

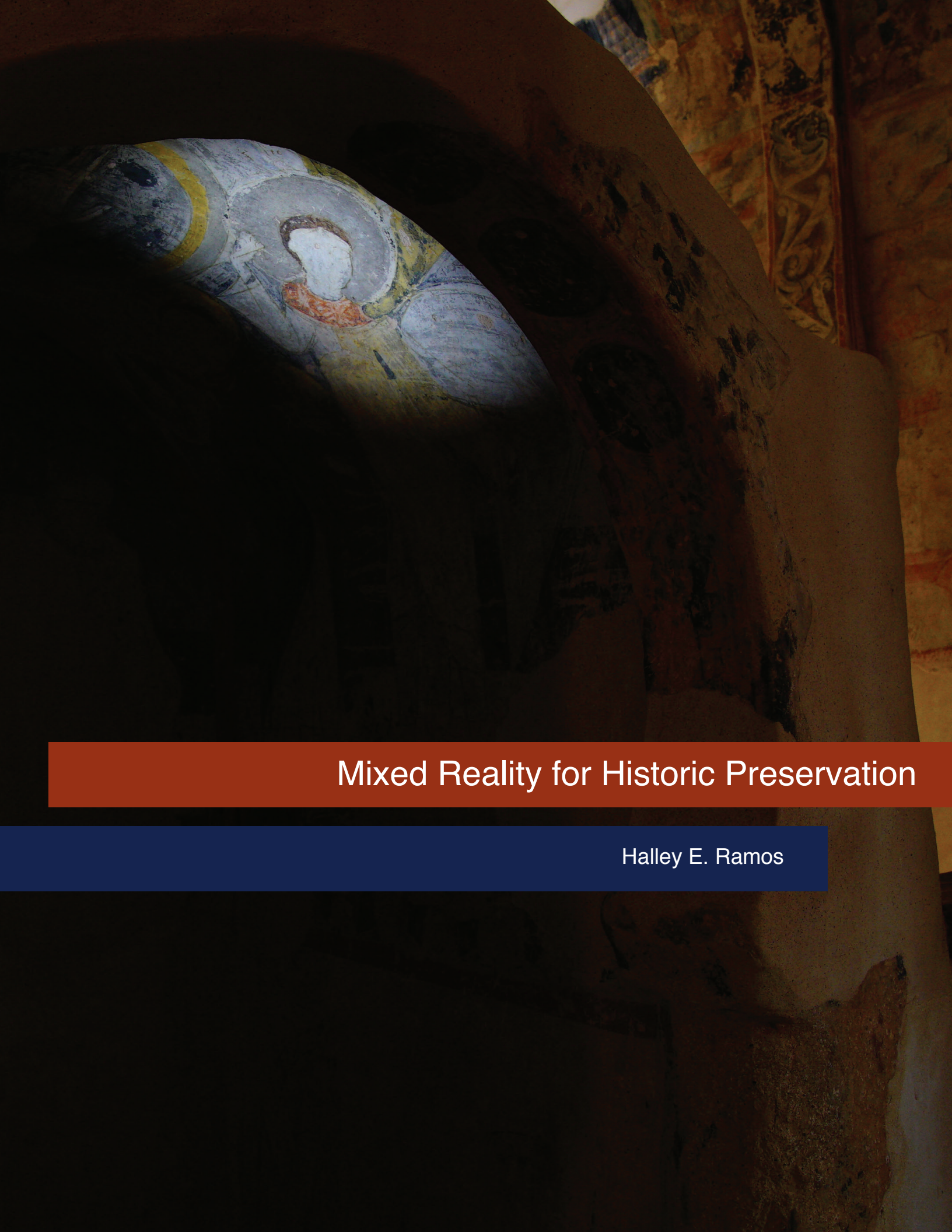
MIXED REALITY FOR HISTORIC PRESERVATION

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Graduate School of Architecture, Planning, and Preservation

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“MAN IS EVALUATED ON HIS ABILITY TO MAKE, AUGMENT AND IMPROVE SOCIALLY USEFUL THINGS.”

- Herbert Marcuse (*Eros and Civilization*)

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*Cover Image: Ray of Natural Light Augments the Wall Paintings at the
San Baudelio de Berlanga Hermitage, Spain (Author)*

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Abbreviations.

MR	Mixed Reality
AR	Augmented Reality
ASR	Augmented Spatial Reality
VR	Virtual Reality
UI	User Interface
GR	Graphics Render
MNAC	Museu Nacional d'Art de Catalunya

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1.1 Abstract

Digital technologies are becoming widely available to experts in the field of historic preservation. These tools equip experts with the capability to obtain high resolution and accurate information about cultural heritage, which can be accurately reproduced and rematerialized without coming into contact with the physical object itself. This preservation approach is described as *non-contact*, meaning that it is not invasive to the material integrity of an artifact. Since the turn of the century, stakeholders in the field have increasingly focused their attention on digital technologies for advancing the field. The motivation for experts to preserve cultural heritage with digital technologies starts with the idea of merging the two, and in recent years, innovations in high-resolution digital imaging, recording, processing, modeling, and reproduction capabilities have fostered the integration of a virtual environment. Mixed Reality (MR), which the merging of digital and physical worlds, not only allows experts to expand possibilities for preservation interventions once all physical range of actions have been exhausted, but it also makes it possible for experts to intervene digitally before carrying out a preservation treatment. MR can be used as a tool to create hybrid environments for experts and researchers to better manage and understand cultural heritage, which in turn allows them to provide the public with a deeper understanding about cultural heritage. The traditionally object-centric nature of the historic preservation field favors MR over Virtual Reality since the former engages with the physical site or artifact themselves. By allowing field experts and visitors to visualize scenes in situ from viewpoints that are impossible due to size, content or accessibility issues, the installation of MR's formless aesthetics engages viewers of cultural heritage through new and innovative ways.

Chapter 1: Introduction.

1.2 Rationale

The application of MR offers countless strategies for approaching conservation and interpretation projects in historic preservation. But, despite its capacity to enhance the practice of historic preservation, MR poses new technological and methodological questions for the field. As a burgeoning tool and constantly changing field, there have been very few studies conducted on the application of MR to the field of historic preservation. This thesis argues that, on the one hand, MR provides innovative strategies for approaching preservation problems; but on the other hand, the absence of standards, guidelines, and techniques make it difficult to evaluate and propose new projects in the field. As a response to this deficiency, I propose a framework to evaluate and use MR for the preservation of cultural heritage. This framework is first tested to evaluate three case studies, and next, to propose a unique MR strategy for the complex preservation case of the San Baudelio de Berlanga Hermitage in the province of Soria, Spain. This thesis aims to contribute an MR framework and methodology that provides a consistent conceptual approach to MR projects in the field.

1.3 Research Goals

1. Determine the existing state of knowledge about MR in the field of historic preservation
2. Determine criteria to evaluate existing precedents
3. Provide standards and guidelines for the use of MR in the field
4. Position MR as an innovative historic preservation strategy

1.4 Research Questions

In order to achieve these goals, the following research questions directed the thesis investigation:

HOW IS MR DEFINED AND CHARACTERIZED?

Several classifications for MR Reality exist, yet the development of MR has been convoluted due to the rapid development of different, competing technologies that are often complex and intertwined. The aim of this research question is to identify its different applications and characterize its aspects in concise terms. By doing so, this thesis provides a clear description of the different technical and contextual components that facilitate the experience of MR.

ARE THERE EXISTING MR APPLICATIONS FOR HISTORIC PRESERVATION?

The different applications of MR in the field of historic preservation need to be analyzed in order to properly assess the techniques available to evaluate and propose projects.

WHAT GUIDELINES ARE NEEDED FOR MR APPLICATIONS IN THE FIELD?

The use of MR in the field of historic preservation presents a set of new and complex challenges that have not yet been addressed in research. With the absence of guidelines for the field, this thesis investigates the relationship of MR and cultural heritage in order to propose techniques for preservation.

WHAT ARE THE BEST METHODS TO RESEARCH AND PRESENT FINDINGS ON MR FOR HISTORIC PRESERVATION?

The research findings that determine the relationship between MR and historic preservation should be presented through a framework, which serves as a tool for evaluating precedents and applying guidelines to new projects. A framework serves as an organizational structure to evaluate the relationship between MR and the historic preservation field.

Chapter 1: Introduction.

1.5 Thesis Structure

This thesis is divided into seven chapters, and begins with an outline of the investigation methodology, followed by an assessment on the use of digital technologies for preservation and their role in the development of MR. Next, I define and characterize MR in order to derive aspects that are used as criteria for evaluating MR projects. Chapter 3 provides a literature review of existing MR applications in the field, where I characterize its use for conservation and interpretation projects. The literature review concludes with an analysis of historic preservation frameworks in order to identify dimensions of cultural heritage that can be used as criteria to assess three MR case studies in the field. The findings from these chapters are organized into a framework that offers guidelines for consistent conceptual MR approaches for cultural heritage. Using this approach, I conclude by proposing a MR strategy for the preservation of the San Baudelio de Berlanga Hermitage in Chapter 6. Finally, in Chapter 7 I conclude with a discussion about the possibilities of MR in the field and the need for further research and development in Chapter 7.

1.6 Methodology

This thesis was developed through the use of two interrelated approaches: first, the investigation of primary and secondary resources; and second, on-site research. Primary resources include photos, digital documentation, paintings and videos, while secondary sources such as scholarly journals, books and articles were consulted. On-site research was conducted both to analyze and evaluate case studies and also to propose a MR strategy for the San Baudelio de Berlanga Hermitage. In addition to visiting the site itself, I conducted research at two museums where its paintings are displayed today. These two research approaches were applied to the following five investigation phases:

PHASE I: COLLOQUIUM PROJECT

This project was completed as an independent investigation that was facilitated through a small working group during the research phase of the thesis. The working group of graduate historic preservation students was determined by overlapping topics that complemented one another, with the final goal of identifying areas of greatest potential cross-fertilization, and was focused on *New Methods of*

Engagement and Interpretation for Historic Preservation. The topics in the group ranged from digital technologies, international tourism, documentary film making, social media and representation, and data ownership. To formalize this effort, the working group gave a joint presentation to other students, followed by a discussion that identified interrelated themes. The purpose of this project was to use the group setting as a laboratory for collaboration to expand the knowledge surrounding digital technologies and MR in the field of historic preservation. While grappling with the fundamental questions underlying digital tools and MR in the field, the project revealed distinguishing features amongst different hypotheses, methods of inquiry and evaluative criteria. The deliverable for the Colloquium Project had a two-fold approach: first, this investigation sought to determine the possibilities and limitations of digital technologies in the historic preservation field; and second, this investigation provided a point of departure into defining, characterizing, and deriving aspects of MR.

PHASE II: LITERATURE REVIEW

Through a comprehensive literature review I sought to investigate existing MR applications in the field, and identify any existing standards, guidelines and techniques. In order answer the research questions posed in this thesis, I conducted an extensive review of published literature on the use of MR for historic preservation using the following research questions:

1. What are the existing applications of MR in the field of historic preservation?
2. What are the current challenges of MR for historic preservation?
3. What frameworks currently exist for MR in the historic preservation field?
4. What existing historic preservation frameworks can be used to evaluate and propose MR projects?

Next, I conducted research across relevant bodies of literature, including primary and secondary resources, such as published books, articles, journals, and institutional materials. This review provided an assessment on the existing state of knowledge about MR in published literature, as well as gaps in knowledge. I conducted an analysis on existing historic preservation standards and guidelines concerning authenticity and use in order to determine standards and guidelines that should be considered for MR applications in the field. This investigation examined existing preservation charters and frameworks at the federal and international levels, which allowed me to identify six dimensions of cultural heritage that were used as criteria to evaluate the three case studies in the next phase.

PHASE III: CASE STUDIES

During this investigation phase, I selected case studies that were both interrelated and interdependent; meaning that all of the precedents focused on the close study of architectural wall paintings and finishes, yet, different types of MR applications with separate preservation approaches extended this analysis. The case studies were investigated through a combination of primary and secondary sources, as well as on-site research. The first case study at the Le Domus di Romane Palazzo Valentini museum in Rome was analyzed through published museum documents and on-site research. I investigated the Salone dei Cinquecento case study through the use of secondary sources, including academic articles and research papers, in addition to attending a lecture by the project developers. Finally, I analyzed the Sant Climent de Taüll case study through published articles and journals, as well a video presentation of the active MR installation.

PHASE IV: FRAMEWORK

In order to address the deficiency of standards and guidelines available for MR in historic preservation, as well as illustrate that common aspects and dimensions can be used as criteria to evaluate these

projects in the field, I provide an organizational structure to carefully consider the relationship between MR and cultural heritage, which is applied in the form of a “grid.” This approach was derived from the *Nara Grid for Authenticity and Use*, and adapted to consider MR aspects in a “test of authenticity.”

PHASE V: PROPOSAL

The proposal for this thesis was developed in response to findings from the previous phases. The research methodology in this phase required a two fold approach; first, the investigation of primary and secondary resources, and next, on-site research. The investigation was supplemented by previously recorded data by Factum Foundation in 2016. The on-site research included visits to the San Baudelio de Berlanga Hermitage, as well as visits to two museums where its paintings are exhibited, including the Metropolitan Museum of Art (MET) Cloisters and the Museo Prado. Additionally, discussions with MR specialists at Factum Foundation provided insight support to determine the technical feasibility of the proposal.

2.1 Digital Technologies for Historic Preservation

Traditionally, the United States National Park Service defines historic preservation as the act or process of applying measures necessary to sustain the existing form, integrity, and materials of a historic property.¹ For this thesis, the scope of historic preservation extends beyond historic properties to encompass cultural heritage. The main targets of cultural heritage in this thesis are clearly defined by the United Nations Educational Scientific and Cultural Organization in the Convention Concerning the Protection of the World Cultural and Natural Heritage in 1972,² which includes the following three scopes:

1. *Cultural relics*: from the historical, artistic or scientific aspect, including buildings, steel, and murals of outstanding universal values, as well as inscriptions, and whole union structures of archaeological significance.
2. *Architectural complexes*: from the historical, artistic, or scientific aspect, individual or joint architectural complexes with outstanding universal values in style, distribution, or surroundings.
3. *Ruins*: from the historical, aesthetic, ethnological, or anthropological aspect, these outstanding including human constructions, human-nature combined works, and archaeological sites.

Since the twentieth century, digital technologies have become increasingly accessible and widely used in the preservation field. These tools equip experts with the capability to capture, process and reproduce digital data of cultural heritage. This digital information can be used for interpretation, conservation and documentation purposes.³ In UNESCO's 1999 World Heritage Magazine, Stone defined digital cultural heritage as: "the utilization of technology for interpretation, conservation and preservation of Natural, Cultural and World Heritage."⁴ In 2003, UNESCO determined that digital technologies for the preservation of cultural heritage include "cultural, educational, scientific and administrative resources, as well as technical resources including different kinds of products such as texts, databases, images,

1 National Park Service. Archaeology and Historic Preservation: Secretary of the Interior's Standards and Guidelines [As Amended and Annotated] revised 1995. Accessed at https://www.nps.gov/history/local-law/arch_stnds_8_2.htm

2 United Nations Educational, Scientific and Cultural Organization World Heritage Center. Basic Texts of the 1972 World Heritage Convention. Paris: 2005.

3 Stone, R. J. (1999, November). Virtual heritage. UNESCO World Heritage Magazine, 18-20. Stone uses the term "Virtual Heritage" interchangeably to describe digital cultural heritage.

4 Ibid.

audio, graphics, software and web pages.”⁵ For this thesis, the scope of digital technologies for the field of historic preservation includes:

1. High-fidelity, integrated storage systems
2. Digital archives and databases
3. 2D and 3D recording systems
4. Modeling, simulation, and rendering systems
5. Fabrication and reproduction systems
6. Diagnostic visualization systems

Cultural heritage stakeholders recognize that digital technologies provide new approaches and methodologies for preserving cultural heritage. In 2011, the “Quebec Declaration” passed at the 17th ICOMOS General Assembly acknowledged that modern digital technologies can be used efficiently and effectively at a low cost to develop multimedia inventories that integrate tangible and intangible elements of heritage, and their widespread use is strongly recommended in order to better preserve, disseminate and promote heritage places and their spirit.⁶ As such, historic preservationists must better consider innovative approaches offered by digital technologies. Frank Matero argues that all preservation projects, especially those that require documentation and information management must include discussions about digital technologies because as long as preservationists continue to treat these approaches as outside the conservation process or as an afterthought, they will fail to inform, manage, and educate effectively.⁷

While digital technologies provide preservationists with new strategies for intervention, experts in the field recognize that a gap currently exists amongst those that develop the technology and those that use it.⁸ The RecorDIM Initiative founded in 2007 by ICOMOS, CIPA Heritage Documentation, and the Getty Conservation Institute (GCI) also acknowledge the disconnect between those who provide recording, documentation, and information management tools and professionals in the preservation field and those who use the tools for analysis.⁹ The gap between computer science and historic preservationists must be narrowed in order to create customized methodologies for field experts. New participative applications provide the opportunity to enhance heritage, and the related concepts of interpretation, memory, and history.¹⁰ The facilitation of these tools between stewards and the public could provide new avenues for preserving and disseminating cultural heritage through shared narratives.

While digital technologies provide preservationists with documentation, diagnostic and visualization capabilities, the recording, processing and reproduction of high-resolution data of cultural heritage depends on tangible and intangible realities. And, because digital technologies directly derive characteristics from physical cultural heritage, the relationship between physical and digital cultural

5 Zhou, Mingquan. Geng, Guohua. Wu, Zhongke. Digital Preservation Technology for Cultural Heritage. Higher Education Press, Beijing: 2012.

6 ICOMOS – the International Council on Monuments and Sites – held its 16th General Assembly and Scientific Symposium in Quebec (Canada) from 29 September to 4 October 2008 under the Distinguished Patronage of Her Excellency the Right Honorable Michaëlle Jean, Governor General and Commander-in-Chief of Canada. The theme of the Scientific Symposium was “Finding the spirit of place”.

7 Matero, Frank. “Editorial.” Change Over Time 2, no. 1, (2012). pgs. 2-4.

8 Ibid.

9 Letellier, Robin. Recording, Documentation, and Information Management for the Conservation of Heritage Places: Guiding Principles. The Getty Conservation Institute. Los Angeles: 2007.

10 Brusaporci, Stefano. Digital Innovations in Architectural Heritage Conservation : Emerging Research and Opportunities. Engineering Science Reference, 2017.

heritage is rapidly developing. Digital technologies provide new strategies to enhance cultural heritage.¹¹ Yet, some historic preservationists argue that digitally modeled cultural heritage might represent values of a physical artifact, but do not substitute it, and therefore question the extent to which the tools contribute to the preservation of cultural heritage.¹²

In 2012, other major key issues were identified that prevent the widespread use of digital technologies in the field. Alonzo Addison argues that “the ‘virtual heritage’ boom has larger issues of data quantity, quality, and longevity and without careful planning and management, many digital efforts might not outlive the heritage they are meant to record and protect and are thus not be a reliable tool capable of what they are employed to achieve.”¹³ Regardless of these limitations, digital technologies continue to develop and gain widespread use in the field. The digital technologies discussed in this section provide critical methodologies required to produce content for MR applications. These methodologies facilitate the input, processing and output of 2D and 3D information of artifacts. Today, advancements in these methodologies make it possible to reproduce accurate and high resolution digital data for MR purposes, which means that the development of MR will continue to depend on the advancement of digital technologies over time.

2.2 Mixed Reality (MR)

The purpose of this section is to contextualize MR and define its terminology. The first framework for MR was created by Paul Milgram and Fumio Kishino in 1994. The pioneers of MR research determined essential factors that distinguish different mixed reality display systems from each other by means of a taxonomic framework in order to clarify terminology issues and to provide an organizational structure for classifying research across different disciplines.¹⁴ Since Milgram and Kishino constructed this framework, the development of MR over the past several decades has been convoluted with the rapid development of competing technologies that are complex and intertwined.¹⁵ Paul Milgram and Fumio Kishino, at the University of Toronto in 1994 first defined MR systems and proposed the theory of “Reality–virtuality continuum,” which is the mixing reality of the real and virtual environments.¹⁶ For this thesis, MR is used as an umbrella term to define the means of display in which real objects and virtual objects are juxtaposed.

There are two MR applications that imply the presence of physical objects, including Augmented Reality and Augmented Spatial Reality. These characterizations of MR can be conceptualized on a spectrum from the complete physical world on one end, to the complete immersion into the virtual

11 de Lusenet, Yola and Wintermans, Vincent. Preserving the digital heritage: Principles and policies. Netherlands National Commission for UNESCO Koninklijke Bibliotheek (National Library of the Netherlands) The Hague, 4-5 November 2005. Netherlands National Commission for UNESCO European Commission on Preservation and Access: 2007.

12 Criticism from graduate students and professors in the Fall 2017 Thesis Colloquium

13 Addison, Alonzo C., “Safeguarding Heritage’s Endangered Digital Record” In *New Heritage : New Media and Cultural Heritage*, edited by Janice Affleck, Yehuda E. Kalay and Thomas Kvan. London; New York: Routledge, 2008.

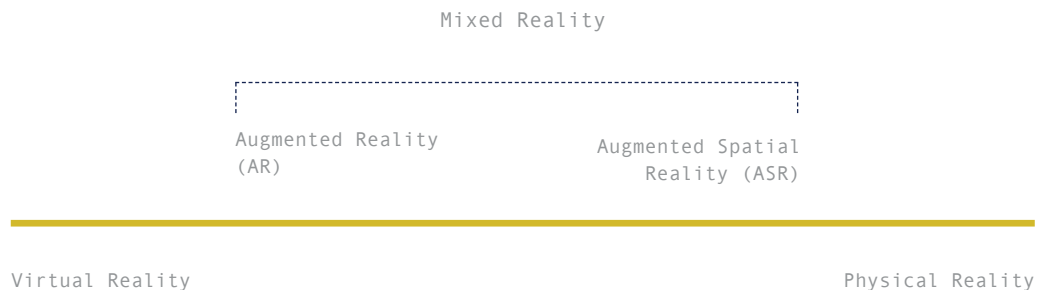
14 Milgram, Paul. et. al. *Augmented Reality: A class of displays on the reality-virtuality continuum*. ATR Communication Systems Research Laboratories. Kyoto: 1994.

15 Gjørøster, Tor. *Interaction with mobile augmented reality: An exploratory study using design research to investigate mobile and hand-held augmented reality*. University of Bergen: 2015. Dissertation.

16 Ibid.

world, or Virtual Reality (VR). MR is situated between the two on the spectrum, which implies the merging of the two worlds. ASR is the closest MR application to physical reality, whereas AR is situated towards Virtual Reality (VR) on this spectrum shown in Figure 1.

Figure 1



Mixed Reality Spectrum. Source: Author

2.3 Augmented Reality (AR)

Augmented Reality (AR) is defined as the merging of physical and digital worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in the virtual world through a device. In AR digital visualizations are superimposed into the physical world through optical, electronic and mechanical components, and it can be performed through the use of hand-held (such as mobile monitors, phones, or tablets) or head-attached (such as retinal displays, head-mounted displays, and projectors) displays.¹⁷ One difference in the two display types resides in user experience; head-attached displays are worn by a single observer, whereas hand-held displays accommodate for multiple users. Another distinguishing feature between the two is the distortion of the images produced on the screen.¹⁸ Hand-held displays are supported by image planes, whereas some head-mounted retina displays require a curved image.¹⁹

In order to create AR applications, digital overlays must register and track to the physical world through a device. Initially, AR applications required the placement of physical markers to register and track digital objects in what is referred to as a *marker-based* application. In these applications, the marker detection and tracking process play a crucial role in the entire system because “they determine the accuracy and stability of an application.”²⁰ Today, the development of AR has advanced to operate

17 Ibid.

18 Ibid.

19 Ibid.

20 Park, Jong-Seung. AR-Room: a rapid prototyping framework for augmented reality applications. *Multimedia Tools and Applications*: Volume 55, Issue 3, December 2011. pp 725–746

efficiently and effectively through markerless registration and tracking processes. In these cases, AR utilizes “standalone” devices, which is an untethered display that provides an augmented overlay.²¹ The first AR systems employed head-mounted displays, which are still commonly used today. However, over the past decade advances in mobile technology have paved the way for the integration of mobile hand-held displays (smart phones and tablets) for AR. Rekimoto argues that head-mounted displays isolate users from the physical world, whereas hand-held systems allow for a more natural immersion.²² Wagner and Schmalstieg created the first standalone hand-held AR application in 1996, while Möhring, Lessig, and Bimber presented the first video see-through AR system on a consumer cell phone in 2003.²³ Mobile hand-held AR devices use a technique known as “video see-through,” to superimpose digital objects in real time onto a live video stream captured by the device’s rear-facing camera. Digital objects are then registered onto the physical world while a user operates and positions the hand-held device.²⁴ The common steps for standalone are:

- Step 1: Context Awareness: Image capturing and real-time marker tracking
- Step 2: Scene Composition: Object feature detection from camera pose estimation
- Step 3: Rendering: Real-time registration of inserting digital objects and into the physical world
- Step 4: Tracking: Maintaining the position of digital objects as a user to navigates inside the augmented environment

The integration of mobile hand-held devices for AR has sparked the release of several commercial and open source systems development kits referred to as SDKs or platforms.²⁵ Two of the most robust platforms are ARKit developed by Apple. and ARCore by Google. In order to provide experts with information required to use their platform Apple published procedural protocols for ARKit, which are a series of design, interaction, and content guidelines (both technical and conceptual) to simplify the task of building an AR experience.²⁶ Google designed ARCore, a platform for building AR applications on Android devices that uses three key technologies to integrate digital content to the physical world as seen through a mobile device camera.²⁷ Fundamentally, ARCore uses the same principles as ARKit to register and track object. The device’s camera identifies features and tracks how they move over time. In addition to identifying features, the ARCore system detects flat surfaces, and can also estimate the average lighting in the area around digital objects.²⁸

The difficulty of tracking and registering points between the digital and physical worlds remains one of the biggest challenges in AR projects today.²⁹ Robust markerless tracking solutions are sometimes missing, which leads to the use of nonaesthetic markers, and planer targets used for markerless tracking

21 Gjørøseter, Tor. Interaction with mobile augmented reality: An exploratory study using design research to investigate mobile and hand-held augmented reality. University of Bergen: 2015. Dissertation.

22 Rekimoto, Jun. Transvision: A Hand-Held Augmented Reality System For Collaborative Design. 1996

23 Wagner, D. and Schmalstieg, D. First steps towards hand-held augmented reality. Seventh IEEE International Symposium on Wearable Computers, 2003. Proceedings., 2003, pp. 127-135.

24 Vanoni, David. Stout Antonino, Samantha. Falko, Kuester Cosentino. ARtifact Conservation: Representation and Analysis of Spectroscopic and Multi-spectral Imaging Data Using Augmented Reality. ICOMOS 18th General Assembly, Emerging tools for Conservation Practice: Florence, 2014.

25 Huang, Mark A. et. al. Human Factors in Augmented Reality Environments. Springer International Publishing : 2013.

26 Apple Inc. Article About Augmented Reality and ARKit. Accessed at: https://developer.apple.com/documentation/arkit/about_augmented_reality_and_arkit

27 Google Developers ARCore Overview. “Fundamental Concepts.” Accessed at <https://developers.google.com/ar/discover/concepts>

28 Ibid.

29 Zoellner, M. Keil, J. Drevensek, T. Wuest, H. Cultural Heritage Layers: Integrating Historic Media in Augmented Reality 2009 15th International Conference on Virtual Systems and Multimedia. Publisher: IEEE, 2009. pp: 193-196

Figure 2



The application *Pokemon Go* was one of the first mobile AR applications to spark widespread interest in AR. Image: CNET

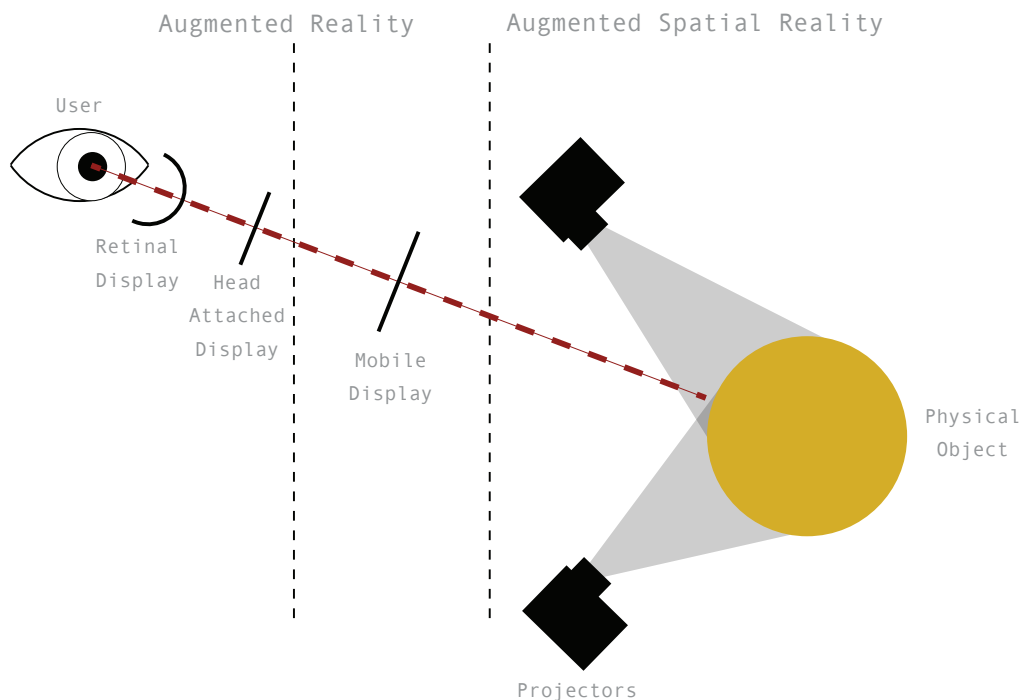
only enables augmentation for flat surfaces. Mobile devices offer high-performing and portable computing platforms, but few devices are able to run demanding MR software. Additionally, AR applications often rely on proprietary software and are not sustainable.³⁰ Despite these challenges, new platforms such as ARKit and ARCore are rapidly transforming AR by resolving many of these issues. Additionally, these platforms have not only made the conceptual approach to AR projects more consistent, but they also increase the accessibility of AR development for non-computer specialists.

30 Huang, Mark A. et. al. Human Factors in Augmented Reality Environments. Springer International Publishing : 2013.

2.4 Augmented Spatial Reality (ASR)

Over the last several decades, MR has taken a new path in technological research with the development of Augmented Spatial Reality (ASR). ASR also referred to as “projection mapping” or “video mapping,” is defined as the merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in the physical world. ASR overcomes technological and ergonomic limitations present in AR with its removal of personal display technology illustrated in Figure 3. Bimber and Raskar authors of the book titled *Spatial Augmented Reality: Merging Real and Virtual Worlds*, published the first resource that provides techniques and guidelines for carrying out ASR projects.³¹

Figure 3



Mixed Reality Display Systems. Source: Author

31 Bimber, Oliver and Raskar, Ramesh. *Spatial Augmented Reality: Merging Real and Virtual Worlds*. Taylor and Francis Group: Boca Raton, 2005

One of the earliest examples of ASR is projection based surround screens. There are two ASR display systems including optical see through and projection based. Today, projector based spatial displays are the most accessible and commonly used display systems.³² Projector based systems for AR incorporate front-projectors that superimpose digital visualizations directly onto a physical object's surface.³³ Front-projectors are optical elements, such as video projectors, that use software rendering and calibration techniques to display digital overlays.³⁴

Although ASR has matured over the years with advancements in computers, spatial display systems continue to face many technological challenges. The limited custom software solutions available for ASR often rely on proprietary software and not sustainable.³⁵ The use of white light projectors makes it difficult to achieve accurate color result, and high image and color quality projectors are often expensive as most projects requiring the use of multiple projectors to reduce image distortion. There are very few established techniques for calibrating and syncing projectors for mapping, which remains one of the most biggest challenges in ASR projects today.³⁶ Since methodological approaches for projection mapping vary, there are inconsistent conceptual ASR approaches.

Figure 4



Projection mapping has been used on architectural facades to display theatrical, artistic and historical content seen here at the San Fernando Cathedral in San Antonio, Texas. Image: Ken Erfurth

32 Bimber, Oliver and Raskar, Ramesh. Spatial Augmented Reality: Merging Real and Virtual Worlds. Page 87

33 Ibid.

34 Ibid.

35 Ibid.

36 Zoellner, M. Keil, J. Drevensek, T. Wuest, H. Cultural Heritage Layers: Integrating Historic Media in Augmented Reality. 2009

2.5 Aspects of Mixed Reality

Although AR and ASR require technologically interdependent strategies, their conceptual and methodological approaches overlap and are intertwined. As such, this section aims to identify aspects of MR that can be applied to both AR and ASR as common criteria for evaluating projects. Existing MR platforms provide standards, guidelines, and techniques from which aspects of MR can be derived and characterized. These aspects include, design, interaction and content, and each contains a series of components that provide a set of criterion for the evaluating the use of MR. While this investigation examines the most recent and robust MR systems available today, this section establishes three aspects of MR that are not dependent on current technologies.

DESIGN

The design of MR includes both digital and physical components. For AR, digital design pertains to the User Interface (UI), as well as tracking and registration of digital objects. The ARKit framework offers techniques and guidelines for designing the User Interface (UI) and describes the ways in which experts can design AR applications that allow users to understand their options for interaction.³⁷ The UI is the series of screens, pages, and visual elements that enable users to communicate with a device. Its modalities constrain how a user interacts with the augmented environment.³⁸ A simple UI allows users to easily understand their options for interaction.³⁹ Registration ability and tracking quality are reduced when the camera can't see details, such as when the camera is pointed at a blank wall or the scene is too dark. Therefore, AR should not be employed in dark environments. ARCore establishes that planar tracking provides a flat surface for digital overlays without the need to install physical markers for tracking and registration.⁴⁰

For ASR, the registration and tracking of digital overlays occurs through the process of mapping. This process is executed by using rendering infrastructure and interactive tools for projector calibration. Calibration refers to the process of aligning and syncing projectors to display digital visualizations in mapped out physical locations. The physical design of MR focuses on the equipment and the physical

37 Ibid.
38 Apple Inc. Article About Augmented Reality and ARKit
39 Ibid.
40 Google Developers ARCore Overview

resources required for both AR and ASR. The design of MR relies on the use of robust digital equipment such as computers and softwares to develop an application. Powerful optical equipment such as hand-held displays and projectors are required to overlay digital visualizations in an augmented environment. However, the equipment required for AR and ASR differ; AR requires a personal devices, whereas ASR relies on one device to control various optical and electrical components (such as projectors, lights and speakers). In some cases, AR applications that rely on outdated systems may use physical markers to register and track digital objects. These markers should be designed in an aesthetic and inconspicuous manner. .

INTERACTION

Interaction determines how a user engages with the augmented environment. The main aspects of interaction are navigation, flexibility, comfort, and security/safety. Navigation is the way in which a user to moves through the augmented environment. For AR, familiar gestures allow users move through layers of information, as well as magnify and rotate specific areas on the display. In general interactions should be kept simple so that a user can easily navigate an augmented environment. For AR and ASR, movement should be progressively encouraged so that users can easily adapt to the augmented environment. The movement of digital objects should track smoothly and not appear to jump, especially in AR as a user resizes, rotates, or moves digital objects.⁴¹

The flexibility provides the possibility for MR to be adapted for different uses with varying sets of features for use in different environments. For AR, interaction methods are based on the context and a user should be able to switch to different interaction methods. Users should have the capability to toggle through different labeling options to appear on the screen.⁴² ASR installations should have the capacity to switch between sequences and types of content.

When designing AR applications it is important to plan for how users hold their device and aim to create a comfortable experience. Comfort is the ability for a user to move through the augmented environment with physical ease and freedom from constraint, which greatly impacts how the physical world is perceived. This is especially important for AR because it requires a user to hold or wear a personal device, and holding or wearing devices at certain distance or angle for a prolonged period can be fatiguing. The user may also want to pause the information on the device for a break. For example, objects should be placed at a distance reduces the need to move the device closer to the object.

Safety and security prevent MR users from dangerous or threatening scenarios. MR applications must clearly communicate requirements or expectations to users up front for scenarios that present challenges. Since ASR environments require a dark environment with limited visibility to support projections, users must be warned of potential hazards. AR applications that require the input of personal information must ensure security. Ganapathy notes that “privacy and security are especially important for AR due to various potential invasion sources including personal identification, location tracking, and private data storage.”

41 Apple Inc. Article About Augmented Reality and ARKit.

42 Ganapathy, S. Design Guidelines for Mobile Augmented Reality: User Experience. In: Huang W., et. al Human Factors in Augmented Reality Environments. Springer, New York, NY: 2013.

CONTENT

Content is the information communicated in MR, which can be presented in graphic, narrative or audio form. The purpose of MR content is to transmit information and knowledge. The main aspects of the content are knowledge, information organization, and accuracy. Knowledge includes the facts, information, and skills provided to MR users. While there are various types and scales of information that can be presented in MR, the application should allow users to gain a deeper understanding of the physical world. The way in which MR information is organized contributes to the transmission of this knowledge. Information organization is the structure of narrative and graphic content in MR. In MR, the entire display of the optical device should be used. For AR, this technique avoids cluttering controls and information that detract from the physical world. Accuracy is the ability for MR to communicate exact information. Digital objects in MR must be scaled properly to the physical site and modeled to reflect environmental lighting conditions. For AR, digital object shadows should be cast on real-world surfaces, and visuals updated as the camera's position changes. The objects in the real and virtual worlds must be properly aligned with respect to each other, or the illusion that the two worlds coexist will be compromised.⁴³

2.6 Conclusions

Although there are technological difference between AR and ASR, both require the presence of a physical object, building or site, and this method improves user immersion over Virtual Reality (VR) systems because a user can move around, see an object in its present scale and materiality, and understand it in a more natural way. The release of commercial and open source toolkits means that AR is becoming increasingly available to non-experts. For ASR, technological developments in optical equipment and projection mapping software allow users to interact in the augmented environment without having to operate a device. Yet, the parallel development of AR and ASR can be clearly drawn. Although both display systems are still rapidly developing, each application has its own set of advantages, capabilities and challenges. While the limitations of both AR and ASR have been identified, Bimber and Raskar argue that the applications are not competitive, but complementary.⁴⁴ As such, the derived aspects of MR including design, content, and interaction can be applied to both AR and ASR. These aspects will be used to evaluate MR case studies for historic preservation in Chapter 4.

⁴³ Azuma, Ronald T. A Survey of Augmented Reality. Hughes Research Laboratories. Presence, volume 6, No. 4, August 1997, 55-385. Massachusetts institute of Technology: 1997

⁴⁴ Bimber, Oliver and Raskar, Ramesh. Spatial Augmented Reality: Merging Real and Virtual Worlds.

3.1 Applications of Mixed Reality in Historic Preservation

In Chapter 2, I determined that the advancement of digital technologies has paved the way for MR applications to the field. By characterizing AR and ASR, I derived three main aspects of its MR including design, interaction and content. In order to determine what is known about MR in relation to historic preservation, this section provides an evaluation on its existing state of knowledge in published literature. This chapter begins by surveying existing MR projects for historic preservation and seeks to identify existing standards and guidelines for its use in the field. The investigation determines that experts have used experimental digital methodologies to create AR and ASR projects for the conservation and interpretation of cultural heritage. The users of these two historic preservation applications are distinguished between experts and the public.

3.2 Conservation: The Experts

Conservation in this thesis refers to the highly specialized aspect in the broader field of historic preservation.⁴⁵ In this thesis, conservation is defined as an intervention to stabilize the physical integrity of a site or artifact. In contemporary practice, conservators rely on advanced technologies for diagnostic tools and therapeutic methods that were inconceivable several decades ago.⁴⁶ MR allows preservationists to interact with cultural heritage without the risk of damage. The use of MR for diagnostics and monitoring provides experts with the possibility to visualize scenes that are otherwise impossible to see in the real world due to size, content and accessibility issues.⁴⁷

For architecture, Building Information Management (BIM) provides experts with an accurate virtual version of a structure that has been digitally modeled in order to provide diagnostics and

45 Fitch, James M. *Historic Preservation: Curatorial Management of the Built World*. The University Press of Virginia: 1990. Page 104

46 Ibid.

3 Vanoni, David. et. al. *ARtifact Conservation: Representation and Analysis of Spectroscopic and Multi-spectral Imaging Data Using Augmented Reality*.

maintenance of the building through its entire lifecycle, including demolition. A new model, known as Historic Building Information Modeling (HBIM), provides experts with a tool for creating, conserving, documenting, and managing drawings and information.⁴⁸ Practitioners have identified HBIM surveying and representation techniques to support the process of information integration and demonstrate the way to manage the complexity of built heritage resources. Researchers have developed theoretical frameworks as a guide towards understanding the different aspects of historic preservation and management through smart open platforms.⁴⁹ Advancements in digital technologies have greatly aided in such diagnoses but can limit the ability to work directly with the artifact in the field. Researchers have developed tablet-based AR systems that enable on-site visual analysis of artifacts.⁵⁰ MR is used as a strategy to preserve cultural heritage on the micro (art, artifacts, monuments, buildings) and macro (districts, municipalities, landscapes) scales. On the micro level, researchers have used MR to analyze and diagnose conservation-related issues and facilitate the monitoring and long-term conservation of a fresco.⁵¹ On the macroscale, experts have deployed AR to evaluate and assess the conditions of historic urban and landscape systems and also to propose the digital reconstruction of the Song Dynasty Ganzhou drainage system to meet sustainability goals.⁵² While MR provides new possibilities to the diagnosis and conservation of cultural heritage, there are very few examples of these applications in published literature.

3.3 Interpretation: The Public

According to the ICOMOS Charter for the Interpretation and Presentation of Cultural Heritage Sites, interpretation refers to “the full range of potential activities intended to heighten public awareness and enhance understanding of cultural heritage site.”⁵³ Interpretive information is disseminated through print and electronic publications, public lectures, on-site and directly related off-site installations, educational programs, community activities, and ongoing research, training, and evaluation of the interpretation process itself. In recent years, historic preservationists have deployed MR for educational resources to better understand historical and cultural contexts with the use of new interpretive methods. Cultural heritage institutions have utilized AR and ASR applications to construct mixed environment museum experiences for both real and digital visitors.⁵⁴ While these technologies open the possibilities for new methods of engagement, they also provoke larger discussions surrounding authenticity, ownership, and value in the field.

48 Megahed, Naglaa. Towards a Theoretical Framework for HBIM Approach in Historic Preservation and Management. *International Journal of Architectural Research*, 2015.

49 Ibid.

50 The application ARTifact will be discussed as a case study later in this thesis.

J. Platonov, H. Heibel, P. Meier, and B. Grollmann. A Mobile Markerless AR System for Maintenance and Repair.in *Mixed and Augmented Reality*, 2006. ISMAR 2006.

L. J. Rosenblum, et. al. The Development of Mobile Augmented Reality,” in *Expanding the Frontiers of Visual Analytics and Visualization*. London: Springer London, 2012, pp. 431–448

51 Zarzo, M. Fernández-Navajas, A. García-Diego, F.J. Long-Term Monitoring of Fresco Paintings in the Cathedral of Valencia (Spain) Through Humidity and Temperature Sensors in Various Locations for Preventive Conservation.

52

53 The ICOMOS Charter for the Interpretation and Presentation of Cultural Heritage Sites Reviewed and revised under the Auspices of the ICOMOS International Scientific Committee on Interpretation and Presentation Ratified by the 16th General Assembly of ICOMOS Quebec, Canada 4 October 2008

54 Kidd, J. Museums are using virtual reality to preserve the past – before it’s too late. *The Conversation Academic Journal*. Cardiff, 2017

In recent years, experts have increasingly explored new methodologies for preserving cultural heritage through digital means. Institutions around the world are investigating the possibilities offered by MR to extend and further examine their collections in a form where the smallest details can be magnified, and subsequent destruction is far less consequential.⁵⁵ The EU's Digiart project used drones to "capture" inaccessible cultural artifacts, before creating advanced 3D representations of them. Factum Foundation has developed new systems to record cultural heritage in high resolution. And Cyark is creating a free online 3D library of the world's cultural heritage sites, using a combination of lasers and computer modeling.⁵⁶ There are many opportunities for these organizations to extend this data for MR purposes.

Virtual tourism and virtual museum exhibits have incorporated MR for interpretation. There has also been a significant number of contributions to the development of MR for the restoration of historical sites.⁵⁷ ART glass is an AR head-attached display system that augments digital restoration and reconstruction overlays onto monuments.⁵⁸ The Harvard museum, in collaboration with research groups at MIT and the University of Basel digitally restored color transparencies of the works from Mark Rothko's Harvard Mural Triptych (1964) by using projection mapping on the canvases to bring the original paint hues back to life.⁵⁹ A similar ASR project at the Metropolitan Museum of Art returned color onto the ancient surface of the Temple of Dendur.⁶⁰ The permanent on-site ASR experience brings visitors to the Romanesque church of Sant Climent de Taüll (in the World Heritage Site Vall de Boí), which displays the church's wall paintings that were removed and are now in museums.⁶¹ Media such as videos, drawings, paintings, and photographs have been seamlessly superimposed on the physical world through AR.⁶²

AR technology has undergone rapid development and can be seamlessly executed with the use of mobile phones. Mobile AR applications allow visitors to obtain information about cultural heritage, which provides an alternative way of visiting the actual monuments that might present new opportunities to prevent overcrowding and promote preservation.⁶³ AR guides have been designed for museums in order to enable a personalized visitor experience through technology that is user adaptable.⁶⁴ Le Domus Romane di Palazzo Valentini is a permanent ASR museum that provides an interpretive immersive experience for enhancing the historical and artistic heritage of the Palazzo ruins,⁶⁵ which will be discussed as a case study later in Chapter 4. However, this review determines that there is limited

55 Lowe, Adam. "Data reality." *Future Anterior: Journal of Historic Preservation History Theory & Criticism*

56 Kidd, J. Museums are using virtual reality to preserve the past – before it's too late.

57 Noh, Z. Sunar, M.S. and Pan, Z. A Review on Augmented Reality for Virtual Heritage System. In: Chang M., Kuo R., Kinshuk, Chen GD., Hirose M. (eds) *Learning by Playing. Game-based Education System Design and Development. Lecture Notes in Computer Science*, vol 5670. Springer: Berlin, 2009.

58 Jennifer, Noémie. *Vivid Color Projections Revive Faded Works of Art*. Conservation Lab: Vice Creators, 2017.

59 Kidd, J. Museums are using virtual reality to preserve the past – before it's too late.

60 This case study is discussed in Chapter 5

61 Zoellner, M. Keil, J. Drevensek, T. Wuest, H. *Cultural Heritage Layers: Integrating Historic Media in Augmented Reality*. 2009

62 Yang, W.B., Yen, N., Cheng, H.M. *Digitalized Preservation and Presentation of Historical Building: Taking Traditional Temples and Dougong as Examples*. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume II-5/W3, 2015 25th International CIPA Symposium 2015. Taipei, 2015.

63 Damala, Areti. Stojanovic, Nenad. Schuchert, Tobias. et. al. *Progress in Cultural Heritage Preservation Adaptive Augmented Reality for Cultural Heritage: ARtSENSE Project*, 2009. pgs. 746-755.

64 Del Signore, Roberto. *Le Domus Romane di Palazzo Valentini*. Giunti, 2016.

Farvo, D. In the eyes of the beholder. *Virtual reality re-creations and academia*, in *Imaging Ancient Rome: Documentation, Visualization, Imagination*, ed. by L. Haselberger, J. Humphrey, D. Abernathy. *Proceedings of the 3rd Williams Symposium on Classical Architecture*, Rome, 20–23 May, 2004. pgs. 321–334

65 Mi Jeong, Kim. *A framework for context immersion in mobile augmented reality*. *Automation in Construction*, Volume 33. Department of Housing and Interior Design, Kyung Hee University: Seoul, 2013. pgs. 79-85

published research about how users interact with AR and ASR displays.⁶⁶

Figure 5



Augmented Spatial Reality at Temple of Dendur. The historic color scheme was returned to the walls of the temple using projection mapping. Image: MET Website

3.4 Findings

For historic preservation, MR can be used as a tool to create mixed environments for experts and researchers to better manage and understand cultural heritage. This method, in turn, allows experts to provide the public with an increased understanding of cultural heritage. Attitudes towards the appropriate treatment of cultural heritage are constantly evolving across theoretical, regulatory and operational frameworks over time;⁶⁷ and non-contact methodologies offer new strategies for preserving cultural heritage by allowing preservationists to expand possibilities for intervention once all physical range of actions has been exhausted. Reciprocally, experts have the possibility to use AR as a testing method to intervene digitally before carrying out a physical intervention. These capabilities of MR facilitate the long-term preservation of cultural heritage.

Potential applications of MR for historic preservation include, but are not limited to: documenting

⁶⁶ See Section 3.5

⁶⁷ Gabbard, Joseph L. and Swan, Edward J. II. Usability Engineering for Augmented Reality: Employing User-based Studies to Inform Design IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, MANUSCRIPT. 2017.

historic buildings and objects; creating educational resources for cultural heritage; restoring and reconstructing cultural heritage that only partially exists; visualizing scenes from viewpoints impossible in the real world due to size or accessibility issues; interacting with objects without risk of damage; and providing virtual tourism and virtual museum exhibits. These capabilities improve the understanding of cultural heritage by generating hybrid environments (physical and digital), mixing together past (non-existing parts, digitally modeled) and present (physical parts, not modeled) scenarios. For conservation purposes, MR's advantage lies in its on site application.

Although there are a range of existing applications and possibilities for the use of MR in the field, today AR and ASR still face many technical and ideological limitations. Computer scientists develop MR applications that historic preservationists must manipulate and customize for use in the field. The participation of preservationists in the development education of these applications could offer customized work-flows to experts. In 2005, Swan and Gabbard pointed out the scarcity of user studies in the field of MR.⁶⁸ Dünser, Grasset, and Billinghamurst concluded in a survey paper that only about 10% of AR-related papers between 1992 and 2007 included any type of user evaluation and instead largely focused on cognition, perception- or task-related performance issues.⁶⁹ Researchers have also determined that more enjoyable and useful information should be provided in MR applications, otherwise users easily lose their motivation for exploring the augmented environment.⁷⁰ Yet, one of the biggest technological challenges of MR is that some applications suffer from poor visual quality, lacking scientific accuracy and are expensive to produce.⁷¹ On one hand, the application of MR for conservation purposes is currently limited by the quality and relevance of the input data (the digital information obtained from the physical cultural heritage), and on the other hand, the use of MR for interpretation purposes is limited by the quality of the output data (the information presented to the public).

Advancements in recording, processing, and reproduction technologies will make MR more useful to experts. Although preservationists have deployed MR for experimental historic preservation projects across the field, there are very few studies that have closely examined the relationship between MR and the preservation of cultural heritage. In conclusion, the lack of scholarly research on the topic reveals the deficiency of evaluation methods and techniques for projects in the field.

68 Gabbard, Joseph L. and Swan, Edward J. II. Usability Engineering for Augmented Reality: Employing User-based Studies to Inform Design IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, MANUSCRIPT. 2017

69 Del Signore, Roberto. *Le Domus Romane di Palazzo Valentini*. Giunti, 2016.

Farvo, D. In the eyes of the beholder. Virtual reality re-creations and academia, in *Imaging Ancient Rome: Documentation, Visualization, Imagination*, ed. by L. Haselberger, J. Humphrey, D. Abernathy. Proceedings of the 3rd Williams Symposium on Classical Architecture, Rome, 20–23 May, 2004. pgs. 321–334

70 Mi Jeong, Kim. A framework for context immersion in mobile augmented reality. *Automation in Construction*

71 Zoellner, M. Keil, J. Drevensek, T. Wuest, H. Cultural Heritage Layers: Integrating Historic Media in Augmented Reality. 2009

3.5 Dimensions of Cultural Heritage for Authenticity and Use

In this section, we turn our attention to the ways in which existing preservation frameworks can be translated to decision making for MR applications. While the MR aspects provide basic criteria for evaluating and proposing new projects, they do not address tangible and intangible dimensions of cultural heritage for preservation. As such, this section identifies criteria that can be used to evaluate MR projects for the field. In order to do so, this section examines the role that authenticity and use have in the preservation of cultural heritage. Criteria for authenticity and use strengthen the quality and scope for regulatory purposes in preservation, and also improve the treatment and management of cultural heritage. In this section, I trace the evolution of authenticity for both a regulatory and operational criteria for safeguarding and managing cultural heritage. As a result, I determine six dimensions of cultural heritage that will later be used to evaluate case studies in Chapter 4.

The notion of authenticity has constantly evolved to maintain relevance in the field. Ruskin, Heidegger, and Reigel were some of the first Western theorists to present contemplate the context of art and objects through authorship and authenticity.⁷² The concept of authenticity has a close relationship with the concept of truth, which is included in the very first issues “which have been discussed in philosophy of all times and all places.”⁷³ While these philosophers are leaders in interrogated notions of authenticity in the field, the Venice Charter was the first regulatory framework in the field to set forth the term in the context of cultural heritage preservation. Since the International Council on Monuments and Sites established the Venice Charter in 1964, authenticity continues to play a key role in a majority of regulatory documents articulating either a theory or criteria for safeguarding cultural heritage.⁷⁴ Yet, the term has evolved over time to offer stakeholders have developed new approaches to making informed judgments about cultural heritage.

The Venice Charter determined that restore means to re-establish, and the aim of restoration is

72 Ibid.

73 Somayeh F. Nezhad, Somayeh F. et. al. A Definition of Authenticity Concept in Conservation of Cultural Landscapes. Archnet-IJAR, International Journal of Architectural Research International Journal of Architectural Research.: 2015

75 Roberts, Bryony. “Competing Authenticities.”

to preserve and reveal the aesthetic and historic value of a monument that is based on respect for the original material and authentic documents.⁷⁵ The document emphasized that authenticity referred to the integrity of an artifact's original material fabric.⁷⁶ Although authenticity has played a fundamental role in scientific studies for the field of historic preservation, affirmed this way in the Venice Charter this way, authenticity appears to be the essential qualifying factor for evaluating the values of cultural heritage.⁷⁷ Since the Venice Charter, there has been an increased recognition and acceptance of the broader values associated with safeguarding cultural heritage, and preservationists have continuously developed new approaches for evaluating authenticity. In 1978, the World Heritage Committee (1978) introduced four criteria for assessing the authenticity of cultural heritage sites including design, materials workmanship and setting. This measure of authenticity was first used as the initial criterion for assessing the property in the World Heritage List.⁷⁸ Shortly after, in 1979 the Burra Charter, recognized the significance of *place* and *setting* of cultural heritage. The Nara Document was established in 1994 at the UNESCO World Heritage Convention to recognize the additional values associated with safeguarding intangible heritage described as "techniques and traditions."⁷⁹ Today, historic preservationists recognize that all judgments about the values attributed to cultural heritage as well as the credibility of related information sources may differ from culture to culture, and even within the same culture.⁸⁰ Since it is not possible to base judgments of values within fixed criteria, the Nara Document determines that stakeholders must develop analytical processes and tools specific to their culture and needs for adequately determining authenticity.⁸¹

The World Heritage Committee used the Nara Document as a framework to apply the test of authenticity with full respect to the social and cultural values of all societies but has been critiqued for its ability to be applied to different cultures across the field.⁸² In 2005, the World Heritage Convention introduced criteria for 'test of authenticity' in operational guidelines to assess the criteria of authenticity, including: form and design; materials and substance; use and function; traditions, techniques and management systems; location and setting; language and other forms of intangible heritage; spirit and feeling; and other internal and external factors.⁸³ The same year, the Operational Guidelines of the World Heritage provided a definition for the concept of authenticity as "the capability of a site to transmit the cultural significance of a place." Some documents published in recent years, including Quebec ICOMOS,⁸⁴ have expanded the scope of heritage to develop the concept of authenticity in the conservation process, as well as emphasizing the preservation of the spirit and sense of place.⁸⁵

With the recent recognition of the spirit and place in evaluating authenticity it can be concluded that, the concept of authenticity has moved beyond the physical aspects of heritage now incorporating

75 According to the ICIMOS Venice Charter. "The process of restoration is a highly specialized operation. Its aim is to preserve and reveal the aesthetic and historic value of the monument and is based on respect for original material and authentic documents." IT also indicates the need to slow down the heritage property erosion process; especially in buildings with more durable materials (stone and brick)

76 International Council on Monuments and Sites. Venice Charter, 1964.

77 International Council on Monuments and Sites. The Nara Document on Authenticity (1994)

78 Somayeh F. Nezhad, Somayeh F. et. al. A Definition of Authenticity Concept in Conservation of Cultural Landscapes.

79 International Council on Monuments and Sites, The Nara Document on Authenticity (1994)

80 Ibid.

81 International Council on Monuments and Sites, The Nara Document on Authenticity (1994)

82 Ibid.

83 Ibid.

84 UNESCO, 2005: paragraph 82

85 Somayeh F. Nezhad, Somayeh F. et. al. A Definition of Authenticity Concept in Conservation of Cultural Landscapes.

social, cultural and intellectual structures.⁸⁶ Today, authenticity is not only considered criteria for designating properties on the World Heritage List, but also a tool for assessing the conservation and management of cultural heritage after this process.⁸⁷ Authenticity was first proposed as a guide post-designation decision in Jokilehto and Feilden’s Management Guidelines for World Cultural Heritage Sites, which demonstrates ‘Test of Authenticity’ can be used in practical ways to define needed treatment for properties. Nezhad et. al. argues that “the decision to demand that cultural heritage properties meet both the conditions of authenticity and of integrity bespeaks a new interest in using the presence of these qualifying conditions, both as references that outstanding universal value is carried by attributes genuinely and credibly expressing that value, and that as references guiding management decision making to priority concerns in sustaining significance.”⁸⁸ In conclusion, authenticity and use not only provides criteria for safeguarding cultural heritage, but also guidance on management and treatment options. I argue that the ‘Test of Authenticity’ can be translated into criteria that can be applied to evaluate and propose MR projects in the field.

The criteria for the ‘Test of Authenticity’ provides the following dimensions of cultural heritage:

Figure 6

Form and Design	The project’s ability to consider, engage and communicate the Form and Design of cultural heritage
Materials and Substance	The project’s ability to consider, engage and communicate the Materials and Substance of cultural heritage
Management and Use	The project’s ability to consider, engage and communicate the Management and Use of cultural heritage
Techniques and Tradition	The project’s ability to consider, engage and communicate the Techniques and Tradition of cultural heritage
Location and Context	The project’s ability to consider, engage and communicate the Location and Context of cultural heritage
Spirit and Feeling	The project’s ability to consider, engage and communicate the Spirit and Feeling of cultural heritage

Dimensions of Cultural Heritage

86 Ibid.
 87 As Jenny Kidd has pointed out, “the concept of authenticity is of course socially constructed.”(2011)
 88 Somayeh F. Nezhad, Somayeh F. et. al. A Definition of Authenticity Concept in Conservation of Cultural Landscapes.

4.1 Evaluating MR Precedents for Historic Preservation

In this chapter, I illustrate that the aspects of MR from Chapter 2 and the dimensions of cultural heritage from Chapter 3 can be used as criteria to evaluate precedents in the field. This chapter includes an assessment of three case studies in which MR is applied as a strategy to enhance the preservation of three significant sites. All of these case studies focus on the close study of interior architectural wall paintings or frescoes. The Sant Climent de Taüll church and the Le Domus de Romane Palazzo Valentini deploy ASR, and the Salone dei Cinquecento project utilizes AR. The purpose of analyzing precedents in the field is to not only examine the capability for MR techniques to enhance the preservation of cultural heritage but also to test these criteria for evaluating HR projects in the field. This chapter concludes with a discussion of the findings from this chapter and a comparison the three case studies.

4.2 Le Domus di Romane Palazzo Valentini ASR

The archaeological remains of the ancient Roman Domus underneath the Palazzo Valentini in downtown Rome were uncovered between 2005 and 2012. In-depth research provided an interpretation of the remains for an on-site ASR museum, and it is the first ASR museum in Italy to employ MR for the site's interpretation. The project's most basic principle was to consider the public for language, and the experts for content.⁸⁹ Archaeological research guided the creation of content, while graphic designers, conservators, technicians, and computer scientists helped to present the findings. The ASR experience employs lighting, audio and sound effects to digital reconstruct the site's missing parts, such as the marble slab walls, staircases, and mosaics.

Figure 7



Projected light reconstructs the mosaic floors, now just fragments. Image: Le Domus di Romane Palazzo Valentini Museum Website

⁸⁹ Del Signore, Roberto. *Le Domus Romane di Palazzo Valentini*. Giunti, 2016.

Le Domus di Romane Palazzo Valentini ASR

4.2.1 Project Overview

The site of the Le Domus di Romane Palazzo Valentini museum dates back to the end of the first and early second century when the Roman Domus was constructed during the period of development on the Trajan Forum. The Palazzo is nestled in the heart of Rome, located adjacent to the Trajan's Column. The Domus once contained large baths that were covered in decorative stone patterns. These ruins display the complex transportation and heating water systems present during this period in Rome. Uncovered rooms also contain flooring with large patterns of a complex motif dated back to the fifth or sixth century. The architectural fragments present today are likely remnants of Trajan's temple, however, some scholars repudiate this and believe the temple existed on the southern portion of the site.⁹⁰

The first archaeological remains on the site were discovered in 1902 during surveys for the construction of Palazzo delle Assicurazioni di Venezia. Recent excavations starting in 2005 by the City of Rome uncovered the small baths complex in the Palazzo basement around 7m below street level. It is believed to have been part of the adjacent residential complex excavated in the early twentieth century. The investigated archaeological area in the museum covers about 1,200 square meters. Today, the museum is divided between the ASR installation and exhibition halls displaying artifacts. Artifacts such as discarded pottery, cookware, and dishware are left intentionally in a ruinous waste pit dating back to the 17th century.

During the initial excavation of the ruins, experts conducted extensive research to uncover the history of the remains. In order to present these findings, the City of Rome commissioned Piero Angela, Paco Lanciano, and SuperQuark to design an ASR interpretive installation. The project funding was three million euros and began in 2007.⁹¹ The first phase of the project was completed in 2012 and the second phase in 2014. The result of the larger preservation project is an interpretive museum that utilizes ASR to reconstruct the ruins through both graphically and in narrative form. Navigation in the augmented environment begins with the descent down glass stairs that connect to a transparent platform hovering above the ruins. This platform guides visitors through the archaeological remains of the Roman Domus. In addition to the projectors that augment digital visualizations onto the archaeological

90 Ibid.

91 Del Signore, Roberto. *Le Domus Romane di Palazzo Valentini*. Giunti, 2016.

remains, physical artifacts such as Renaissance-era pottery and ceramics are displayed throughout the museum. The ASR installation deploys projection mapping to reconstruct different architectural elements of the site, such as the fragmented marble and mosaic floors. The goal of the installation was to provide an installation that enhanced the preservation of the site and retained the integrity of the Palazzo's physical fabric.

Figure 8



The transparent floor system hovers above the ruins and conceals most of the ASR equipment.
Image: Le Domus di Romane Palazzo Valentini Website

4.2.2 Design

Digital

The ASR application deploys a complex video-mapping system that projects digital visualizations onto the ruins, operating through the use of 40 projectors. Although there are several examples in which digital projects reconstruct floor and wall finishes, the projectors are mostly used to highlight areas of the site with various colors and patterns while audio narration discusses the projected areas.

Physical

Every room within the ASR museum contains a wall mounted, touch screen device with the UI to control the audio and visual interpretation of the installation. Each of these devices is concealed behind the architecture itself, or blackout curtains, which darken the rooms in order for the projections to be visualized. As a guide leads visitors through the museum, they must activate the ASR installation through separate interfaces in each augmented environment. The museum has the potential to offer a self-guided experience by limiting the system to one interface. The projectors, audio, and lighting equipment are secured to the transparent flooring system. Projectors are positioned at specific angles to accurately map digital objects.

4.2.3 Interaction

Navigation

Tours at Le Domus di Romane Palazzo Valentini are guided and navigation through the museum requires that visitors remain in a group as they are escorted through the augmented environment on the transparent platform that hovers over the physical ruins. This complex structural system serves as the museum floor and also harnesses some of the physical equipment. Since navigation in the ASR environment is controlled by a guide, visitors are unable to menuvre through the ASR installation freely.

Flexibility

The content of the installation is translated into seven different languages, so that diverse visitors are able to understand the site. This is the most flexible aspect of the installation that is otherwise a fixed guided tour.

Comfort

The guide informs visitors that the tour will last for 90-minutes and require mostly standing, but the controlled experience is difficult for those that cannot stand for long periods of time (such as the elderly and children).

Safety and Security

Prior to entering the museum, visitors are warned of potential hazards for navigating the augmented environment, as well as security expectations of the site. This message limits potential safety and security risks within the ASR installation.

4.2 Le Domus di Romane Palazzo Valentini ASR

4.2.4 Content

Knowledge

The project team considered the public for language, and required the experts to develop content. Not only does the ASR installation highlight and describe the ruins, the digital overlays also reconstruct and restore architectural elements and finishes. The installation provides a detailed interpretation of the site's history and transformation over time. The Roman ruins were vacated until cardinal Michele Bonelli constructed a new Palazzo in 1585. The Palazzo is an excellent example of urban renewal efforts in Rome by cardinals in the sixteenth and seventeenth century.⁹² During the 17th century the Palazzo was subjected to a series of major renovations and expansions, and in 1827, Vincenzo Valentini a Prussian banker acquired the Palazzo. After Valentini's death, the Palazzo was handed to the provincial deputation of Rome and was established as their base in 1873 where they and commissioned architect Gabet to complete the structure.⁹³ Today, the Palazzo retains several artworks from Valentini's collection, including paintings, furniture, sculptures, and engravings.

Information Organization

The content in the ASR installation is organized spatially, meaning that the various forms of information are organized in correspondence to the organization of the physical site. Visitors are guided through the physical ruins as they simultaneously navigate through the augmented environment. At certain points throughout the spatial sequence, artifacts are displayed without the ASR installation activated. And, halfway through the installation physical artifacts are exhibited, followed by a multimedia presentation that describes the different transformations of the site over its 1,800-year history.

Accuracy

Some of the narrative and graphic content in the ASR installation appears inaccurately. First, the narrative for the site relied on scarce historical evidence. And second, the graphic content was not derived in

92 Ibid.
93 Ibid.

a scientific manner because the digital projections were modeled based on hypothetical reasoning.⁹⁴ In fact, much of the interpretation of the ruins was based on fourth-century villas in Rome. As such, there is an overall lack of a scientific approach for the ASR installation.

4.2.5 Findings: Evaluating Dimensions of Cultural Heritage for Authenticity and Use

Today, museum staff members manage and maintain the digital and physical design components of the ASR installation. In evaluation of the existing location and context of the site, the ASR museum continues to provide a covered indoor environment beneath historic structures. Yet, the physical changes made to the site to support the required ASR equipment disrupt the ability to understand and engage with the forms, design, and materials of the physical ruins. The transparent glass platforms and staircases, in addition to projectors, lighting and curtains and sound equipment, were designed to be non-invasive, but the final design of these components starkly contrast the ruins and interfere with the design of the site. Although the site is underground creating a naturally dark environmental condition for ASR, the lack of visibility in the museum prevents visitors from experiencing the entire site without the installation. Additionally, the dark condition only allows visitors to engage with the materials and substances of the ruins as they are actively highlighted by projected light. For brief moments during the guided tour the lights are turned on for visitors to examine the remains, however, these environmental lights are supposedly more invasive to the materials and finishes of the site compared to the projector lights.⁹⁵

Interaction in the augmented environment is immersive, yet limited. Due to the sensitive location of the museum, on royal grounds beneath the Palazzo Valentini, there are many restrictions imposed upon visitors to control navigation of the installation. Although the ASR museum allows visitors to experience the ruins in an enhanced way, the guided nature of the installation prohibits visitors from freely navigating the site. Visitors are also prohibited to take photos inside of the museum, which decreases the knowledge production of the site. Overall, the controlled interaction experience of the tour limits the tangible and intangible dimensions of the site.

The content approach for the ASR installation is to highlight and reconstruct fragments of the remains through a combination of audio narration and projection techniques. Not only does the content in the ASR museum communicate the techniques traditionally used to create the Roman Domus, but also the methods for uncovering and stabilizing the archaeological remains. The appearance projected content is outdated and low-resolution. It would be beneficial for site managers to develop a plan for maintaining and updating content in the installation as data recording and projection capabilities continue to advance.

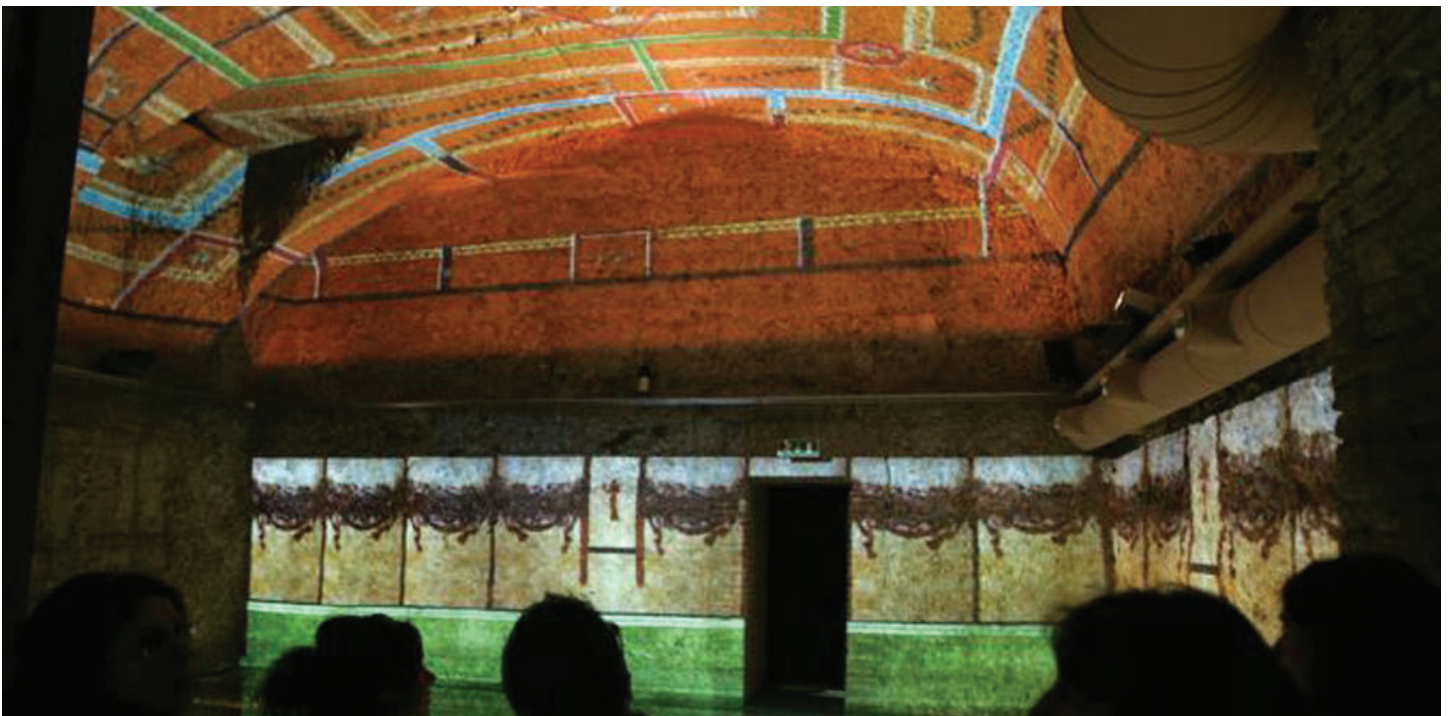
⁹⁴ Fabrizio Oppedisano, a historian who collaborated on the project, said that the interpretation for the ruins is “hypothetical, based on the general layout of what was found... the red walls in the reconstruction, for example, were based on a few centimeters of red fresco found on one of the walls.”

⁹⁵ Del Signore, Roberto. *Le Domus Romane di Palazzo Valentini*. Giunti, 2016.

At the end of the installation there is a short multi-media presentation that describes the transformation of the site's form and design since the 15th century. Ultimately, this approach is disconnected from the ASR installation, and this information has to potential to be more effective incorporated into the ASR installation itself. Yet, the information transmitted in the installation is not only meaningful and relevant to the Roman Domus, but also contextualizes the historically significant Palazzo Valentini above the museum. To evoke the spirit and feeling of the original site, the sounds of rain, fire, and earthquakes are played in the installation. In addition to the over-romanticization of the audio, the graphic content is displayed with low resolution digital projections. The inaccuracy of the content causes the installation to become a "disneyfied", meaning that the graphics do not accurately represent the true appearance of the historic design and materials of the Domus. This condition is illustrated in Figure 9, where the colors of the restored frescoes appear brighter and unnatural.

In conclusion, this project is one of the first ASR museums carried out for the preservation of cultural heritage, and it continues to be well received by both experts and the public.⁹⁶ However, in order for the installation to be more effective at communicating the significance of the site for preservation purposes, the museum must better consider ways to increase the understanding about the tangible and intangible dimensions of the site. This begins with the development of higher resolution content that accurately corresponds to the historic materials of the site. This project is a strong example showing the importance of ongoing maintenance. As technology continues to advance, experts must maintain MR systems that achieve the most accurate imaging results to enhance the authenticity of a site. The costs required to maintain ASR installation at the site are already high due to projector light bulbs that need to be replaced every two to three months. While the annual operation and maintenance costs for the museum is 600,000 euros, earning about 620,000 euros from annual ticket sales,⁹⁷ the generated revenue of 20,000 euros need to be increased to cover the costs required to upgrade or add to the ASR installation.

Figure 9



Projected light restores a fresco. Image: Le Domus di Romane Palazzo Valentini Museum Website

96 Ibid.
97 Ibid.

4.3 Case Study 2: Salone dei Cinquecento AR

Between 2012 and 2014 heritage experts developed the application ARtifact, a tablet-based AR system, to enable on-site visual analysis of the Salone dei Cinquecento or “Hall of the 500” in Florence’s Palazzo Vecchio. The University of California San Diego Center of Interdisciplinary Science for Art, Architecture, and Archaeology developed the application for experts to study various layers of data registered with the physical object in situ through AR. These layers represent data acquired through various conservation imaging modalities such as infrared thermography and ultraviolet fluorescence. The purpose of the application is to provide a user with an augmented view of the hall to aid in on-site diagnosis for conservation. Intuitive interaction techniques further enable targeted analysis of artifact-related data for the diagnosis and preservation of the 16th-century hall. This section provides an analysis of the project’s MR aspects and examines their relationship to dimensions of Salone dei Cinquecento.

Figure 10



Existing Salone dei Cinquecento in Florence’s Palazzo Vecchio. Image: lucenews.it

Salone dei Cinquecento AR

4.3.1 Project Overview

Over the past seven centuries, the Palazzo has experienced a series of extensions and transformations. In the middle of the 16th century, artist Giorgio Vasari was commissioned to update and expand the hall. As a part of this intervention, Vasari and his helpers painted six large frescoes depicting various battle scenes honoring Florentine military victories on the east and west walls of the Salone dei Cinquecento. Today, the Palazzo retains its architectural significance in part due to restoration work carried out in the mid-sixteenth century. Cosimo I de' Medici ordered the adaptation of the monument to serve its new function as the Palazzo Ducale. Today, its frescoes remain in a sensitive conservation state.⁹⁸ And, until the application ARtifact was developed for this project, very little was known about the hall prior to its 15th-century intervention.

Experts developed the application ARtifact to explore artifacts and related media through the use of a mobile tablet device. It was designed as an interactive multi-touch display to enable expert analysis by allowing the user to “wipe through” to different data layers to diagnose cultural heritage in situ.⁹⁹ In this case study, I evaluate the application ARtifact for on-site analysis of the Salone dei Cinquecento or “Hall of the 500” in Florence’s Palazzo Vecchio, which focused on the east wall fresco depicting the Battle of Marciano shown in Figure 8. In preparation for the design of the AR application, experts recorded and processed layers of data for use on the tablet, including historic images and diagnostic imaging. After these layers of data were prepared, experts brought ARtifact on site loaded with a thermal image data of the east wall, which contains dark lines scattered throughout that correspond to cooler areas within the fresco. By using the application, experts identified cracks within the fresco revealing conservation issues not only for the fresco but also for the structural integrity of the hall.

114 Ibid.

99 Vanoni, David. Stout Antonino, Samantha. Falko, Kuester Cosentino. ARtifact Conservation:Representation and Analysis of Spectroscopic and Multi-spectral Imaging Data Using Augmented Reality..

Figure 11



ARtifact user wipes away existing context to reveal x-ray data. Image: David Vanoni et. al.

4.3.2 Design

Digital

The UI for ARtifact is based on Androids standard interface, which is both minimal and graphic. The UI has simple slider elements allow a user to adjust various parameters of the visualization, such as overlay opacity and camera zoom.¹⁰⁰ The AR application utilizes the platform *Vuforia AR library* to process the live video stream from the tablet's rear-facing camera. This provides the "see-through" functionality of the interface, rendering the unmodified video stream as the background for subsequent augmentation rendering.¹⁰¹ The AR application allows experts to view layers of data through "a simple file hierarchy stored on the tablet that contains high-resolution image files representing the various layers of data available for each artifact."¹⁰² The tablet's Graphics Renderer (GR) receives input from the tablet's rear-facing to compose and render the desired augmentation for registration and tracking. Next, the GR aligns the digital overlay in situ and superimposes the image onto the physical site with data provided by the Data Manager (DM), which is responsible for managing the stored TIFF image files that are used as the data layers.¹⁰³

Physical

The displays used for this project are ten-inch tablets that are equipped with multi-touch screens. The AR application was developed for Android-based tablets because of the operating system's availability and accessibility. In order to superimpose digital images onto the real world, a live camera view from the tablet's rear-facing camera is aimed at the artifact. The application recognizes the physical artifact and overlays a selected layer of data.

100 Vanoni, David. Stout Antonino, Samantha. Falko, Kuester Cosentino. ARtifact Conservation: Representation and Analysis of Spectroscopic and Multi-spectral Imaging Data Using Augmented Reality.

101 Ibid.

102 Ibid.

103 Ibid.

4.3.3 Interaction

Navigation

A user begins navigating the augmented environment by activating the application and selecting a layer to view from the layers list. By aiming the tablet camera at the object in question, the *data manager* loads the corresponding image data as a texture and passes it along to the *graphics renderer* where the object is detected, registered and tracked to the site. In order to better investigate the data, a user can pan and zoom with standard multi-touch gestures. With the wiping mode enabled a user reveals layer data. The application was developed to allow multiple users to collaborate simultaneously to perform different analyses on the hall and easily compare different views or datasets.

Flexibility

The AR approach means that users have the ability to personalize interaction in the augmented environment. Different “layers” available on the UI can be previewed and loaded with simple gestures. Although the application can only be used for the specific site with pre-recorded and processed data, ARtifact can be updated and developed for MR at different sites and extra layers of previously recorded information.

Comfort

If users want to focus on a specific area of the hall they are able to pause the application to freeze the current camera view. Next, they can modify other parameters of the visualization without having to hold the tablet in place. This gives users a break because holding the tablet in place for extended periods of time can become tiresome and make it difficult to perform a precise analysis.

Safety and Security

In terms of security, the AR application does not require the input of personal information. However, the developers of the system hope to add a database for storing annotations for users to reference at any time. The development of a database would require additional security measures.

Salone dei Cinquecento AR

4.3.4 Content

Knowledge

The purpose of the AR application is to transmit knowledge to experts and stakeholders in situ for an increased understanding about the physical context of the conservation issues at hand. In the application's existing state, experts are able to use ARtifact as a standalone visualization tool to better analyze conservation-related issues of the hall in situ in comparison to in the lab.

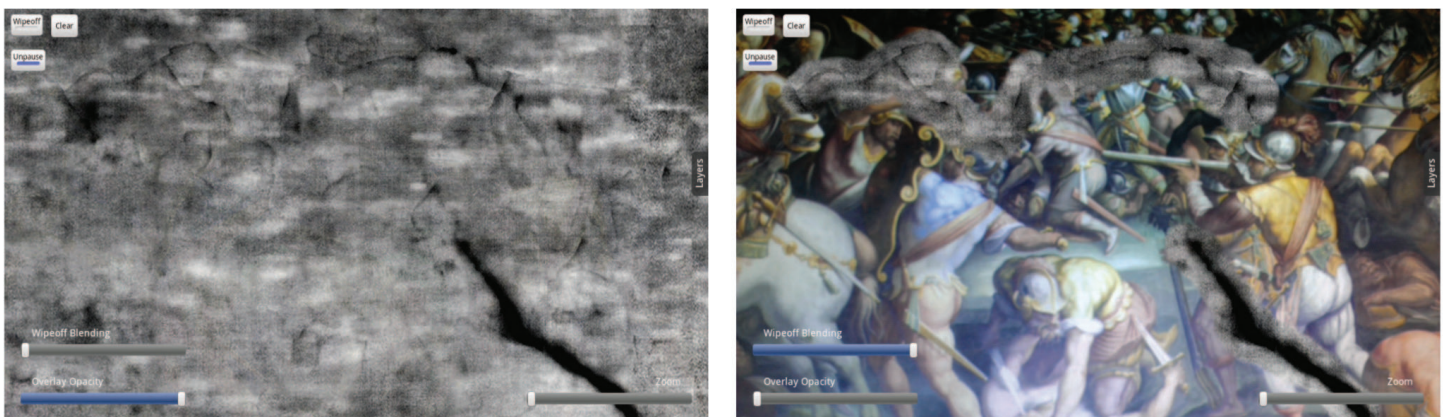
Information Organization

The application provides pre-recorded data and processed information that is presented through layers in a file hierarchy. The information is organized for a user to easily identify and select relevant content.

Accuracy

In order to accurately register and track digital overlays, the application detects features from the device's video stream. Features of the hall are detected through descriptions stored within the tablet application. To ensure the proper alignment of these layers when superimposed onto the physical site, experts edited each TIFF image in order for the layers to accurately align. Moreover, the applications GR automatically scales overlays based on the viewport transforms provided by the UI Manager.¹⁰⁴ The data used for the image layers appear to be obtained from accurate diagnostic imaging systems. While the data forms presented in this application deploy visualizations that are scientific in nature, experts are able to analyze scenes otherwise impossible in the real world.

Figure 12



Left: AR Overlay showing thermal image with visible cracks, Right: Specific areas wiped to view cracks in relation to fresco. Image: David Vanoni et. al

¹⁰⁴ Vanoni, David. Stout Antonino, Samantha. Falko, Kuester Cosentino. ARtifact Conservation: Representation and Analysis of Spectroscopic and Multi-spectral Imaging Data Using Augmented Reality.

4.3.5 Findings: Evaluating Dimensions of Cultural Heritage for Authenticity and Use

Through the use of ARtifact experts were able to visualize the entire wall east wall of Vasari's frescoes with an augmented area of about 10,000 square feet. By examining pre-recorded thermal data of the fresco wall, experts were able to identify an archway within the wall of the hall that is now filled with bricks and otherwise impossible to see. The application provides a means understand the relation of this archway to the present day hall. With the use of AR, a user can go into the hall and use the application to reveal where the archway resides in live view.¹⁰⁵ Another advantage of the AR application is that users do not have to crowd around a single hand-held display since each can operate their own tablet and have full control over navigation. As such, the tablet-based approach promotes collaborative analysis among multiple users. Instead of viewing this data in the lab, ARtifact enables users to analyze the hall in an interactive mode of analysis.

In consideration of the application's physical design, the video see-through AR approach means that a user does not have to shift their attention away from the physical frescoes to view content. Since the fresco is flat, the use of planar registration and tracking was deployed so that markers were not physically fastened to the wall. While ARtifact can currently track planar targets limiting experts to only analyze the hall in a two-dimensional view, ARtifact developers hope to extend the capabilities to support complete analysis of three-dimensional artifacts in the hall from any viewing angle.¹⁰⁶ This will allow experts in the field to use the diagnostic tool across different types of cultural heritage for specific analyses.

Experts were able to focus on the hall while exploring previously recorded data, such as thermography data of the fresco, allowing them to identify and locate damaged areas.¹⁰⁷ The UI provides experts with the capability to highlight specific crack regions within the data and superimpose these regions onto the live view of the fresco. The ability for users to change the opacity of content allows experts to compare the physical frescoes with related data in order to understand the materials of the physical site. To better investigate the design and materials of the wall frescoes, the ability to precisely define locations (Figure 12) enables experts to refine the analysis of an area. In comparison

¹⁰⁵ Vanoni, David. Stout Antonino, Samantha. Falko, Kuester Cosentino. ARtifact Conservation:Representation and Analysis of Spectroscopic and Multi-spectral Imaging Data Using Augmented Reality.

¹⁰⁶ Ibid.

¹⁰⁷ Ibid.

to traditional techniques (such as paper printouts) used in field for diagnostic analysis, ARtifact offers a new approach to aid with on-site analysis that ensures the monument's continued management and use.

With ARtifact, interaction in the augmented environment is fixed to the display and only allows for analyses on one wall of frescoes. This limits the user's ability to engage with the other dimensions of the site. While the application allows experts to visualize various layers of important information in situ, ARtifact, as it exists today, is limited in its capability to aid in the conservation of the site, because it relies on diagnostic imaging modalities that do not reflect real-time data and must be continuously updated for accurate analysis. Additionally, the application requires users have previous knowledge about the historical context of the site, such as the techniques used in the hall's renovations. The implementation of captions would facilitate the transmission of the layer content, because otherwise new users may be unable to understand exactly what they are looking at without conducting research. Added layers of information should describe in narrative or graphic form the historical context of the Palazzo Vecchio. Captions could describe that the site was built between the end of the thirteenth century and the beginning of the fourteenth for Florence's supreme governing body, the Priori delle Arti and the Gonfalonier of Justice as the largest hall constructed at the Palazzo Vecchio in Florence, Italy during the late 15th century and remains a symbol of the civic power of Florence.¹⁰⁸

For this application to be extended to other projects, the collection of additional data layers is required, and for experts, the application would benefit from utilizing higher resolution data making it possible to better inspect details and add annotations. By modifying the approach of the application, ARtifact offers the potential to be an effective tool for visitors to experience the site, and for researchers to better understand the relation to the frescoes and its architectural context. In conclusion, ARtifact provides a compelling, but limited, platform for experts to analyze the Salone dei Cinquecento. With further development of the application's content, ARtifact has the potential become an effective asset for conservation and interpretation projects alike.

4.4 Sant Climent de Taüll ASR

ASR, or “video mapping,” enhanced the preservation of Sant Climent de Taüll Church. The installation projects digitally restored wall paintings onto the church’s main apse through a video mapping structure of six high-quality projectors. The digital visualizations are projected during a thirty-minute sequence composed of three different phases. Visitors are allowed to view the church in various conditions; first, as it currently exists without augmentation; next, with its paintings, now in museums, overlaid onto the physical remains; and last, an audio-visual projection mapping show titled #taull1123.¹⁰⁹ The show highlights significant moments in the church’s history beginning in the year 1123 when its apse was freshly painted with iconic religious figures, and then when the church was rediscovered in the nineteenth century.

Figure 13



Projected light reconstructs the mosaic floors, now just fragments. Image: Museums and the Web

¹⁰⁹ Museums and the Web. #Taull1123. Immersive experience in a World Heritage Site (or augmented reality without devices). MW2015: Museums and the Web, 2015.

Sant Climent de Taüll ASR

4.4.1 Project Overview

The church of Sant Climent de Taüll was built on the site of an earlier church dating from the 11th century. The church is a prototype of a basilica plan, with three naves and apses separated by columns and covered with a wooden gable roof. The figure of Christ from the church is the most frequently used emblematic image to represent Catalan Romanesque art. Today, the original painting is kept in the National Museum of Catalan Art.

Figure 14



Sant Climent de Taüll. Photo: Dir. Gen. Arxius, Biblioteques, Museus i Patrimoni

Sant Climent de Taüll is, one of Europe's foremost examples of Romanesque architecture and was declared a world heritage site by UNESCO in 2000 alongside other Romanesque churches in the

Vall de Boí built in the 11th and 12th century. The church once possessed artworks of great significance, including outstanding Catalan Romanesque wall paintings, and most prominently, a representation of God surrounded by tetramorphs and angels, the Christ in Majesty of Sant Climent de Taüll.¹¹⁰ By the beginning of the twentieth century, these works attracted the attention of international art dealers. To prevent their export, the Spanish government campaigned between 1919 and 1923 to remove the frescoes and house them in what is now the Museu Nacional d'Art de Catalunya (MNAC), where they have been displayed since.¹¹¹ Despite the removal of the paintings, the church walls retain fragments of the paintings remain in stable condition. In 1959, a replica of the restored wall paintings was created and placed in situ over the physical remains of the paintings.¹¹² The replica suffered considerable damage over the decades and by 2012, it cracked, its colors were significantly deteriorated, and the metal supports originally intended to be temporary failed. The church itself was also in a poor state of conservation. Its entire east end suffered from moisture problems due to its leaky roof, and the central part of the apse floor was completely compromised.

The site faced many cosmetic and structural issues and the number of visitors to the monument significantly declined over the years. Although it had two existing museum installations, the site's interpretative efforts were not effective at transmitting the value of the monument.¹¹³ The Catalan Government Ministry of Culture recognized that the monument must be restored in order to attract more visitors and ensure its preservation into the future. La Caixa Bank contributed 40,000 euros to fund the restoration of the church's original wall paintings.¹¹⁴ The project formed part of the "Open Romanesque" program promoted by the Catalan Government Ministry of Culture and "la Caixa" Foundation and was conceived to integrate and unite conservation techniques, illumination, contemporary architectural design, museography, artistic restoration, and the installations necessary for ASR. This project was carried out over eight months by a wide-ranging team of archaeologists, architects, restorers, conservators, historians and specialists in audiovisuals, graphic design and animation.¹¹⁵ The scientific, technical, and artistic process required to reconstruct the original frescoes in all their parts had a complex approach. First, it required the digital restoration of all the cracks, missing sections, and gaps in the original fragments. Second, the marks left by the removal of the original frescoes from the walls had to be repaired. Finally, it was difficult to recover the pictorial fragments that had remained on the church walls that were severely deteriorated.

The first structural restoration efforts began at the beginning of 2012. In order to prevent further damage, the church was drained to prevent moisture from accumulating in the structure and the roof was repaired to prevent leaking. During repair, the removal of a modern beam from the framework of the roof revealed preserved fragments of the original Romanesque paintings on the frontispiece over the central apse, which displayed a helmeted figure playing a horn. Archaeological excavation made it possible to identify and recover the original paving in the center of the apse, and the position of

110 Ibid.

111 Metropolitan Museum of Art. *The Art of Medieval Spain, A.D. 500-1200, Parts 500-1200*. New York, NY: 1993

112 The most outstanding figure today are the framed figure of a dog, the representations of Saint Clement and Saint Peter on the columns, and those of Cain and Abel on the right wall of the presbytery.

113 The first exhibits a model of the church's exterior that shows its original appearance as it once was white with dark crimson decoration still seen on fragments of the bell tower. The second shows a video presentation explaining the site's history with a focus on the efforts of the architects Lluís Domènech i Montaner and Josep Puig i Cadafalch to both study and raise awareness about this church.

114 *Museums and the Web. #Taull1123*. Immersive experience in a World Heritage Site (or augmented reality without devices). MW2015: Museums and the Web, 2015.

115 Ibid..

the original altar was discovered.¹¹⁶ To make the apse accessible again, and re-establish its previous liturgical use, a reversible wood platform was added, and a new altar was installed to replace the original stone one. Finally, a pew was formed to mount projectors onto in order to be concealed from view.

Figure 15



Conservators removing the modern layer of paint. Image: Dir. Gen. Arxius, Biblioteques, Museus i Patrimoni

The first phase of the ASR project was the removal of the 1959 replica, which revealed a layer of indigo-white paint that almost completely covered the deep layers of historic paint. This finding complicated the preservation process by requiring that conservators use the tip of a scalpel to slowly remove the modern layer of paint being sure not to damage the fragile remains behind. Finally, after four months of consolidation work, the original layers of Romanesque painting were once again visible. Further study showed that there was two phases of pictorial decoration on the church walls before they were covered.¹¹⁷ The gaps and cracks on the substrate and paintings were repaired as delicately as possible.

The Burzon*Comenge studio designed and supervised the project, while the company Playmodes oversaw the technical production of the audiovisual system and commissioned the soundtrack for the mapping. In order to design the ASR installation, researchers investigated both written and graphic documentation of the church's condition since it was rediscovered in 1904. The paintings now at the

116 ibid.
117 ibid.

MNAC were also studied in detail during the process of restoration in order to accurately reconstruct the missing parts of the paintings.¹¹⁸ During the research phase, a photograph from 1920 revealed that after the wall paintings were removed, deep layers of remaining paint were hidden by the 1959 replica that was installed. Conservation analysis with endoscopy confirmed the existence of these remains under various layers of whitewash and indigo-white, and the recovering these deep layers of paint paintings was one of the project's main goals in order to create a surface for projection.

The church's apse and the fragments of paintings both on site and in museums were recorded in high resolution. A three-million-point 3D laser scan was created from the nave. The resulting point cloud was simplified and rendered into a mesh and used as a surface for the digitally restored and reconstructed paintings to be superimposed.¹¹⁹ The digital restoration of the paintings was carried out in three phases. First, the removed fragments now on exhibit at the MNAC were digitally restored and reconstructed based on the new findings from research. Next, the deteriorated parts still situated on the church walls were recreated following the techniques used to form the original brushwork, restoring both the main figures as well as the ornamental patterns. Finally, in the third phase included the reconstruction of the missing parts of the paintings by analyzing and comparing similar artworks.

Figure 16



Deep layers of paintings after fresco removal. Photo: Biblioteca de Catalunya, Salvany Archive.

118 *Ibid.*
119 *Ibid.*

4.4.2 Design

Digital

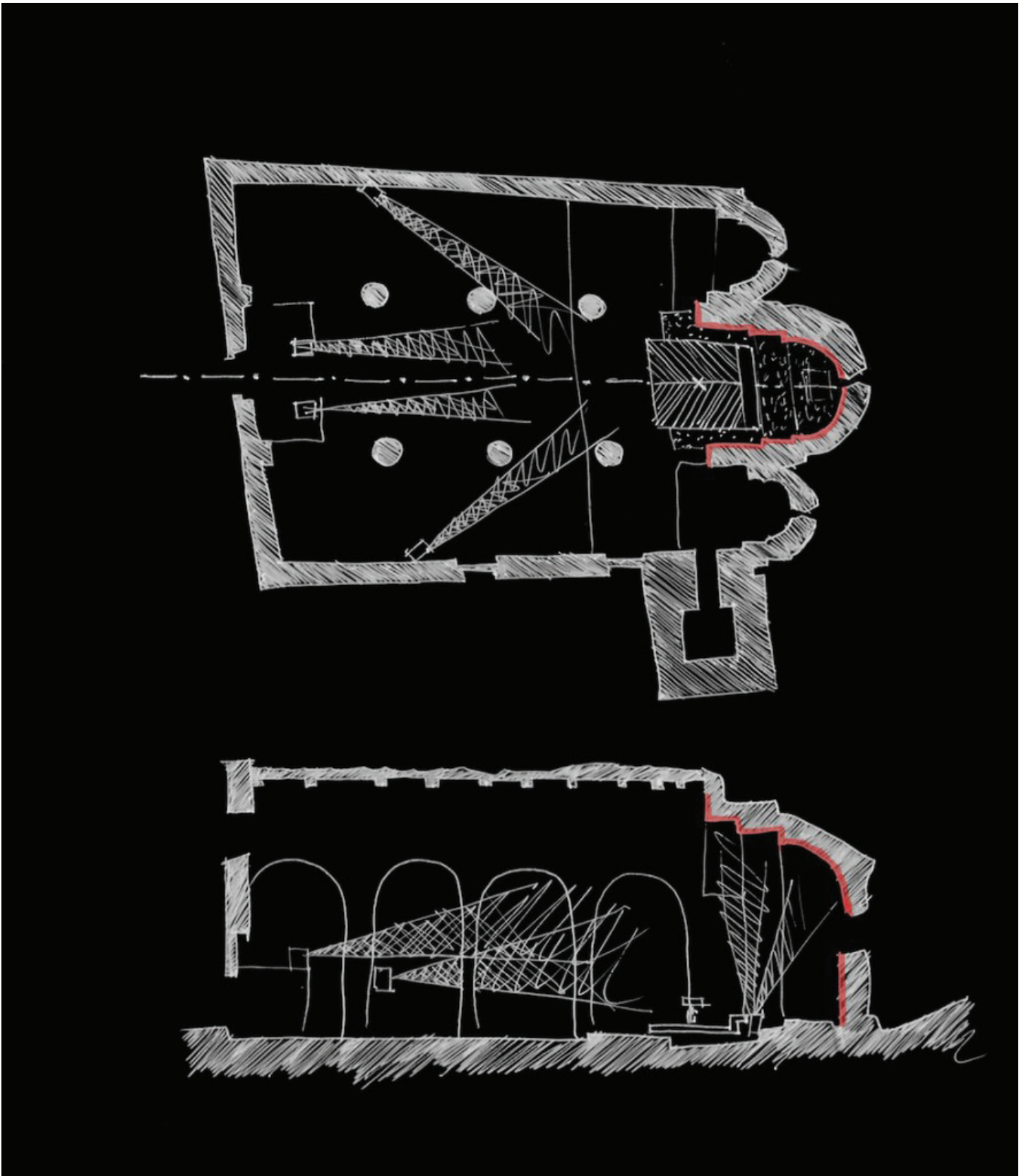
This project required extremely high precision in the mapping of digital projections since the 2D projections had to be matched to a range of challenging physical forms presented by the apse. Once the digital content was properly mapped, a series of calibration tests were required to ensure the accuracy of the projections. Two computers located above the reception provide the UI software Vioso's Wings AV system that allows a user to control the six synchronized projectors, lighting and audio equipment.

Physical

The ASR installation deploys six Christie E and G Series high definition projectors.¹²⁰ A total of 6 projectors are used to cover an area of about 100 square meters. The projectors are positioned with two at the church entrance above the reception, two concealed by metal supports in the side aisles, and two in the apse behind the flooring shown in Figure 17. Two of the projectors were positioned at the base of the apse and have angular optics to cover the majority of the central apse and the ceiling. On the sides of the naves, there are two additional projectors situated in vertical positions to cover the sides of the apse with through a mirror angled at 45°. The last two projectors are located over the church entrance to cover the lower and upper part of the central nave. The projectors are positioned at fixed positions with distances ranging from 50 feet maximum and 10 feet minimum from the wall. The projectors are placed at a maximum height of 15 feet, with the two nearest projectors positioned at floor level. The floor level projectors are concealed by the new flooring system, while the electrical components that connect the projectors and computers are situated above the main entrance of the church.

¹²⁰ Rajinder Sodhi. Saint Climent de Taüll – First Permanent Projection Mapped Church. 2014. From projection-mapping.org/mapping-sant-climent-de-taull/

Figure 17



Sketch showing distribution of the six projectors. Illustration: Burzon*Comenge.

4.4.3 Interaction

Navigation

The ASR installation is designed to allow visitors to freely navigate the church until the #taul1123 show is activated, at which point the darkness prohibits the user from moving in the augmented environment. As such, the ASR installation is perceived both from a fixed and changing point of view.

Flexibility

The content in the installation has a fixed narrative and is not flexible or adaptable amongst users. Users can only engage with the application at the pace of the fixed animation. The installation has the potential to benefit both experts and visitors with flexible interaction modes.

Comfort

The ASR installation does not require users to hold or wear a device allowing users to experience the site in a natural way. This means that extra efforts are not required to experience the ASR installation.

Safety and Security

While the ASR application is active, the darkness of the church presents safety concerns if not addressed by the application or site managers.

4.4.4 Content

Knowledge

The ASR project conceives a narrative for the site that transmits significant moments in the church's history, and the project allows visitors to engage with the site through various states in the cathedral's existence. The experience allows visitors to understand the walls first as they currently exist when the installation is not active in *phase 1*, the walls with the removed paintings as they exist in museums in *phase 2*, and a hypothetical reconstruction of the paintings as they were in 1123 *phase 3*. This animation provides an interpretation of the church from an "artistic" point of view, which could be supplemented by more scientific information for expert and public use. The preservation efforts of both the past and present could serve as an added layer of information about the site that would, in turn, serve to extend knowledge about the interventions over time. This strategy would also serve as a method of documentation for experts in the field. The intention of the installation is to transmit information about the monument without the use of words to help visitors to see different layers of the wall paintings. While the ASR experience gives the public a deeper understanding about the site's wall paintings, the animated approach is relatively abstract and not fully capable of providing clear information to users.

Information Organization

The ASR installation provides three phases of visualizations to offer diverse layers of information. In order to understand the ways that visitors engage with the monument, the project team conducted a study to determine the amount of time that visitors spend at the site.¹²¹ As a result, they determined that the digital projections should exhibit in three different sequences in cycles of thirty minutes. Phase 3 recreates the original paintings in the animation through a layer-by-layer sequence meant to reflect the original pictorial technique used by Master of Taüll. The storyline was devised in collaboration with the MNAC. First, the hierarchy of the painted subjects are outlined, and next, each character is individualized through the layer-by-layer building up of color. After the paintings are completed the projectors fade to darkness until spotlight reveals the remains of the site, which is meant to reflect the moment that the paintings were rediscovered. Finally, visitors are able to compare the digital and physical paintings as a beam of light scans the walls to reveal the physical remains of the site.

¹²¹ United Nations Education, Scientific and Cultural Organization. Catalan Romanesque. Center del Romànic de la Vall de Boí. Sant Climent de Taüll. Accessed at <http://www.centreromanic.com/en/church/sant-climent-de-ta%C3%BCll>

Accuracy

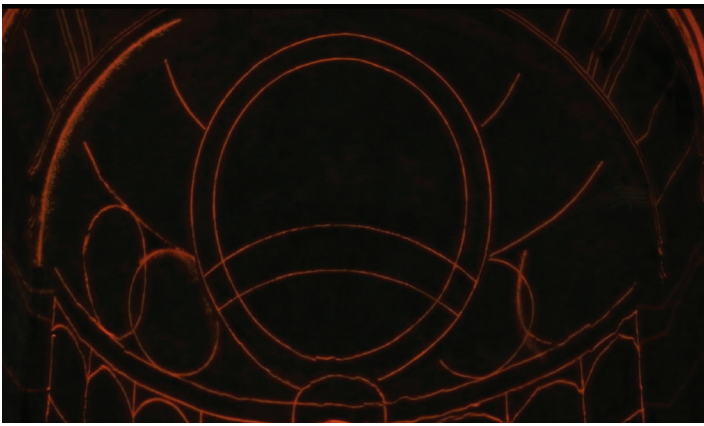
The apse of the church and its fragmented paintings, both in situ and in museums, were recorded in high resolution. The team produced a three-million-point 3D laser scan of the nave. They simplified the resulting point and rendered it into a mesh to use as a surface for the digitally projected paintings to be superimposed.¹²²

The painted fragments remaining on the church's walls were severely deteriorated, which required experts to digitally restore and redraw outlines based on comparisons to other preserved fragments. The church's apse contained paintings that followed patterns with precise rhythms and measurements from the Romanesque period, which provided some evidence on how to restore the paintings.¹²³ The fragments of the original paintings, now at the MNAC, were also studied, recorded, and digitally restored through an ana historical evidence and the remaining paint on the church walls.

While the goal of the ASR project was to create an accurate restoration of the church's paintings, a majority of the modeling relied on low-resolution or missing data that was derived from 2D photographic documentation and hypothetical research. For phase 2, employing techniques such as photogrammetry or 3D laser scanning would provide more detailed information about the relief of the paintings of existing fragments, and would make the digital visualizations and restoration more accurate. For instance, in addition to considering the brightness of the projected light in this phase, the color correspondence of digital objects to physical artifacts must be executed. The inaccuracy of the installation also results from lack of historical evidence about the paintings that have disappeared over time, which results in hypothetical restorations in phase 3. The accuracy of this phase should be determined by an expert that could undertake a scientific paint analysis.

¹²² Museums and the Web. #Taull1123. Immersive experience in a World Heritage Site (or augmented reality without devices). MW2015: Museums and the Web, 2015
¹²³ Ibid.

Figure 18



The different stages of the #taull1123 show. Image: From #taul1123 video

4.4.5 Findings

The ASR installation at Sant Climent de Taüll considered, engaged and communicated many dimensions of the physical site to ensure an appropriate preservation approach. Overall, ASR was an appropriate MR application for the site because it is equipped with the necessary electrical requirements to support the installation. The dark environmental condition of the church itself provided a controlled lighting situation for the digital projections. The requirements for the project were demanding for both technological and ideological reasons alike. In order for the artistic and architectural character of the church to be preserved, all ASR equipment had to be concealed from visitors. The physical design of the ASR installation ensured that projectors, lighting, and audio equipment were secured in a non-invasive and reversible manner, and required custom-designed mounts.¹²⁴ Furthermore, the restored paintings had to be projected with the maximum image quality for detail and color for the close correspondence to the original. The projected images had to align with the three-dimensional surface containing the remains of the original painting, and the digital replica seamlessly incorporated into the general restoration of the church. These guidelines were to be implemented so that the restored paintings would not be seen as an independent display, but rather a complementary mode of preservation that facilitates the artistic and architectural reading of the site.¹²⁵

In evaluation of the site's materials, the team of conservators tested the projected light to ensure it was within the recommended levels and not be damaging to the remaining paint.¹²⁶ The team determined that the intensity of the projection is actually less than that of the interior lighting in the apse. Visitors are able to view the materials and substances in phase 1 of the experience when the ASR installation is not activated, and also in the conclusion of the #taull1123 project as a beam of light broadens its focus and erases the projected visualizations to reveal the physical remains. This approach allows the church to remain interesting and meaningful even when the ASR is not activated. The execution of the design for this ASR project made it possible to vary the intensity of light for the projection to view the materials and substances of the site. This allows visitors to view the restored paintings both in complete darkness and also activated on and off at a lower intensity to guarantee the digital projections retain a harmonious continuum with the remains of the physical paintings seen in Figure 18. The interior lighting

124 Ibid.
125 Ibid.
126 Ibid.

Figure 19



Remains of original paintings shown on the left, with the restored digital paintings projected on the right. Image: Eloi Maduell

of the church was also designed in accordance to approach.

The navigation of the ASR application was investigated during the design phase of the project in order to determine the optimal activation time for each phase. As such, the project team determined that the remains should be shown in phase 1 for three minutes, then seventeen minutes for phase 2, followed by the ten-minute #taull1123 show.¹²⁷ The resulting sequence of the projections allows visitors to engage with the physical dimensions of the site without an augmented environment. The ASR installation is in permanent operation whenever the church is open to the public, however, in low

¹²⁷ Museums and the Web. #Taull1123. Immersive experience in a World Heritage Site (or augmented reality without devices). MW2015: Museums and the Web, 2015.

season the projections are only shown on demand for visitors in order to economize the system's life span. While the ASR installation is activated, it provides a new environment for visitors to interact and engage with the tangible dimensions of the site. In evaluation of the management and use of the site, MR returns the church's liturgical use and is now also open to visitors.

These use of powerful equipment ensures that the content is projected at a high resolution with accurate color. The first two phases of the project especially provide accurate visualizations that in turn allow the public to gain a deeper understanding about the site's tangible and intangible dimensions. In these two phases, the content is derived from recording and modeling techniques that produce accurately corresponding digital projections to original fragments. While the animation in phase 3 breaks down each layer of paint to reflect the original technique presumed to have been to create the original artworks, most of this content was derived from hypothetical assumptions about the techniques used by the Master Taull.¹²⁸ The installation plays recorded sounds of the valley accompanied by music produced from traditional medieval instruments such as fiddles, flutes, and psalteries is meant to evoke the feeling and spirit of the site. But, this audio content is neither authentic or scientific.

This project has the potential to incorporate new layers of information to provide more diverse knowledge levels for experts and the public by better transmitting all of the monument's dimensions. For example, the animation of #taull1123 would improved with more informative and less theatrical content. In order to increase the transmission of the church's significance, visualizations could show the moment in time when the paintings were first conceived and rediscovered, and the process of constructing the church, and other significant moments of its history. The existing 3D point cloud data of the church's 1959 replica could be mapped and projected over the physical remains of the restored apse. Also, the most recent conservation and restoration processes involved with preserving the site could be conveyed to increase and diversify knowledge levels for both visitors and experts.

In conclusion, the AR installation provides a solution for completing and preserving the church in a manner that is reversible and non-invasive. This project is a strong example showing that MR can accompany and enhance a range of physical preservation efforts. MR provides an innovative approach to both conservation and interpretation practices by blurring the line between the physical remains of the paintings and the digital restoration and now visitors can observe both conditions of the monument in a manner that is both revealing and concealing.

4.5 Conclusions

By examining and evaluating each case study through the matrix developed in this thesis, I argue that it is possible to compare the precedents even though each project approach has a varied set of preservation goals. While these AR and ASR case studies provide innovative MR approaches for preserving architectural wall paintings and their sites, as well as transmitting their significance, the ability for these projects to consider dimensions of cultural heritage varies. The use of ARtifact to preserve the frescoes at Salone dei Cinquecento is limited by its content and interaction techniques. While the application provides layers of data for an expert to view in situ, the use of AR does not provide a deeper understanding about additional dimensions of the physical site besides the design and materials.

Although ASR enhances the understanding of Le Domus di Romane Palazzo Valentini, MR techniques are limited in their capacity to consider, engage and communicate dimensions of the site. In this case, the projection mapping technique highlighted and describes artifacts, but was only used in several instances to restore or reconstruct missing fragments. Le Domus di Romane Palazzo Valentini installation provides a more “Disneyfied” experience to visitors due to the inaccuracy of the digital visualizations derived from hypothetical digital reconstructions. A major disadvantage for the Palazzo is the guided interaction that controls the ways a visitor engages with the site. Additionally, the dark environmental conditions prohibits visitors from fully understanding the complex ruins. In contrast to Le Domus di Romane Palazzo Valentini, the Sant Climent de Taüll ASR installation content is played in a loop so that visitors are able to freely navigate the augmented environment, and also engage with the church without ASR. The use of ASR at Sant Climent de Taüll completes the church by returning its wall paintings through digital projections, which is essential for understanding the monument in its entirety. After the church’s historical replica was removed, and its underlying paint consolidated, MR was a compelling strategy to re-contextualized the missing dimensions of the site. The design of the ASR installation in combination with the site’s physical restoration and conservation, allows the church to return its liturgical use. Overall, this case study was the most effective at authentically considering, engaging, and communicating all of the six dimensions of the site. In particular, the installation at Sant Climent de Taüll was especially successful at representing the spirit, feeling and traditions of the church.

This case study analysis reveals that the MR applications for these projects were executed in

tandem with other physical preservation efforts, demonstrating that MR has the capacity to enhance physical interventions by providing new innovative strategies for diagnosing, restoring and reconstructing significant architectural wall paintings. Furthermore, these precedents demonstrate the ways in which MR not only allows preservationists to expand possibilities for intervention once all physical range of actions have been exhausted, such as in the cases of Church of Sant Climent de Taüll and Le Domus di Romane Palazzo Valentini, but MR also allows experts to intervene digitally before carrying out a physical intervention shown in the Salone dei Cinquecento. While there are limitations to comparing precedents across applications (AR and ASR) and purposes (conservation and interpretation), analyzing the case studies through common aspects and dimensions provided a basic structure for evaluating the relationship MR and cultural heritage to guide preservation decisions. Overall, the matrix evaluation determined that the Sant Climent de Taüll case study is the most effective preservation project analyzed in this thesis to consider, engage, and communicate the authenticity of the site. While the case study serves as successful example of a MR project in the field, I argue that there is great potential for applications in the field to extend beyond these methods and provide increased scientific methodologies and techniques.

5.1 Purpose

In Chapter 3 of this thesis, I determined that there is an absence of standards and guidelines available for the use of MR in historic preservation. Chapter 4 of this thesis demonstrates that it is possible to evaluate an MR project's ability to consider, engage, and communicate dimensions of cultural heritage in an authentic manner. In order for experts in the field to grasp the layered concept of MR, a framework can be used as a tool to evaluate the relationship between MR and cultural heritage. In this chapter, I provide an organizational structure to guide the evaluation of MR and cultural heritage, which can be applied in the form of a "grid." I derived this approach from the *Nara Grid for Authenticity and Use* and adapted it to consider aspects of MR in a "test of authenticity." The first step of applying this framework is the close analysis of each MR aspect in a project; and next, using these findings the relationship between MR aspects and cultural heritage dimensions can be evaluated.

5.2 Application

In historic preservation, theoretical, regulatory and operational frameworks play a central role in decision making across the field. For example, the US Secretary of the Interior's Standards for the Treatment of Historic Properties is a series of non-technical principles for promoting best historic preservation practices to protect cultural resources.¹²⁹ The framework offers both regulatory and operational guidance for the management of cultural heritage by first outlining the standards, which are a series of concepts about maintaining, repairing, and replacing historic materials, as well as designing new additions or making alterations.¹³⁰ Next, the guidelines outline general design and technical recommendations to assist in applying the Standards to a specific property.¹³¹ Historic district and planning commissions across the country use the Standards and Guidelines to guide their design review processes, while state and local officials use them in reviewing both Federal and non-federal rehabilitation proposals. At the regulatory level, federal agencies also use the Standards and Guidelines as a framework for

75 National Park Service. Archaeology and Historic Preservation: Secretary of the Interior's Standards and Guidelines [As Amended and Annotated] revised 2017

130 Ibid.

131 Ibid.

carrying out historic preservation responsibilities.¹³²

In order to understand the application of this framework, it is important to turn our attention to the ways in which the proposed framework determines the “authenticity” of preservation project that employs MR, or in other words, whether the MR application provides a faithful and true perception of cultural heritage. The proposed framework serves as a “test of authenticity” for MR, which can be used in the field as a series of parameters for evaluating the outcome of all preservation efforts in recognition of universally shared values. This framework does not provide an absolute determination of authenticity because the evaluation of authenticity is qualitative.¹³³ And, since authenticity is not based upon fixed criteria, the framework offers a flexible structure that can be adapted across cultures and anticipate the development of technology over time. Furthermore, the framework is not a “one size fits all” approach, but rather is intended to provide a consistent conceptual approach to MR applications across the field. Although this framework attempts to make the evaluation of MR applications in historic preservation an objective a universal process, its practical application requires a certain degree of subjectivity. The first step of applying this framework is to identify and evaluate the three MR aspects provided in Chapter 2 which are as follows:

Figure 19

Design	Digital
	Physical
Interaction	Navigation
	Flexibility
	Comfort
	Security and Safety
Content	Knowledge
	Information Organization
	Accuracy

MR Aspects. Source: Author

¹³² Ibid.

¹³³ David Lowenthal, “Changing Criteria of Authenticity,” in “An Introduction to Authenticity in Preservation”, Pamela Jerome, APT Bulletin 39, no. 2/3, 2008 p.4

Design	How does the design of the MR application <i>consider</i> each dimension?
Interaction	How does the design of the MR application <i>engage</i> each dimension?
Content	How does the design of the MR application <i>communicate</i> each dimension?

After identifying and analyzing the three MR aspects, the design, interaction, and content of the application can be evaluated in order to understand a project’s ability to consider, engage, and communicate dimensions of cultural heritage for preservation. By evaluating each aspect and dimension, I determine MR guidelines for the historic preservation presented in Section 5.3.

Figure 20

	Design	Interaction	Content
Form and Design	How does the project consider the Form and Design of cultural heritage?	How does the project engage the Form and Design of cultural heritage?	How does the project communicate the Form and Design of cultural heritage?
Materials and Substance	How does the project consider the Materials and Substances of cultural heritage?	How does the project engage the Materials and Substances of cultural heritage?	How does the project communicate the Materials and Substances of cultural heritage?
Management and Use	How does the project consider, the Management and Use of cultural heritage?	How does the project engage the Management and Use of cultural heritage?	How does the project communicate the Management and Use of cultural heritage?
Techniques and Tradition	How does the project consider the Techniques and Traditions of cultural heritage?	How does the project engage the Techniques and Traditions of cultural heritage?	How does the project communicate the Techniques and Traditions of cultural heritage?
Location and Context	How does the project consider the Location and Context of cultural heritage?	How does the project engage the Location and Context of cultural heritage?	How does the project communicate the Location and Context of cultural heritage?
Spirit and Feeling	How does the project consider, the Spirit and Feeling of cultural heritage?	How does the project engage the Spirit and Feeling of cultural heritage?	How does the project communicate the Spirit and Feeling of cultural heritage?

MR Framework for Historic Preservation. Souce: Author

5.3 Framework Evaluation: Standards and Guidelines

The proposed framework provided a matrix to develop standards and guidelines for MR projects in the field. By closely evaluating the physical and digital design aspects required for both AR and ASR in relation to dimensions of cultural heritage, I determined MR techniques for preservation projects. In order to develop MR content that communicates each dimension of cultural heritage, it is important to first develop methodologies for accurately gathering and overlaying digital information. This approach is supplemented with guidelines on organizing information.

DESIGN

1. A simple UI allows users to easily understand their options for interaction, and also allows them to engage with the tangible and intangible dimensions of the physical site.
2. The design of physical equipment, including optical and electrical equipment, must consider the dimensions of cultural heritage. Optical and mechanical equipment for ASR can be bulky and should be placed in an inconspicuous and reversible manner.
3. Markerless registration and tracking should be prioritized for historic preservation projects that incorporate flat planar surfaces.
4. If physical markers are required for AR, they should be aesthetic and inconspicuous as to not detract from the presence and understanding of cultural heritage.
5. The concept of reversibility in MR projects ensures that experts can reestablish – in as unlimited a manner as possible – the previous condition of the site.

INTERACTION

1. The navigation of the MR application for cultural heritage must allow a user to move through the installation in a manner that considers the tangible dimensions of cultural heritage, such as its design, materials, and forms.
2. Both AR and ASR may be employed in environments that are not optimal for MR, including location and contexts with limited room to move around, or in environments that do not have large, flat surface areas. As such, practitioners must anticipate scenarios that present challenges and clearly communicate requirements and expectations to users up front.
3. AR and ASR each require different modes of interaction, so researchers must investigate the ways that visitors engage with a site in order to determine which application should be used

to enhance, rather than detract, from the cultural resource's spirit and feeling.

4. MR should be flexible between expert and public use, and users should also have the capability to activate and deactivate the application to engage with the site without its use.
5. Finally, visitors can compare the digital overlays with physical artifact with different opacity parameters.
6. Experts should consider varying sets of features for applications, and interaction methods must be based on the context. A user should be able to switch to different interaction methods.

CONTENT

1. In order to accurately communicate the different dimensions of cultural heritage, content should always be derived from the input of high resolution recording methods. The use of high quality and accurate content avoids the "Disneyfication" effect, in which MR installations are experienced as theme park amusement rather than legitimate interventions for historic preservation.¹³⁴ Disneyfication refers to an unauthentic representation or over-romanticization of cultural heritage. While an array of sensory components can contribute to the "theme park effect" the output of inaccurate and low-resolution data is the main contributor to this effect.
2. When digitally restoring and reconstructing artifacts, preservationists must conduct robust scientific and historical research.
3. If physical artifacts are not available for study, experts should create new content based on available artistic, social, historic, and scientific resources.
4. Digital objects must be scaled properly to the physical site and modeled to reflect environmental lighting conditions of the site.
5. Sensory features such as sound, smell and touch should be carefully designed so that they are appropriate for the spirit and feeling of the site.

To render this matrix more effective for making qualitative assessments, qualitative indicators can be applied to the framework to better compare to different projects. The score for the aspects or dimensions could be totaled in order to more accurately assess MR projects across the field. For example, each evaluated aspect and dimension could be assigned a score as follows:

- 5 - excellent
- 4 - very good
- 3 - acceptable
- 2 - need improvement
- 1 - poor

I conclude with the recommendation that MR should complete or enhance cultural heritage rather becoming the main focus. This means that AR and ASR should deepen the understanding of the dimensions of cultural heritage instead of becoming the main visitor "attraction." While this framework allows preservationists to determine if MR projects considers, engages, and communicates dimensions of cultural heritage, other indicators should be used to evaluate the effectiveness of projects in the field. This includes receiving visitor feedback about the MR experience, and perhaps most importantly,

¹³⁴ Cameron, Fiona, and Sarah Kenderdine. *Theorizing Digital Cultural Heritage : A Critical Discourse*, edited by Sarah Kenderdine, MIT Press, 2007.

monitoring the project over time to determine the preservation outcome.

6.1 Project Summary

Up until the twentieth century, colorful iconographic wall paintings covered the interior of the San Baudelio de Berlanga Hermitage. In an act of what Benito describes as “a sad point in the history of artistic spoliation in this country [Spain],” an art dealer removed the paintings and sold them to museums around the world.¹³⁵ Today, the monument only exists in parts and its original nature is now scattered in various locations; the structure remains in its location in Spain, and the wall paintings are displayed in different museums across the United States and Spain. From a conservation perspective, both the Hermitage and the wall paintings have had a complex history, yet the site and its fragments remain relatively stable today. A series of interventions in the building structure and immediate surroundings have been carried out in the last decades to control the excess of humidity in the walls in order to ensure the conservation of the paintings. Now displayed in museums, the paintings also remain in stable condition as they have been previously restored and preserved in controlled environments. Most of the painted surface that is still visible inside of the Hermitage results from later monument consolidation where the remaining paint was removed (in a more secure version of strappato), restored in Madrid, and re-inserted on the walls in the late twentieth century.¹³⁶

In recent years, site managers have implemented different approaches to improve the monument’s interpretation. In 2014, they created an off-site visitor center containing partial replicas and infographic representations of various medias. The experience of visiting the Hermitage is compelling yet incomplete. Although visitors can still appreciate the very subtle traces of the paintings on the wall, the absence of the wall paintings has reduced the monument’s authenticity and significance. This also applies to the removed paintings that are currently displayed without their architectural context. The paintings and the hermitage are now isolated works and what might be considered a masterpiece of medieval art and architecture, can now only be appreciated in fragments. When visiting the site in Spain, and visiting its paintings in museums, you one experiences the original objects, but not the authentic monument. This condition breaks the holistic intent of the Mozarabs that created the monument. Since the physical reintegration of both the structure and its paintings seems impossible, I propose MR as an alternative preservation treatment for the Hermitage San Baudelio de Berlanga.

In this thesis, I identified that there is an absence of standards and guidelines for MR applications

¹³⁵ Benito, Agustin E. San Baudelio de Berlanga Guia y Complementarios. (Published by Author) Soria, Spain: 2005

¹³⁶ This information was provided by my thesis advisor, who received this information from the site managers, although very little documentation exists for this intervention.

in the field. In Chapter 5, I argued that aspects of MR and dimensions of cultural heritage can be derived, characterized and used as a criteria for evaluating historic preservation case studies. In response to these findings, in this chapter, I demonstrate the way that these standards and guidelines can be applied to propose a MR project. First, I frame the preservation problem of San Baudelio de Berlanga Hermitage, and next, situate AR as an effective strategy to preserve the site. I begin by making recommendations for each MR aspect of the project, and next determine whether the proposed aspects contribute to the preservation and understanding of the hermitage through the 'test of authenticity' to evaluate the effectiveness of the application to consider, engage and communicate the complex dimensions of the monument and its parts. The purpose of this chapter is to propose an idealized MR application for historic preservation that serves as a model for other projects.

Figure 20



Blank walls inside of the hermitage. Image: Author

San Baudelio de Berlanga Hermitage

6.2 Project Overview

The San Baudelio de Berlanga Hermitage is an isolated, rural sanctuary in the Soria region of Spain. It is located approximately about 120 miles north of Spain's capital city, Madrid. The rural landscape isolates the site from nearby towns, and access is limited by one road. The Hermitage dates back to the late eleventh century, although the foundation of the original hermitage, is thought to have occurred during the height of medieval times (*the origin of the lands traditions*).¹³⁷ The Hermitage interior contains several paintings that depict when the monument was situated on a main hunting trail during a time when Spain was still heavily forested. The site of San Baudelio was historically a place where Muslims and Christians coexisted, and the architecture itself resembles both an Iglesia (church) and a Mezquita (mosque) referred to as a Mezquitilla. The palm tree, was a symbolic of exotic paradises, and ironically placed in the aired passage of Castilla, and was likely a metaphor the architect used to represent the crossing of distinct cultures that had taken place during those mystical dates.¹³⁸

Figure 21



Left: Site Exterior, two cubes joined on the rock hewn foundation. Right: Northern View from Site, the site overlooks the surrounding pastoral landscape. Images: Author

137 Benito, Agustin E. San Baudelio de Berlanga Guia y Complementarios. (Published by Author) Soria, Spain: 2005
138 Ibid.

San Baudelio remains an expression of aesthetic convergence between the Romanesque and Andalusian styles. One of its most significant architectural features is the contrast between the sanctuary's modest exterior, and extraordinarily colorful interior as nearly all of surfaces were once covered with vibrant paintings. The wall paintings of San Baudelio serve as important examples of the important integrated architecture styles that appeared during the Moorish rule in Spain.

Today, the hermitage retains its architectural simplicity and is characterized by two interconnecting cubes of different masses. The main cube, or the *nave*, is 8.5 by 7.3 meters, and the apsidal chapel is 4.10 x 3.60 meters. A horseshoe archway typical to Mozarab architecture is centrally located on the main facade. This arch contains the original heavy, wooden door. The structural shell of the building is constructed from rough-hewn stacked stone and mortar, and the Hermitage floor is carved from the hillside in monolithic stone. Gomez Moreno was one of the earliest writers to interpret that the interior style of the architecture based on characteristics of the represented liturgy.¹³⁹ The main interior space or nave is characterized by a 28 feet central column "palm tree" with branches that connect and support the vaulted ceiling. The column is a striking feature within the small hermitage due to the intensity of remaining paint.

Figure 22



Left: The palm tree column, still decorated with historic paint, provides the structural support for the ceiling, Right: Decorative motifs still remain on the archway of the apse. Images: Author

In the upper part of the column, nestled between the arches, there is a small cylindrical lantern covered by a dome of six crossed nerves, two by two, similar to the Muslim vaults of the Mosque in Cordoba. This area was allegedly used to store sacred scriptures and books. Beyond the central column is a colonnade that supports a choir balcony accessible by a rock-hewn staircase (now closed to the public for safety reasons). The small singular window at the balcony level provides light for the interior of the Hermitage. The adjoining cube is an altar connected by three steps. The altar cube contains a central alabaster window and also contains traces of wall paintings. Below the ground, in the southern corner of the hermitage, there is the access to the grotto or cave excavated in the rock by the primitive occupants.

Figure 23



Chior balcony. Image: Author

In 1866, San Baudelio was cited in ownership of Pedro Jose de Cae who passed it down to others until 1893, when it was acquired by twelve neighbors of Casillas, the closest neighboring village. The site was rediscovered in 1884 by a local writer who presented it to the Spanish Royal Academy of History.¹⁴⁰ In 1926, twenty-four of the wall frescoes from the Hermitage were sold to an antique dealer by art dealer Leone Leví who employed an Italian team to remove the paintings using the strappato method. After they were removed, the paintings were rolled and taken to London, where they were mounted onto canvas, restored, and framed. In February 1927, Gabriel Dereppe brought twenty-three of the paintings to New York. The wall paintings were sold to various art museums in several US cities including the Cincinnati Museum, the Cloisters section of the Metropolitan Museum of New York, the Art Museum of Indianapolis and the Museum of Fine Arts in Boston. Smaller elements from the hermitage including scenes of hunting and falconry and decorative copies of textiles are on display at the Museo del Prado in Madrid, Spain. Two sections showing the *Entry of Christ into Jerusalem* and the *Wedding at Cana* are now on canvas in the Indianapolis Museum of Art. Other sections, including *The Healing of the Blind Man and the Raising of Lazarus* and *The Temptation of Christ by the Devil* and the Muslim motif inspired *Camel* also on display in the Cloisters.

Figure 24



Left: *Camel* ca. 1129-34 (97 x 53 ½ inches) The Cloisters Collection, 1961. Top: *The Temptation of Christ by the Devil* ca. 1129-34 (69 ½ x 118 inches) Right: *The Healing of the Blind Man and the Raising of the Lazarus* ca. 1129-34 (65 x 134 inches). Images: MET Website

140 In 1884 Elias Romera was published in “el Boletín de la Real Academia de la Historia” and described the medieval art present at San Baudelio. Later, Anibal Alvarez’s wrote about the paintings on the walls of the hermitage in 1907.

Figure 25



The traces of remaining paint from the *Healing of the Blind Man and the Raising of Lazarus*. Image: Author

MR offers a non-invasive and reversible strategy for preserving the San Baudelio de Berlanga Hermitage. The proposed MR application would serve as an interpretation tool that not only returns the paintings to the site but also provides a deeper understanding about the monument's significance and transformation over time with additional layers of scientific and historical information. An expert could also collect additional types of technical and scientific data for extended conservation purposes. This proposal outlines how the *Camel* painting now on display at the MET Cloisters can be digitally re-inserted onto the walls of the hermitage using MR, along with additional layers of information for both experts and visitors to foster deeper understandings about the site. I propose the *Camel* painting is proposed first as a pilot project, while the rest of the paintings now in museums can be gradually re-inserted over time. This project should be carried out in phases because it requires the collaboration of different institutions. The main focus of this proposal is to apply the framework from Chapter 5 to propose an MR as a preservation strategy for the hermitage. In order to use this framework as a guide for this proposal, I first selected the appropriate MR application for this project. I argue that AR is the most effective and appropriate MR application in consideration of the site's tangible and intangible dimensions. By selecting AR as the project approach, I was able to make decisions about the appropriate design, interaction and content techniques for this complex monument.

San Baudelio de Berlanga Hermitage

6.3 Design

Digital

For this project, a simple UI provides users with an intuitive experience of the augmented environment and means that visitors do not have to learn how to operate a new system. Using a similar UI to ARtifact's approach would provide users with a standard interface that is both minimal and graphic. The UI should use simple slider elements allow the user to adjust various parameters of the visualization, such as overlay opacity and camera zoom. The ability for users to change the opacity of content will allow experts to compare the physical frescoes with related data. Registration and tracking possibilities offered by planar targets could be used for the flat surfaces of the hermitage walls. The rear-facing camera on AR devices will provide the "see-through" functionality of the interface, which renders unmodified video stream as the background for subsequent digital overlays.¹⁴¹

Physical

Site managers could supply tablets to the visitors to use, and offer the application for download and installation on personal devices. The provided tablets should be equipped with the highest resolution rear-facing camera as possible (usually means the newest model of Apple or Android operating systems). AR encourages collaborative experiences and site managers should investigate the optimal number of devices to have on site for visitors. Although devices with larger screens provide larger displays for users to view content, they are not ergonomic. On-site tablets should be no larger than 10 inches.

¹⁴¹ Vanoni, David. et. al. ARtifact Conservation:Representation and Analysis of Spectroscopic and Multi-spectral Imaging Data Using Augmented Reality.

Figure 26



Conceptual image showing a digital overlay of the *Camel* painting in situ. Image: Author

San Baudelio de Berlanga Hermitage

6.4 Interaction

Navigation

The AR application will facilitate interaction between users and the augmented environment by indicating locations with digital content. Users will be encouraged to explore the monument without AR at the beginning of their visit so that they can become familiar with their surroundings. A user would begin navigating the augmented environment by activating the application and selecting the interaction mode and layer to view from the layers list, similar to the application ARtifact. By aiming the tablet camera at the indicated surfaces of the hermitage, the application will load the corresponding digital overlay. For example, a user would first position the camera at the wall where the *Camel* painting is located, and the application would detect, register and track the layers of information to this target. In order to better investigate the data, a user should pan and zoom with standard multi-touch gestures. This interactive approach encourages different users to collaborate simultaneously while performing comparative analyses on the hall.

Flexibility

The advantage of AR is that visitors will have a personalized interaction with the monument because they have the option to 'opt-in' to view the MR installation. This means that the monument can be experienced with or without the activated AR environment. The AR application will have different interaction modes for different users. Experts should be able to switch interaction modes to add annotations and view scientific content.

Comfort

Users will have that capability to freeze information on the device so that they do not have to keep arms raised for long periods of time.

Safety and Security

Security measures for the AR application would ensure personal information is secured when providing visitor feedback. Safety messages should appear at the startup of the application to warn visitors of potentially hazardous scenarios, such as the uneven of the ground.

6.5 Content

Knowledge

With the aid of AR, users should be able to better understand the significance of the site. Experts should guide the creation of content, and consider the public for language. In order for expert and visitors to use the application, it should provide diverse levels of information that can be used for conservation and interpretation purposes alike. This can be achieved through both graphic and narrative information. Historic and artistic content provide the public with additional knowledge of the site in an intuitive way. The use of scientific data allows experts in the field to document and monitor the hermitage in situ over time. This proposal's most basic principle is to consider the public for language, and the experts for content.

Information Organization

The information presented in the application must be organized so that a user can easily navigate through content in a logical sequence. Each user should have the ability to personalize content within the augmented environment. By selecting different "layers" on the UI with a simple gesture, users can preview and select overlays. Narrative captions can be used to explain the content on each activated layer. Users would also have the option to listen to audio narration through headphones. The layers of information provided by the application should be presented in file hierarchy of pre-recorded and processed data in the following sequence:

Layer 0

The existing walls of the hermitage will be displayed as they exist in real-time. Users will have the ability to magnify details of the physical site that are far away or inaccessible.

Layer 1

The original techniques that Master Taull used to create the wall paintings will illustrate the artist's technique to create the iconography by building up paint layer by layer.

Layer 2

Through narrative captions, the application will interpret the iconography and pictorial depiction of the *Camel* painting. The same approach can be taken for the rest of the painted figures and architectural features. For example, the application could explain that the column represents an exotic and mythical tree, which represents safety and refuge in the medieval iconography of Christian and Muslim religions.

Layer 3

Historical and scientific research provides evidence about the appearance of the paintings when they were completed in the 12th century. Using this evidence, the *Camel* painting can be digitally restored, similar to the approach shown below in Figure 27.

Layer 4

Historical photographs, such as the image in Figure 28, provide documentation of the wall paintings' condition before they were removed in the twentieth century. Experts can use this information to digitally restore the wall paintings to their condition in 1920.

Layer 5

A combination of narrative text and animations demonstrate the original technique used to removed the paintings in the twentieth century. The art dealer Levi, and his team, used the strappato method to removed the monument's paintings, which involved saturating a mesh-like cloth with a glue substance to superficially remove the top layer of paint.

Layer 6

A combination of narrative text, images and animations demonstrate the technique used to remove, consolidate and re-situate the paintings in the twenty-first century

Layer 7

The 2D paintings can be digitally recorded as they currently exist on canvas in museums using composite color photography to derive accurate color information. Activated at a lower opacity, the overlaid color will have the appearance that it is superimposed onto the hermitage walls.

Layer 8

The layering of 2D color information from Layer 6 and 3D surface relief of the painting will allow users to view the paintings in greater detail and accuracy to illustrate their transfer from wall to painting. This method also allows users to analyze the current condition of the off-site paintings.

Layer 9

Experts can add layers of scientific information, such as previously captured thermography and x-ray data, to further analyze the complex conservation state of the site and its paintings in situ. Narrative captions can describe each content layer to users.

Layer 10

Experts will have the ability to add annotations to each layer of information, which can be securely stored in a database on the device or a data storage cloud.

Figure 27



Digital Restoration of Decorative Wall Painting Fragment from San Baudelio. This approach can be translated to the paintings proposed for this project. This process requires the expertise of an art history researcher. Image: Factum Foundation (2016)

Figure 28



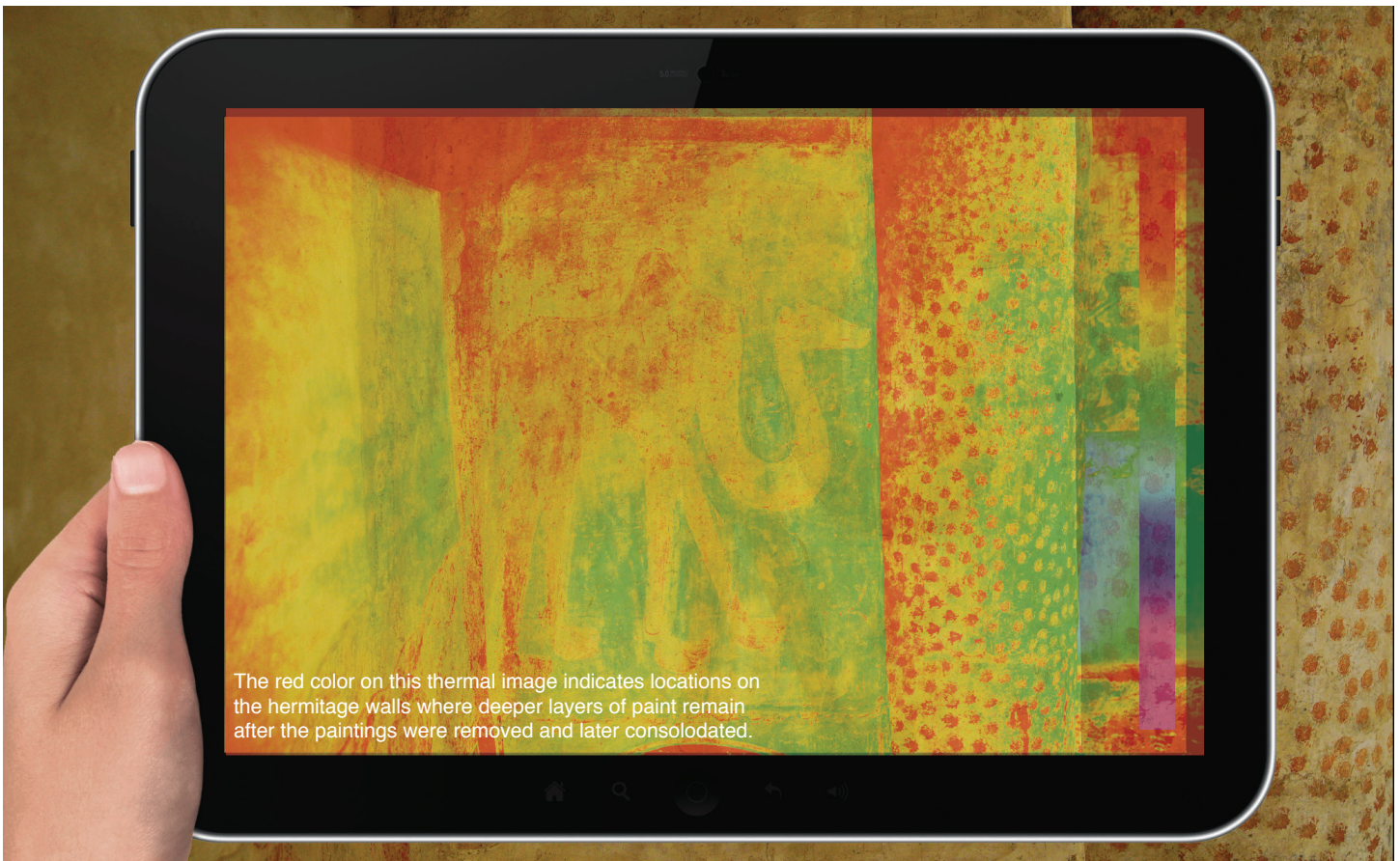
Historic photo showing the Healing of the Blind Man in its original location and condition, ca. 1920. Image: Juan Cabre Aguil

Figure 29



Left: Partial Lucida 3D Scan of Camel, Middle: Partial 2D Color Composite Photography, Right: Partial Registered 3D Surface Relief and 2D Color. These layers of digital data can be combined to reflect the accurate appearance of the paintings. Images: Factum Foundation (2016)

Figure 30



Conceptual image showing overlaid thermal data of the *Camel* at the hermitage with captions.
Image: Author

Accuracy

In order for the proposal to be carried out with the highest level of accuracy, the paintings and the hermitage interior should be digitally recorded both in 3D (shape and texture) and 2D (color). High-resolution data collection of the hermitage will provide accurate 2D and 3D information to register and track digital objects. Once the data has been obtained, it must be accurately processed and modeled for the application. In addition to these techniques, in-depth historical and scientific research must be undertaken for any digital restoration work.

The devices camera will accurately register and track digital overlays by detecting features from the video stream through descriptions stored within the application. To ensure the proper alignment of these layers when superimposed onto the physical walls of the site, the application requires that each layer of data is previously converted into a TIFF image and edited to be accurately aligned. Moreover, the applications should automatically scale digital objects projected onto the hermitage.

Figure 31



Conceptual image showing the accurate overlaid 2D data of the *Healing of the Blind Man*.

Image: Author

San Baudelio de Berlanga Hermitage

6.6 Proposed Methodology

Phase 1

Conduct historical and scientific research required to model data for layers 1-5

This project requires the investigation of both primary and secondary resources to accurately communicate the dimensions of the site in its entirety. Primary resources include other artworks by Master Taüll, as well as historic photographs and documentation that illustrate the previous conditions of the paintings, as well as removal and conservation techniques. Secondary scholarly resources also provide content information.

Phase 2

Record the interior of the hermitage to provide a 3D surface for superimposing digital overlays

A FARO laser scanner will be used to obtain an accurate digital 3D model of the Hermitage interior. The surface detail of the walls can be recorded at a higher resolution with the aid of photogrammetry. The resulting point clouds from these scanning processes can be simplified and converted into a mesh that acts as a surface for superimposing digital objects.

Phase 3

Digitally record the paintings, now in museums, in 2D and 3D

The 2D color of the Camel can be accurately obtained in high resolution through the use of composite photography. The 3D information of the painting can be scanned using a 3D laser scanner, such as the Lucida, or through photogrammetry.

Phase 4

Obtain diagnostic imaging of paintings and the hermitage

Digital thermal and x-ray data of areas of interest in the hermitage, and the paintings can be recorded, processed, analyzed, and overlaid onto the physical site.

Figure 32



Previously recorded composite color photography. Image: Factum Foundation (2016)

Phase 5

Design AR application

The design for the UI, as well as registration and tracking processes for aligning digital overlays, can be carried out through the use of accessible AR platforms, such as ARKit or ARCore. The selected platform determines the corresponding operating system and physical equipment that should be used for the application.

Phase 6

Install AR application

Once the design phase of the application is completed, it can be installed on a tablet device for testing.

Phase 7

Test the application on-site

The testing process should ensure that objects are accurately detected, registered, and tracked to the physical site. After the application has been successfully installed onto devices, it should be tested on-site to ensure that it works properly. Any issues should be resolved before its release to visitors.

Phase 8

Repeat phases 3-7 for other paintings

After the Camel has been successfully carried out as the pilot project for the application, the other paintings can be sequentially added, starting with the two remaining paintings at the MET Cloisters.

Figure 33



Author conducting on-site research and testing at the hermitage. Image: Author

6.7 Recommendations

This idealized proposal illustrates the best practice and approach for implementing MR as a preservation strategy for the hermitage based on the matrix provided in this thesis. By comparing the idealized proposal to the evaluated case studies, I argue that this project has the potential to be the most effective MR preservation approach to consider, engage, and communicate each complex dimension of the monument. By examining proposed AR techniques for this project and the multi-faceted dimensions of the hermitage, this proposal models best practices for applying MR as a preservation strategy in an authentic manner.

The digital components of the proposed AR project demonstrate that the UI, registration and tracking techniques can consider each dimension of cultural heritage and do not detract from the natural experience of the site. I propose that a simple UI will allow users to easily understand their options for interaction, while allowing them to fully engage with the dimensions of the site. The UI should use simple slider elements allow the user to adjust various parameters of the visualization to engage with the form and design of the site, such as overlay opacity and camera zoom. The ability to control the opacity of the digital visualization blurs the line between the physical materials and the digital overlay as visitors can observe both conditions in a sequence that is both revealing and concealing.

In consideration of the application's physical design, the hermitage will maintain its origin traditions through the continued transmission of the site's significance through both graphic and narrative content displayed in the AR application. The video see-through AR approach means that a user does not have to shift their attention away from features of the monument to view content. With the use of planar targets, a non-invasive approach for registration and tracking can be take since the cubic form of the structure provides many flat planar surfaces. The mobile devices used to support AR at the site should be equipped with highest resolution cameras that will allow the application to augment accurate results, which in turn will allow users to have a deeper understanding about the physical dimensions of the hermitage.

Digital content should only be provided in appropriate areas of the site that support interaction. Some areas of the hermitage are not optimal for AR, such as in areas with limited room to move around, or where there aren't large, flat surface areas. Experts must anticipate scenarios that present challenges, and clearly communicate requirements or expectations to users up front. For example, the

steps to the chapel apse and choir balcony along with its colonnaded supports are hazardous areas of the site. In order to ensure user safety and physical integrity of the site safety warnings should caution users about potential risks. Site managers should store the tablets in the ticketing kiosk until visitors request their use. Sensory features such as sound should only be activated through personal earphones. Ultimately, the design approach for AR is in keeping of spirit and feeling of the monument because it is more appropriate for the quiet and tranquil environment than equipment required for ASR. And, like cultural heritage, the devices for the AR application will require ongoing maintenance and management over time.

Figure 35



Left: The steps up to the apse, Right: Colonnade balcony support. Both of these areas present hazards to AR users navigating in the hermitage. Images: Author

The different features of the AR application should be derived from studies about how users engage with the site without the use of the application. Flexibility not only allows the MR application to be adapted for different users (experts vs. public), but the augmentation can be activated and deactivated so that users can experience the monument with or without the use of MR. Users should be able to switch to different interaction methods and content types. Instead of incorporating audio in the AR application for alerts and indicators, vibrations might be used to maintain the nature of the monument.

The ASR installation at the hermitage is essential to communicating the dimensions of the monument in its entirety. The digital overlays used in the application should be derived from accurate data collection methodologies. The digital overlays must be scaled properly to the hermitage walls and modeled to reflect the darker environmental lighting conditions of the site. The colors used for the overlay must correspond to the original fragments of the paintings. Approachable terminology should communicate the monument and its paintings over time. Graphic and narrative content can be used

to explain the techniques and traditions involved with creating and preserving the hermitage and its paintings over time. The strappato process involved with the removal of the paintings in the twentieth century can be demonstrated in the application in graphic or narrative form. Similar to the Sant Climent de Taüll project, the application can overlay layers of paint in a sequential manner to reflect Master Taüll's technique, but in a more precise and clear manner. While the proposed design, interaction, and content techniques are intended to increase the understanding about the dimensions of the site, one of the most important aspects to consider is that the application allows the hermitage to maintain its use today as a spiritual sanctuary.

7.1 Conclusion

In this thesis, I determined that digital technologies provide new methodologies for preserving cultural heritage. The advancement of these methodologies will continue to play a critical role in the development of MR in the field. As stakeholders in historic preservation continue to focus their attention on digital technologies for advancing the field, innovations in high-resolution recording, processing and reproduction capabilities will allow for a more seamless integration of a digital environment. Both the case studies and the proposal in this thesis demonstrate that MR allows preservationists to expand possibilities for intervention once all physical range of actions have been exhausted. In the case of the Salone dei Cinquecento, AR created a mixed environment for experts to better understand and diagnose cultural heritage; and for Le Domus de Romane Palazzo Valentini and the Sant Climent de Taüll, the use of ASR allowed experts to provide the public with deeper understandings about cultural heritage. These case studies illustrate the capability for MR to engage every dimension of cultural heritage, which in turn increases its effectiveness for the preservation of cultural heritage. Since notions of authenticity are constantly evolving over time, the non-contact characteristic of MR provides new preservation approaches that do not compromise the physical integrity of a site or contact.

Although MR presents new opportunities to enhance practices in the field, the literature review for this thesis determined there has been very published studies on the application of MR to the field of historic preservation. The absence of standards, guidelines, techniques and evaluation methods for the field make it difficult to provide innovative and authentic preservation strategies. As a response to these challenges, I proposed a framework for MR that can be applied as a matrix to evaluate existing historic preservation projects. The proposed framework is an organizational structure for examining the relationship between the researched concepts of MR and historic preservation. These criteria form the 'test of authenticity' for AR and ASR projects in the field.

Finally, using the guidelines provided by the framework, I proposed an innovative strategy for the complex preservation case of the San Baudelio de Berlanga Hermitage in the province of Soria, Spain. Not only does this proposal demonstrate the ways that AR can be used as a preservation strategy to complete the site in an authentic manner, the proposal also offers a basic methodology for carrying out an MR projects in the field. This proposal serves as a model for MR projects in the field. In conclusion, this thesis contributes an in-depth investigation and MR framework for the field that historic preservationists can adapt over time.

Le Domus di Romane Palazzo Valentini ASR Framework Evaluation: Cultural Heritage Dimensions for Authenticity and Use

	Design	Interaction	Content
Form and Design	<p>The transparent glass platforms and staircases, in addition to projectors, lighting and curtains and sound equipment, were designed to be non-invasive, but the final design of these components starkly contrast the ruins and interfere with the form and design of the site.</p>	<p>Interaction with the form and design of the site in the augmented environment is immersive, yet limited by the physical infrastructure.</p>	<p>At the end of the installation there is a short multi-media presentation that describes the transformation of the site's form and design since the 15th century. Ultimately, this approach is disconnected from the ASR installation. This information has to potential to be more effective if it is incorporated into the ASR installation.</p>
Materials and Substance	<p>The dark condition of the site only allows visitors to engage with the materials and substances as projected light actively highlights the ruins. For brief moments during the tour the lights are turned on for visitors to examine the remains, yet these environmental lights are more harmful to the materials and finished compared to the projector lights.</p>	<p>The increased visitation to the site potentially presents concerns to the conservation of the archeological ruins.</p>	<p>The inaccuracy of the content causes the installation to become a "disneyfied", meaning that the graphics do not represent the true appearance of the historic design and materials of the Domus.</p>
Management and Use	<p>The digital and physical design of the ASR installation is closely managed and maintained by museum staff members.</p>	<p>Due to the sensitive location of the museum, on royal grounds beneath the Palazzo Valentini, there are many restrictions imposed upon visitors to control navigation of the installation.</p>	<p>The accuracy and resolution of accuracy appears outdated, and it would be useful for site managers to develop a plan for updating the content in the installation as more research is undertaken for the site.</p>

Techniques and Tradition

Audio narration communicates the techniques involved with the site's transformation over time.

n/a

Not only does the content in the ASR museum communicate the techniques traditionally used to create the Roman Domus, but also the methods for uncovering and stabilizing the archaeological remains.

Location and Context

The ASR museum continues to provide a covered indoor environment beneath historic structures.

There are many restrictions imposed upon visitors to control navigation of the installation due to the location of the museum, and the guided nature of the installation prohibits visitors from freely navigating the museum. Visitors are also prohibited to take photos inside of the museum, which decreases the monument's knowledge production.

The information transmitted in the installation is not only meaningful and relevant for the Domus ruins, but also to the historically significant Palazzo Valentini situated above the museum.

Spirit and Feeling

The digital and physical design components in the installation change the spirit and feeling of the original site because ASR is the main attraction of the site.

The installation is meant to evoke the original spirit and feeling of the historic ruins. Yet, visitor interaction with the ASR installation is more immersive rather than interactive.

To evoke the spirit and feeling of the original site, over-romanticized audio clips of rain, fire, and earthquakes play in the installation, making the site feel more like a theme park than a museum.

Framework Evaluation: Cultural Heritage Dimensions for Authenticity and Use

	Design	Interaction	Content
Form and Design	By examining pre-recorded thermal data of the fresco wall, experts were able to identify an archway within the wall of the hall that is now filled with bricks and otherwise impossible to see.	With ARtifact, interaction in the augmented environment is fixed to the display and only allows for analyses on one wall of frescoes. This limits the users ability to engage with the other dimensions of the site.	While ARtifact can currently track planar targets limiting experts to only analyze the hall in a two-dimensional view. Developers hope to extend the capabilities to support analysis of three-dimensional artifacts in the hall from any viewing angle. This opens up new possibilities for augmenting complex 3D objects.
Materials and Substance	The digital overlays and low camera resolution of the tablet make it difficult for users to engage with the materials of the frescoes in detail.	The ability for users to change the opacity of content allows experts to compare the physical frescoes with related data in order to understand the materials of the physical site	For a closer analysis of the materials of the wall and frescoes, experts have the ability to precisely define locations to enables a refined investigation of an specific area.
Management and Use	The application provides a means understand the relation of the concealed archway within the existing hall. With the use of AR, a user can go into the site and use the application to reveal exactly where the archway resides in live view.	An advantage of the AR application is that users do not have to crowd around a single hand-held display since each can operate their own tablet and have full control over navigation. The tablet-based approach promotes collaborative analysis among multiple users.	Experts are able to focus on the hall while exploring previously recorded data, such as thermography data of the fresco, allowing them to identify and locate damaged areas.
Techniques and Tradition	n/a	n/a	The application would be more effective to diverse user groups if it described in narrative or graphic form the techniques used for the hall's renovation and conservation over time.
Location and Context	The application allows experts to visualize the entire wall in which Vasari's frescoes are located, with an augmented area of about 10,000 square feet.	Instead of viewing this data in the lab, ARtifact enables users to move around the hall in a more interactive and accurate manner for analysis.	Additionally, the application requires a user to have previous knowledge about the historical context of the site. Since the application does not provide this context, new users may be unable to understand what they are looking at without having to conduct prior research.
Spirit and Feeling	The AR approach of this project means that users opt-in to view the augmented environment, which maintains the natural experience of visiting the Salone.	n/a	The application is used to transmit scientific information and its purpose is not necessarily to evoke the spirit and feeling of the monument.

Framework Evaluation: Cultural Heritage Dimensions for Authenticity and Use

	Design	Interaction	Content
Form and Design	<p>The dark environmental condition of the church itself provides a controlled lighting condition for the digital projections. The projectors are placed in a manner that allows them to remain hidden from public sight, in niches or corners formed by the architecture itself.</p>	<p>The apse is the only area within the church that displays the digital projections.</p>	<p>The digital projections are accurately and precisely mapped to the physical forms of the church's apse.</p>
Materials and Substance	<p>The execution of the design for this ASR varies the intensity of projected light allowing visitors to view the materials and substances of the site</p>	<p>Visitors are able to view the materials and substances in phase 1 of the experience when the ASR installation is not activated, and also in the conclusion of the #taull1123 project when a beam of light broadens its focus and erases the projected visualizations to reveal the physical remains</p>	<p>These use of powerful equipment ensures that content is projected at a high resolution with accurate color.</p>
Management and Use	<p>The project team of conservators tested the projected light in order to ensure it would not be harmful to the remaining paint within recommended levels. The team determined that the intensity of the projection is less than that of the interior lighting in the apse.</p>	<p>MR facilitated the return of church's liturgical use, and is now also open to visitors. The ASR installation is in permanent operation whenever the church is open to the public, however, in low season the projections are only shown on demand for visitors in order to economize the system's life span.</p>	<p>The ASR content restores the monument in its entirety, and this preservation approach allows the church to operate as a museum for visitors.</p>

Techniques and Tradition

The physical design of the ASR installation requires that the projectors, lighting and audio equipment are secured in a non-invasive and reversible manner, requiring the fabrication of custom designed mounts

n/a

While the animation in phase 3 breaks down each layer of paint to reflect the original technique presumed to be the method to create the original artworks, most of the content for this phase was based from hypothetical assumptions about the techniques used by the Master Tauli

Location and Context

Overall, ASR was an appropriate MR application for the site because the church is equipped with the necessary electrical requirements to support the installation.

The navigation of the ASR application was closely investigated during the design phase of the project. First, the team studied the amount for the activation of the ASR experience and determined that the remains should be shown in phase 1 for three minutes, then seventeen minutes for phase 2.

The first two phases of the project especially provide accurate visualizations that in turn allow the public to gain a deeper understanding about the site's context and significance

Spirit and Feeling

n/a

The phased approach of the content allows visitors to engage with the spirit and feeling with the capability to engage with the site without MR.

While audio that plays therecorded sounds of the valley accompanied by music produced from traditional medieval instruments such as fiddles, flutes, and psalteries is meant to evoke the feeling and spirit of the site, the recorded content is ultimately more theatrical than scientific.

San Baudelio de Berlanga Hermitage

Framework Evaluation of Cultural Heritage Dimensions for Authenticity and Use

	Design	Interaction	Content
Form and Design	AR reduces the need to secure bulky physical equipment to the hermitage. For the design of the application itself, the UI should use simple slider elements allow the user to adjust various parameters of the visualization to engage with the form and design of the site, such as overlay opacity and camera zoom	Some areas of the hermitage are not optimal for AR, such as in areas with limited room to move around, or where there aren't large, flat surface areas, and digital content should only be provided in appropriate areas that support interaction.	The content should describe and relate the iconographic paintings to the forms of the site. For example, graphic and narrative techniques can interpret the liturgical symbology of the central column, which is compared to a palm tree to represent a place of refuge.
Materials and Substance	The ability to control the opacity of the digital visualization blurs the line between the physical materials and the digital overlay as visitors can observe both conditions in a sequence that is both revealing and concealing	Flexibility not only allows the MR application to be adapted across different users (experts vs. public), but the application can be activated and deactivated so that users can experience the physical remains of monument with or without the use of MR.	The colors used for the overlay must correspond to the original fragments of the paintings.
Management and Use	In consideration of the application's physical design, the video see-through AR approach means that a user does not have to shift their attention away from features of the monument to view content	Experts must anticipate scenarios that present challenges, and clearly communicate requirements or expectations to users up front. Users should be able to switch to different interaction methods and content types. Instead of using audio in the AR application for alerts and indicators, vibrations could be used to maintain quiet nature of the site.	The application must allow the hermitage to maintain its use today as a spiritual sanctuary.

Techniques and Tradition

The hermitage will maintain its traditions of origin by continuing to transmit information about the site through graphic content displayed in the AR application.

Interactive gestures can allow users to gradually rebuild the layers of paint on the hermitage walls in a sequence similar to the original techniques used to create the paintings.

Graphic and narrative content can be used to explain the techniques and traditions involved with creating and preserving the hermitage and its paintings over time. The strappato process involved with the removal of the paintings in the twentieth century can be demonstrated in the application in graphic or narrative form. Similar to the Sant Climent de Taüll project, the application can overlay layers of paint in a sequential manner to reflect the Master Taul's technique, but in a more concise and clear manner.

Location and Context

With the use of planar targets, a non-invasive approach for registration and tracking can be taken since the cubic form of the structure provides many flat planar surfaces.

The steps to the chapel apse and choir balcony along with its colonnaded supports are hazardous areas of the site. In order to not only ensure user safety, but also the physical integrity of the site, safety warnings should caution users about site hazards.

The digital overlays must be scaled properly to the hermitage walls and modeled to reflect the darker environmental lighting conditions of the site.

Spirit and Feeling

AR is a more appropriate MR application for the monument in comparison to ASR, because this approach allows users to opt-in to view the augmented environment, which maintains the natural experience of visiting the sanctuary in a manner that maintains the quiet and tranquil environment.

Sensory features such as sound should only be activated through personal earphones.

In order to maintain the spirit and feeling of the site, the application content should explain the spiritual function of the sanctuary today.

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