / museum content.

[1] The application has been recently announced and there is no much information about it except for the information available in [22].

In addition to the previously discussed systems, there are a number of consumer-level museum applications that do not require proprietary hardware.

The Smithsonian Institution and Arcade Sunshine Media have developed *The Peacock Room Comes to America* app. The iOS application was built specifically to explore artist James McNeill Whistler’s *Peacock Room* in the Smithsonian Freer Gallery [23]. The application allows for a virtual exploration of the space by presenting a scrolling image of the room with tapable artworks in the scene. When tapped, these artworks offer expanded textual and audio information. *Peacock Room* does not require the visitor to be physically located within the museum to view content, meaning that it does not actively drive visitors to the exhibit. The entirety of information (text, audio, and video) is locally stored on the user’s device. As such, the application must be reprogrammed and downloaded again by the user, if information is edited or new information is created, which may result in the user missing updates and/or corrections/additions. *Musing* includes a setting referred to as the “Permanent Exhibition,” which allows museums to create sampler exhibits to advertise new exhibitions. However, in addition to this option, *Musing’s “*AR” optio enables augmented reality and real-time/on-location user interaction with the artworks on exhibition within the galleries.

The Museum of Modern Art (MoMA) in New York has developed the *MoMA* application, containing a large amount of information about the museum, including a calendar, ability to purchase tickets, and the ability to browse the MoMA’s extensive collections, either by physically visiting the museum or browsing at home [24]. *MoMA*’s primary interface involves typing-in reference numbers (located next to artworks in the gallery) to allow visitors to listen to audio descriptions of artworks and view large photos. Much of the information is not locally stored on the device and is downloaded from an online database. Although there are reference numbers posted next to artworks in the physical gallery, the visitor is not required to visit the museum in order to consume the information. Additionally, content is not relayed contextually within the picture-plane which does not allow for direct connections to be made.

Reality Check, created by the McNay Museum of San Antonio, allows visitors to use their own device’s (smartphone, tablet, etc.) camera (or that of a loaner device) to scan artworks in the physical gallery to initiate image recognition [25]. The application is designed to be game-like, allowing the visitor to recognize an artwork by first selecting a “clue.” These clues are unique shapes of objects present in the artwork. Once the chosen shape is recognized in the artwork by the device’s camera, the visitor is presented with supplemental textual, audio, and video information. *Reality Check* stores all of the information locally on the hardware, thus, a new build of the application is required as information is edited or created.

While the aforementioned systems show promise, they suffer from a variety of potentially problematic issues. Of the systems that require proprietary hardware, museums must use financial resources to purchase and maintain loaner devices. Systems that rely on external devices, such as Bluetooth emitters, increase workload of museum staff who must install them within the space. Most importantly, the majority of these systems require reprogramming when content is created and edited.

IV. Application Development and Deployment

Musing was developed by an interdisciplinary team that included researchers within computer science, communication design, and museology. The client application, built on iOS, was initially deployed from October 8th, 2013 through November 14th, 2013, in The University Galleries at Texas State University, for the exhibition, *Eric Zimmerman: West of the Hudson* (Figure 2) (additional example images, scanable by *Musing*, are available in [26]). During the 38-day run of the exhibit, 242 visitors downloaded *Musing*. In addition, 11 visitors checked-out iPod Touch devices provided by the galleries, indicating a high number of visitors used their personal devices. Gallery guest book logs showed that a minimum of 962 visitors attended the exhibit, denoting that about 25% of visitors had chosen to use *Musing*. This indicates a relatively strong initial acceptance rate of the concept. However, these figures do not account for repeat visitors, visitors who did not sign-in at the front desk, or visitors who shared devices.

Figure 2. *Head of State* by Eric Zimmerman, 2013. Example artwork from exhibit, *West of the Hudson*

The first deployment of the Musing client indicated promising results. However, data for the exhibit was manually input into the database by developers. In order to fully test a system that could be deployed in a functioning museum, the Web-based administrator panel would need to be tested as well.

A second deployment was designed to test the entire system, including the museum professional's ability to add, edit, and delete exhibit content with the Web-based *Musing Administrator Panel* (MAP). In addition, new artworks were chosen, which created unique challenges for the image recognition algorithm and were used in order to test its robustness.

In order to test for a greater variety of artwork media, the second trial utilized two concurrent exhibitions, which ran in two separate rooms of the gallery from March 17 through April 11, 2014. The first was an exhibition of photographs by artist, Lauren E. Simonutti titled, *The Devil's Alphabet*. The second was an exhibition of paintings by artist Richard Martinez titled, *¡PAINTINGSFORNOW!*, This exhibit was chosen explicitly because of the artworks' strong silhouettes, large areas of solid color, and limited visible surface detail.

Before exhibition installation and during content development, the museologist was able to input data into the database via the MAP for both exhibitions. This allowed the user to add, edit, and delete information, which included the uploading of reference photos, adding and rearranging POIs, populating content for the added POIs, and adding artists' biographical information. Additionally, this trial allowed the development team to discover any programmatic issues and resolve them during the data entry process.

Testing in the gallery indicated that the imagery in *The Devil's Alphabet* was satisfactorily recognizable by *Musing* (Figure 3). As these artworks were photographic prints behind glass, there were some adjustments needed for lighting within the exhibition space in order to minimize environmental reflections, which circumstantially interfered with image recognition.

Figure 3. *The Devil's Alphabet: A* by Lauren E. Simonutti, 2007. Example artwork from exhibit, *The Devil's Alphabet*

Musing's recognition rate of artworks in *¡PAINTINGSFORNOW!* was not satisfactory. As the paintings in this exhibit displayed strong silhouettes, but very little surface variation in tone or texture, it is theorized that the flat color and limited amount of detail in the artworks were the cause of the recognition failure (Figure 4). As an alternative, this exhibit was offered as a "Permanent Exhibit" within the *Musing* library so that the visitor could still access and view the information without utilizing image recognition. This points to a need to improve the image recognition capabilities of *Musing* for artworks of this kind.

During the second trial, additional 58 users downloaded *Musing*. This number is influenced by the fact that the second trial took place during the same exhibition schedule as well as the same exhibition venue. Visitor attendance logs establish the fact that because the venue is within an academic setting, many of the visitors are the same for each exhibition. As a result, it is thought that the majority of users may have already downloaded *Musing* for the prior usage.

Figure 4. *BEALDARC* by Richard Martinez, 2012. From exhibit, *¡PAINTINGSFORNOW!*

A. Pedagogical Design

Making associations is essential to deepening understanding and the pedagogical shifts that are occurring within museology reflect the changing needs of the museum visitor. In addition, art museums may have difficulties in identifying effective ways to provide the proper context for the art they exhibit, something that may result in a lack of connection to their visitors. As such, the use of *Musing* can result in an enriched aesthetic and educational experience for the visitor and provide a large context for exhibited artwork to encourage and deepen personal connections to the exhibition objects and expand the visitors' knowledge and understanding of the artwork, itself. These connections can be made by broadening the context for the novice viewer while adding to the experience of the initiated viewer. Further results can be a bridging of gallery programming within the daily life of the visitor via their in-gallery experience and connections. The use of *Musing* within an exhibition setting can provide an interpretive framework, which allows access to supplemental didactic information about the exhibitions while offering opportunity for interactivity.

At the heart of the concept of the ideal 21st century museum/gallery experience is what educator and innovator John Dewey referred to over a century ago when he spoke of the importance of interactivity to provide for an enriched learning environment [4]. Such interactivity, and the resulting enrichment, requires providing for diverse learning styles by including visual/print, visual/picture, auditory, and verbal/kinesthetic modalities, as well as a variety of user types [12]. These enriched learning environments are comprised of seeing, hearing, and interaction by moving beyond the traditional linear model of communication that provides didactic information via textual labels and gallery talks, to a non-linear model of communication through the provision of individual POIs, associated with each scanned artwork. Through the visitor's ability to access the POIs, which reflect a variety of types of didactic content contained within *Musing*, the application provides for an enriched environment in which the visitors can participate in creating a large context for the works exhibited. The provision of additional information about each work via POIs positions the visitor as a collaborator in the process of making meaning and serves to engage the visitor with the provided information which solidifies the content knowledge [4]. Meaning is made by the viewer in a variety of ways, which can begin by looking at art through several different filters. The individual POI provides an opportunity to show the viewer the works within an art historical, biographical, conceptual, or technical framework. As museums and galleries continue to seek ways in which the visitor's experience can be augmented, these POIs are an effective way to provide access for visitors to contextual information for the exhibited works, broadening the exhibitions' theses for the novice viewer as well as augmenting the meaning for the initiated viewer. This extends the application's ability to meet the needs of a variety of visitors who learn in different ways and access works on a multitude of levels, as well as John Falk's five types of user experiences [12]. As such, the broadening of the exhibited works' context via interviews, videos, Web sites, source material, art historical influences, and other art with shared conceptual frameworks allows for a personalization for the visitor through the implied narratives. This is thought to be the most effective way to expand the context for the work and deepen viewers' connections through the exercise and action of gathering the information [2]. The resulting associations within the gallery setting, moving into the viewers' world, are essential to deepening the understanding of subject matter—a result of the user transferring what he or she already knows and reflecting upon it [4].

For the novice viewer, whose frame of reference may be lacking in depth to fully make these associations, the POI format is ideal to expand reference points. As these associations and connections deepen, the experience begins to look familiar, something that can also make looking at art more comfortable. As Marjorie Schwarzer writes, "Today, when the meaning of art is more contested than ever, [technologies] offer visitors the possibility of diverse interpretations" [27]. Schwarzer adds, "The branches of information available on these devices are close in spirit to the multiple ways in which we engage art" [27]. The ability to allow for different levels and a wide range of information, as well as a seemingly endless number of interpretive applications, reflects the diversity of the museum audience, itself [27].

Marjorie Schwarzer also notes, "As society is bombarded with rapidly changing multimedia messages, our ways of deciphering and understanding information have changed. We increasingly rely on a combination of sound, moving image, and text. Like it or not, new technologies outside of a museum's four walls alter the way that people process information inside the museum" [27]. *Musing's* effectiveness comes from the immediacy with which the user can access the POI content and making information available on demand allows for visitors to move freely within the space, not having to rely upon the preconceived schedule of their guide or any predetermined path.

Within the preferred postmodern approach to museology, the ability of the visitor to gain information and knowledge in an interactive capacity reflects several of the key tenets of the *New Museology*—value, meaning, and access—while allowing for greater meaning and relevance of the content in contemporary society [28]. An undesirable level of institutional authority can be implied or inferred through exhibitions that are authoritative in their approach to didactic display and interpretation, seen in limited interpretive labels and language wherein the curator's voice is solely represented. Without the constructed intellectual space needed to create meaning, the visitor may fail to foster an individual relationship with exhibition objects [28]. This, in turn, can determine whether the visitor's experience is enriched, aggregated, and circular in nature—comprised of many small connections formed between objects and the visitor's personal connections—or an isolated, linear-oriented experience—formed from objects considered in isolation via limited interactivity. As such, the visitor's relationship and connections to exhibition objects depends heavily on subjective and experiential aspects such as interactivity and consumption of information with which they make their own meaning [29]. We can see the ways in which visitors' relationships to objects are defined by how active/passive they are allowed to be; the more restrained the institutional authority associated with the experience is, the closer the relationship may be that the visitor can develop with the object [28][29].

The effects of this enriched experience build on each other. Providing a large narrative context for the exhibition objects allows the visitor to make greater connections with the individual works of art within an exhibition and make connections between the works contained within the exhibition and a large relationship between exhibitions offered through *Musing*. In this way, the artworks themselves become an interpretive tool, which allows for a familiar relationship on the part of the visitor and a greater connection to them. This focus on communication of content and provision of context for the object is what Stephen Weil refers to as "The Poetics and Politics of Representation" [28]. In so doing, the visitor looks *at* the featured works and sees, understands, and connects *through* them.

B. Client User Interface Design

Musing was designed to employ a client-server architecture that allows museum administrators to upload, remove, and alter content, post-deployment. This is accomplished through an administrative Web interface (MAP) which feeds the shared database. The application retrieves this content as requested by the user. This approach allows the material provided to the user to be as current as possible. Hence, the application is flexible and not limited to "on board" data, allowing any museum to closely serve the needs of its visitors. The application relies on an open source library called *OpenCV* for the processing and recognition of images which have been captured by the user.

The User Interface was designed in such a way as to adhere to the Apple Human Interface Guidelines for a tab-bar navigation style application: Consisting of the Exhibitions Screen, Scan Artwork Screen, Artwork View Screen, and Favorites Screen.

C. The Exhibitions Screen and the Artwork View Screen

The Exhibitions Screen, depicted in Figure 5a, consists of a list-view of exhibits that a visitor can visit, organized by "Permanent Exhibits" and "Augmented Reality Exhibits". Permanent Exhibits are previews of the experience that visitors can expect when using the application in-gallery. These exhibits contain artworks that can be viewed outside of the gallery setting (e.g., residence, dorm, etc.). This type of exhibit is included to advertise the application's features, to familiarize the user with the way that the application works, and encourage users to attend a live exhibition. The AR exhibition section includes exhibits that must be attended in person to view the didactic information for the artworks. This view provides information such as the name of the exhibit, in which museum the exhibit is located (provided more than one organization uses *Musing*), and a representative image to advertise the exhibition. Figure 5b shows a portion of the "Art View" screen: a captured and identified image along with the overlaid POIs.

POIs—tapable buttons that represent the types of content available to the user—are able to provide the user with a variety of didactic information. The individual POIs are as follows: 1) Factoids: Small pieces of text that can be attached to a feature in an artwork (Figure 6a); 2) Web site: Links provide information about the artist, or historically pertinent information (Figure 6b); 3) Video: Takes the user to an established internet video site such as YouTube and Vimeo or a locally hosted video within the application (Figure 7a).

These individual POIs can be tied directly to the aforementioned learning types (visual, auditory, and kinesthetic) written about by Pashleret et al. [11]. Through the diversity of information dissemination methods such as

Figure 5. (a-top) Exhibitions Screen, including exhibition selection, and primary navigation; (b-bottom) A captured and identified image along with the overlaid POIs.

video, web based content, and text, as well as image based content, the visual learner's needs are met, while the auditory learner is stimulated as well by video and audio files and the kinesthetic learner enjoys the interactivity with the technology, itself. Through the exploration of the elements that comprise the experience provided by Musing, each of the learning types can be stimulated in ways that allow for their access to the content.

Figure 6. (a-top) Factoid POI; (b-bottom) External Web site

D. The Favorites Screen

Many museum visitors wish to retain information in order to consume or refer to at a later date. *Musing* allows the visitor, to favorite any of the artworks they scanned while visiting the museum. These favorites are saved in the Favorites Screen in a list view for later retrieval (Figure 7b).

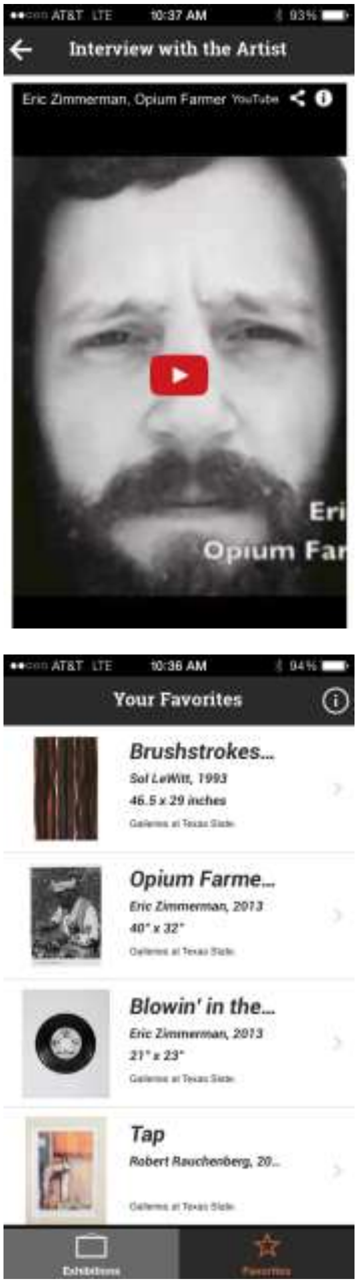

Figure 7. (a-top) YouTube video, created and uploaded by the musing professional; (b-bottom) Favourites Screen with list-view of saved artworks

E. Server User Interface Design

In order for *Musing* to be used in a wide variety of museums and galleries, the MAP Web site was created to provide museologists with the ability to easily create, retrieve, update and delete content in the system. As all consumable content for the client application is provided from a database, without MAP, the *Musing* system would require expensive upkeep by software developers.

MAP includes four pages for data entry: Exhibits, Artworks, Edit POIs, and Artists.

The Exhibits page allows the user to create/add exhibits, edit, and delete existing exhibits (Figure 8). From this page, the user is able to select existing exhibits for editing as well as create new ones.

Figure 8. Exhibits page, showing existing exhibits

When a new exhibition is created, MAP initiates the Edit Exhibition page (Figure 9). This interface allows the user to browse their local machine for an exhibition image (automatically resized by the system), choose a beginning and end date for the exhibit, enter the museum or gallery name, and set the exhibit type to Permanent or Augmented Reality. This information is displayed in the client on *Musing'*s Home Screen (Figure 5a).

Figure 9. Adding a new exhibit (detail)

After a new exhibit is created, the user is taken to the Artworks page. This page allows the user to add new artwork images to the exhibition, delete artworks, or edit artworks within the exhibition (Figure 10).

When adding a new artwork to an exhibition, the artwork editing page allows the user to upload and crop a reference photo of the artwork (used for image recognition by the client application) and enter information about the artwork. This information includes the artwork's title, dimensions, materials, year created, and artist (maintained separately by the Artist page). The entirety of this information is displayed in the *Musing* client after image recognition has taken place (Figures 5b and 6a).

From the selected artwork's page, the user is able to edit the POIs (Figure 11). The user has the ability to add new POIs, placing them by clicking and dragging. Additionally, the user is able to assign content to each POI, and assign a category: History, Technique, Information, Web, or Video. The POIs are assigned (x, y) coordinates and appear in the *Musing* client in the same locations on the artworks (Figures 5b and 6a).

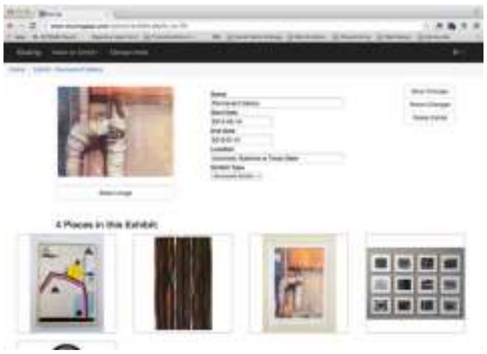

Figure 10. Managing artworks within an exhibit

Artist information is kept separate from the exhibits and the individual artworks to avoid duplication of data entry. The Artist section of MAP allows the user to add new artists or edit existing ones (Figure 12).

Figure 11. Editing POIs on the artwork (detail)

The Edit artist page allows the user to upload and crop a photo of the artist, input names, birth/death dates, and links to artist biographies, as well as bibliographic references. This biographic information is displayed in the *Musing* client at the bottom of the View Artworks Screen (Figure 5b).

Figure 12. Editing Artist information (detail)

After selecting an exhibit, the authenticated user is presented with a thumbnail for all of the artworks currently associated with that exhibit. In addition, the user is given the option of adding a new artwork to the exhibit. When a new work is added, the user selects an image of the art from local storage on their machine. The image is expected to be cropped such that only the artwork itself and its frame are shown. This greatly improves the recognition performance of *Musing* and creates a better experience for users of the application.

When an image has been selected for a new artwork, the user is directed to a page where information regarding the particular artwork can be entered or edited. This same screen is reached when an existing work of art is selected from the exhibit listing. The user is able to enter the artwork's title, size, year of creation, medium, and the artist's name. Artists are stored and catalogued in the database and information such as year of birth, year of death if applicable, and a link to a biography, can be entered and stored as a unique entry to the artwork in the database to avoid duplication of entries.

Next, the administrative support utility enables the administrator to define and edit POIs for an artwork. This is done using a graphical interface designed with JQuery. The user selects a position on a displayed image of the artwork, chooses the media type that the POIs references—along with its associated icon—and the text or URL as appropriate. In addition, users can alter the position of existing POIs by dragging and dropping them. The user can add and modify exhibits, as well as artists in a manner similar to that described for artworks.

F. Hardware/Software Architecture

The *Musing* server, or MAP, UI is constructed with HTML and CSS, reading from and writing to a MySQL database hosted on a Linux Web server. Currently, the *Musing* client runs on iOS based hardware, such as iPhone, iPod Touch, and iPad. An Android version is under design.

1) Back-end Processing

The back-end (server) application provides two main functionalities. First, it supplies information in the form of reference images and relevant didactics to the user, enabling its operation inside the gallery or with a permanent exhibition. Second, the back-end is designed to provide an administrator (e.g., a museum staff member) with the capability to edit the contents of an exhibition within the system. The server, which is shared by the application and the administrative support back-end utility, is used by the gallery administrators to load content into *Musing*.

The back-end, administered by MAP, is written in PHP and uses standard web-technologies (including HTML, CSS, JavaScript, AJAX, jQuery, and several Open-Source JavaScript libraries) to deliver a user-centric experience. It is designed to allow users unfamiliar with database systems to create, read, update, and delete entries for exhibits from a database stored within the web application's framework. The entries include artworks contained within a chosen exhibit, the associated artists, and curated POIs.

The primary vehicle for data entry into MAP is via Web forms depicted in Figures 8-12. These forms, when submitted, write data into the appropriate fields in the database. The database for the entire system is comprised of eight tables. One table is responsible for user authentication, along with another which records failed login attempts. Two tables are responsible for tracking permissions of the exhibits and the artists. These tables separate exhibits and artists by user, so that administrators may only view their own information. The remainder of the tables are responsible for holding artworks, exhibits (Figures 9-10), POI placement/content (Figure 11) and data for artists (Figure 12).

When a new image is uploaded via a Web form, either for an artist headshot or an artwork reference image, the image is saved into a folder on the server and a pointer is saved to the appropriate database table for later retrieval.

JQuery and JavaScript are used to facilitate the placement of POIs (Figure 11), by allowing the museologist to drag and drop POIs wherever they wish in the picture plane. The (x, y) coordinates of the POIs are saved to the database in the POI table, along with the Artwork's ID, icon type, media type (e.g., text, video, audio) and URL for that content.

Musing was developed with the intention of packaging within the application as little data as possible. When the user activates *Musing*, it requests an XML document containing a list of available exhibits from the back-end data server. The application parses the XML document and extracts the information into an Exhibit object within the application. Along with the XML document, which contains the names of the exhibits, locations, and id values which the application can use to retrieve data about specific exhibits, the application retrieves a "banner image" for each exhibit, which is displayed in a list for the user to browse.

When the user selects an exhibit from the list on *Musing*'s Home screen (Figure 5a), the application passes its id value to a PHP script hosted on the data server. This process is referred to as 'synching'. During synching, the server compiles the pertinent information and returns information in the form of XML file and a set of JPEG images of the gallery artworks to the app. The XML document contains information about each artwork, along with the set of POIs related to the information. The user can tap on POIs to display additional information about the artwork or artist. The images retrieved along with this document are used both for displaying POIs on the Artwork View screen and as references by the image recognition.

As in the case of the exhibit list, the XML document provided by the data server when the application is synched to a particular exhibit is parsed. The extracted information is used to populate painting and POIs within the application for each painting and POIs listed in the database. The images are also incorporated into these objects. Testing has shown that this process of synchronization typically takes approximately 20 seconds, during which time the user is shown a modal progress graphic.

2) Front-end Processing

Musing supports two types of exhibits— permanent and AR. The synching process is the same for both. If the database indicates that an exhibit is permanent, the user is shown a list of artworks available in an exhibit and each may be selected by tapping. This displays the artwork's image with the proper set of overlaid POIs. The second type of exhibit is the AR variety. In this case, the user is given an image detection view rather than a list, which displays a real-time feed from the devices camera over which is laid a graphic of an empty painting frame, along with a button which the user can use to capture a photograph.

During image detection, the users are instructed to position themselves so that a *Musing* enabled artwork fully fills the frame displayed (this is not mandatory, yet it can improve the recognition rate) on the device's screen and to take a picture of the artwork. When this is done and an image is captured, the application compares the captured image to each reference image currently synchronized for the exhibit. If a match can be made, the application proceeds to the Artwork View screen, exactly as it does when the user selects an image in a permanent exhibit. Otherwise, an error message is displayed in a modal dialog. To save in storage space, the captured image is discarded after being matched or rejected.

From the Artwork View screen, the user has the option of capturing the artwork and its information by making the artwork one of their "Favorites." This is the only condition under which *Musing* locally stores the artwork and its information. This is done by passing the image, POIs data, and artist information to a Favorites Database object that incorporates those values into an array of artwork objects. The data is then written into *Musing's* internal database. The information stored in the favorites array is accessible by the user regardless of whether or not the device is connected to the internet.

3) Image Processing and Recognition

Musing relies on the Oriented FAST and Rotated BRIEF (ORB) image detection algorithm [30]. The ORB procedure combines the "FAST" key-point detection and "BRIEF" determination of descriptors. Key-points are clusters of pixels within an image which are unusual enough to stand out and to help distinguish a particular image from other images. After identifying a set of key-points within an image, a set of descriptors is calculated for each key-point using BRIEF [30]. This functionality is provided by the *OpenCV* open source computer vision library which is available for use in iOS and Android devices.

Key-point detectors frequently rely on finding "corners" and "edges" within images since image boundaries often create distinguishable pairings of shade and color [30]. ORB is translation invariant. Additional operations are performed to compensate for rotation and scaling [30].

In the training stage, BRIEF employs binary comparisons between pixels in a smoothed image [30]. This algorithm takes a relatively large set of key-points—often as many as 500—and builds a classification tree for the set. The tree serves as an image "signature" used to measure similarities between images. Alternatively, under the approach used in this research, one can employ the results of the BRIEF stage using the *k* nearest neighbors (kNN) and one-to-one and onto mapping (bijection) test approach.

Following the synching process, users can point their device camera at an artwork in the gallery and capture its image. This image is processed using ORB and then compared to each of the reference images which were downloaded at sync time. Each reference image is processed to determine its key-points / descriptors at the time of comparison and this information is recalculated for each comparison. *Musing* employs the kNN and bijection approach to the key-points. Each key-point in a captured image is compared to each other in the reference image. A small set of matching key-points in the reference image is found for each key-point in the captured image. The goal is to find a maximal, high reliability, bijection between a subset of the key-points in a reference image and a subset of the key-points in the captured image. Hence, if any key-point in the reference image matches more than one key-point in the captured image with equal reliability, then *Musing* dismisses that match. The literature has suggested 0.65 as a reliability threshold and as the best threshold ratio for selecting one match as superior to the other [31]. Musing image recognition procedure uses this (0.65) threshold. The kNN is done twice, creating a set of directional matches that compares the reference image to the photograph taken and vice-versa. Then both sets are compared, dismissing any match that is not bidirectional. If a significant number of bidirectional matches is identified, the images are considered a match. *Musing* currently uses a threshold of 4 bidirectional matches as the minimum subset size.

When *Musing* has determined that a captured image matches a reference image, the reference image is displayed on screen along with an overlay of POIs.

The following is a description of the applied image recognition algorithm, starting with the captured image and the first reference image.

Step One: Captured Image Key-point Calculation - Find the key-points for the captured image using the FAST method [30]. This method checks a ring around each pixel and compares their intensities. It returns the point as a key-point if the gray level of a number of pixels within the ring is sufficiently higher or lower than the nucleus pixel itself.

Step Two: Captured Image Descriptor Calculation - BRIEF is used to take a patch of pixels surrounding a key-point and uses binary intensity thresholds to create a 256-bit binary vector describing the area around the key-point [30].

Steps Three & Four: Reference Key-points and Descriptors - Steps one and two are repeated for the reference image.

Step Five-A: Descriptor Matching (Captured to Reference) - A kNN matching of the Hamming Distances of each descriptor in the captured image to its K nearest neighbors in the reference image is performed. The two best matches for each key-point are retained.

Step Five-B: Descriptor Matching (Reference to Captured) - Step Five-A is applied with the roles of the captured and reference image reversed.

Step Six-A: Ratio-Test (Captured to Reference) - This step discards every match identified for the captured image where the best match and second-best match have similar Hamming distances. This produces a one-to-one match.

Step Six-B: Ratio-Test (Reference to Captured) - Weeding, using the same criteria as in step Six-A is performed on any match from the set of matches identified in the reference image.

Step Seven: Symmetry Cross-Check Test - The Symmetry cross-check test returns only the pairs of matches that are found from the captured image to the reference image and from reference image to the captured image. This process enables keeping only the strongest symmetric correspondences and maintaining a bijection.

Figure 13 illustrates the process performed in steps 5 to 7.

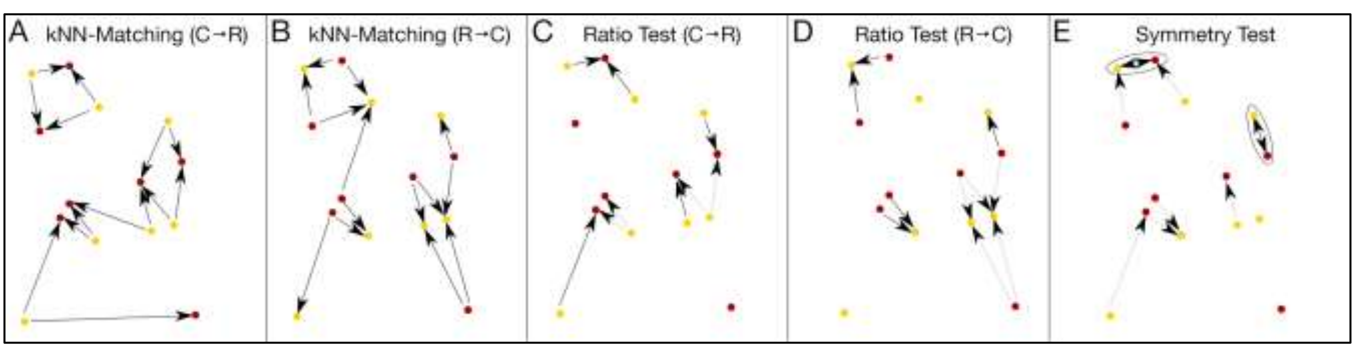

Figure 13. (A) and (B) kNN matching ($k = 2$); (C) and (D) Descriptor matching - the process discards matches with similar quality (Hamming distance) and retains the best match for distinctive matches; (E) Symmetry cross checking – only bidirectional matches are retained.

Step Eight: Output if Found - If four or more matches remain after the weeding performed by the ratio tests and symmetry test, the procedure retains the identity of the reference image and returns to step three for the next reference image (if such an image is available). The procedure keeps track of the identity of the image that produced the largest number of matches and outputs its id. If all reference images have been tested and no match has been found, then a message "Image Not Found" along with instructions to the user on ways for improving the possibility of match are displayed.

G. *Design of Testing Instruments*

Although this project seeks to augment the viewers' experience, while traditional didactics and tours remain in place, it is not simply an "add-on" to the material that the galleries already provide. It is a model for directional movement in museum practices, so to assure its success, proper analysis must be done. Utilizing Scott Sayre's model of evaluation—Pre-production Surveys, Formative Testing, Summative Evaluation, Audience Focus Groups, and Computer-collected data – we can get a thorough evaluation before, during, and after production that provides a myriad of benefits relative to the assurance of effectiveness [2].

Testing instruments consisted of quantitative benchmark testing and a qualitative user perception exit questionnaire. As a part of the quantitative testing, each reference and captured image has been processed to generate 500 identifying key-points in each of 60 total images. The 60 images consist of: ten reference images ($R_1 - R_{10}$) and ten images that served as captured images($P_1 - P_{10}$). Each of the captured images was captured four additional times for a total of five capturing per image. The first one used maximum alignment to the reference images the rest of the four were taken with increasing rotation translation and scaling (due to different distance). The maximal rotation was 40 degrees.

The procedure described above was applied to the ten reference images and fifty captured images. A threshold of 0.3% over the percent of matching key-points, which was empirically identified as the most suitable threshold was used by the program and applied to the matching results.

For the qualitative testing we have used a 23-question exit questionnaire designed to capture feedback from in-gallery users. The questions were written to determine the user's acceptance of the application, their perceptions of application performance, enjoyment of the application, as well as pedagogical concerns.

V. Deployment Results

A. *Technical Results (Internal Testing)*

Figure 14 shows a heat-map of the results of this experiment in the form of a confusion matrix. The figure shows a recognition rate of 96.4% with 0% error of type-1 (false positive) and 3.3% error of type-2 (false negative) obtained with $P_{(1,4)}$ and $P_{(1,5)}$. We have found however, that with rotation of more than 45 degrees there were numerous false negatives; but, still 0% of false positive error.

The testing has shown that *Musing* recognizes images with near perfect reliability under ideal conditions, that is, when a user is directly in front of the artwork, has positioned the artwork correctly within the image capture frame, and is not holding the device at an angle. Nevertheless, excessive rotation of the camera while capturing an image diminishes reliability. Our testing indicates that *Musing* recognizes images at a 45 degree rotation with 90% reliability and a 90 degree rotation with 84% reliability. The application performance degrades when the user stands off of the center line when photographing a piece of art, producing a skewed image. A slight deviation from the center (approximately 15 degrees) produced no noticeable change in testing but at greater values (approximately 45 degrees) the system produces 40% true positives and 60% false negatives. As far as can be determined, in the field-deployment testing, the system did not generate false positive results. Furthermore, the user surveys have not indicated that the application has produced a false positive error in use. Additionally, if the user stands too far from the artwork to properly fill the capture frame the reliability has suffered as well, with the reliability rate dropping to 48% at approximately twice the recommended distance.

Testing indicated that the image recognition algorithm failed when artworks were behind glass, causing heavy reflections, as well as those artworks with little tonal variation or surface detail. Artworks behind glass can often create reflections of the user as they are standing in front of the artwork. These reflections interfere with the image recognition by creating an image that falls outside the tolerance range of the algorithm. Artworks that exhibited little tonal variation (i.e., large patches of solid color) or little surface detail also created challenges for the image recognition algorithm, as there were not enough unique identifier points for the algorithm to affect recognition.

Testing performed to evaluate the processing time revealed that with 10 reference images, the application was able to compare and either display or reject an image in approximately 3.3 seconds on a stock iPod Touch-5. Again, user surveys indicate that this was sufficient to produce a positive experience for most users.

Finally, User surveys conducted during the trials indicate that the application's reliability was sufficient to produce a positive experience for most users.

B. *Exit Questionnaire Results with Live Users*

Of the pertinent questions, 83.6% responded that *Musing* was able to recognize the artwork "every time" or "most of the time." 77.5% considered *Musing* to be quick and responsive. 87.7% considered *Musing* enjoyable to use and 93.8% wishing to see *Musing* in a future exhibit.

VI. Results Evaluation

The deployment results show high recognition accuracy and relatively short synching/recognition delay time, therefore the functionality of the entire system has been verified. The application has passed the Apple approval process and is available for download [5].

Formal user feedback obtained via questionnaire was consistent with our evaluation of the system and with informal feedback. The visitors that have responded to the survey have found the application as informative and usable. Their perception of precision and timing was favorable and overall they have commended the system and expressed interest in its further use. Informal feedback from users, including several staff members of other galleries, was overwhelmingly positive.

VII. Conclusions and Future Research

We have designed, implemented, and deployed a usable mobile application that facilitates an enriched museum visitor experience via AR using interactive didactics. Per our assessment, the application has achieved its stated goals and has shown that the research hypothesis is valid.

Although tried and true wall labels, pamphlets, and gallery talks are sufficient for conveying information and serve to extend interpretive opportunities [32], they carry with them constraints that do not adapt in the ways that mobile media can. Mobile media technology provides the ability to allow for different levels and a wide range of information, as well as a seemingly endless number of interpretive applications and these interpretive strategies can reflect the diversity of the museum audience, itself [27]. These diverse and changing multimedia messages are reflected in the ways that *Musing* can be used.

Ultimately, the knowledge and deepened understanding that *Musing* can facilitate is filtered through the learning and innovation skills of the 21st Century – that of creativity and innovation, communication and collaboration, and cross-disciplinary thinking [32].

The field testing via the exhibition shows that *Musing* can be used on non-proprietary smartphone hardware and provide visitors with didactic information, without the need for external tokens and reprogramming for information changes. This enables reduced reliance on loaner hardware. In addition, the implementation of MAP allowed for the museologist to curate an exhibition within a simple to use Web application, without the need for software development abilities. This ability allows musing to be deployed in external museums and galleries as a complete, turn-key solution.

A. Future Research

Future enhancements to the *Musing* smartphone application (client) will include abilities for users to share images and didactics via social media such as *Facebook* and Twitter, as well as the ability to comment on artworks within the application so users can "join in the conversation." Additionally, there are plans to complete a port of the current iOS-based implementation to the Android environment.

It was determined that number of user downloads did not provide sufficient information about the way that users were interacting with the client. The addition of data analytics within the client, including collecting the number of times a user accessed the client, the number of times that an artworks scanned, the number of POIs accessed, and additional information could provide insight into the relative success of the client.

Future research with regard to MAP includes a redesigned GUI and improved user experience, as well as user testing with multiple users in order to provide the research team with a plan for feature enhancements.

Other plans for future activities include expanding the image processing capabilities by further improving recognition accuracy, resilience, and time performance. We plan to investigate the integration of algorithms for recognition of 3-D objects using the smartphone/tablet camera.

Lastly, in the Fall of 2014 and Spring of 2015 the research team has tested the *Musing* system (client and server) in external galleries, not directly attached to this project. The Bluestar Gallery in San Antonio, Texas and the Wittliff Collection Gallery in the Texas State University has tested an exhibit with *Musing*. Both galleries provided important positive feedback concerning the experience of visitors that used the app and the ease of use for gallery stuff. Additionally, the feedback provided helped improving some of *Musing* features. We plan to continue testing *Musing* in external galleries. It is hoped that more information can be gleaned from implementing Musing from these exhibits and in a large variety of gallery spaces.

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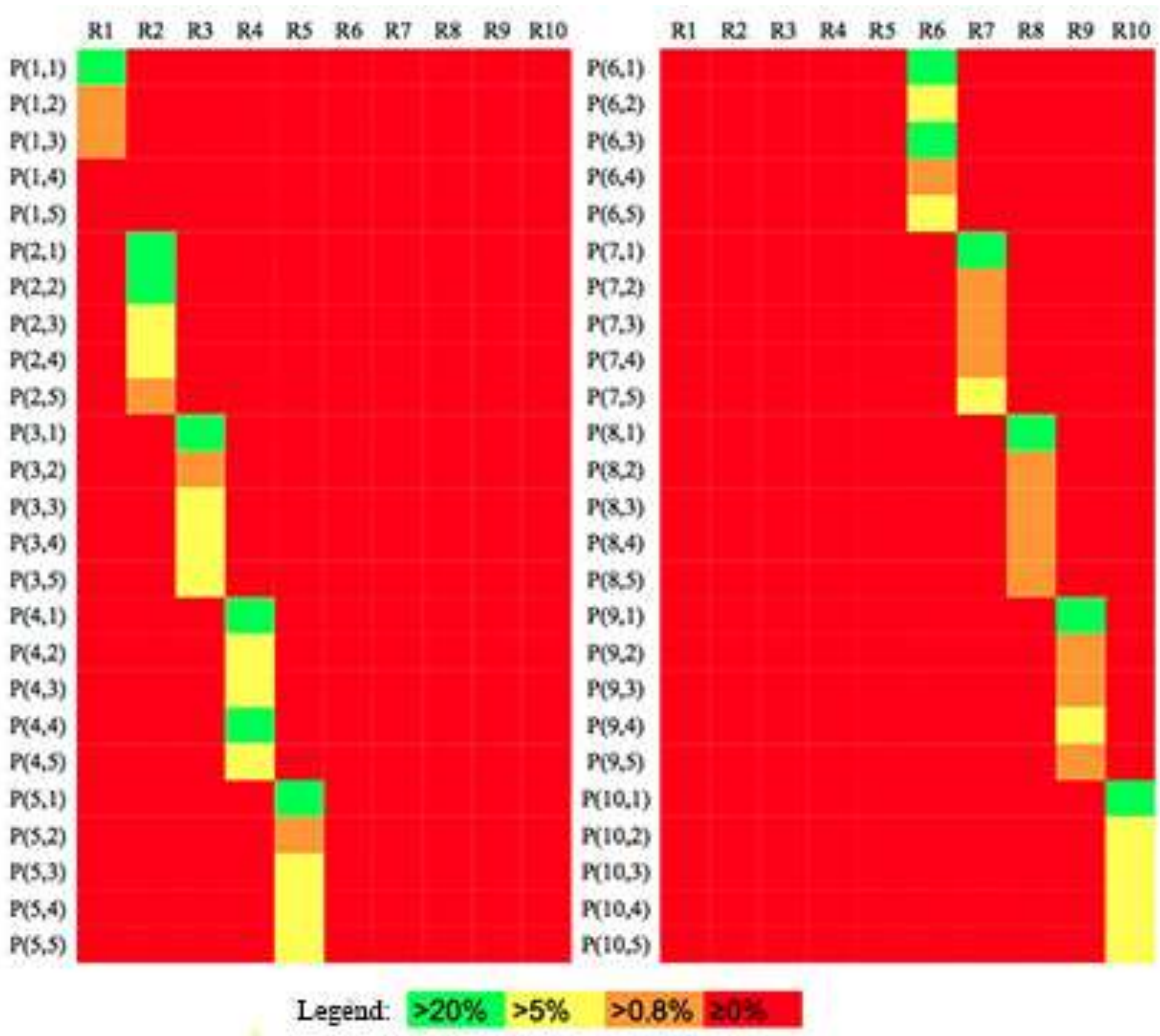

Figure 14. A heat-map of the results of the image matching experiment.

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