5-2016

City-Scaled Digital Documentation: A Comparative Analysis of Digital Documentation Technologies for Recording Architectural Heritage

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CITY-SCALED DIGITAL DOCUMENTATION: A COMPARATIVE ANALYSIS OF DIGITAL DOCUMENTATION TECHNOLOGIES FOR RECORDING ARCHITECTURAL HERITAGE

A Thesis
Presented to
the Graduate Schools of
Clemson University and the College of Charleston

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Historic Preservation

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by
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May 2016

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ABSTRACT

The historic preservation field, enabled by advances in technology, has demonstrated an increased interest in digitizing cultural heritage sites and historic structures. Increases in software capabilities as well as greater affordability has fostered augmented use of digital documentation technologies for architectural heritage applications. Literature establishes four prominent categories of digital documentation tools for preservation: laser scanning, photogrammetry, multimedia geographic information systems (GIS) and three-dimensional modeling. Thoroughly explored through published case studies, the documentation techniques for recording heritage are most often integrated. Scholarly literature does not provide a parallel comparison of the four technologies. A comparative analysis of the four techniques, as presented in this thesis, makes it possible for cities to understand the most applicable technique for their preservation objectives. The thesis analyzes four cases studies that employ applications of the technologies: New Orleans Laser Scanning, University of Maryland Photogrammetry, Historic Columbia Maps Project and the Virtual Historic Savannah Project. Following this, the thesis undertakes a trial of each documentation technology – laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling – utilizing a block on Church Street between Queen and Chalmers streets within the Charleston Historic District. The apparent outcomes of each of the four techniques is analyzed according to a series of parameters including: audience, application, efficacy in recordation, refinement, expertise required, manageability of the product, labor intensity and necessary institutional capacity. A concluding matrix quantifies the capability of each of the technologies in terms of the parameters. This method furnishes a parallel comparison of the techniques and their efficacy in architectural heritage documentation within mid-sized cities.

ACKNOWLEDGMENTS

I would like to thank all of the exceptional people who have helped, guided and encouraged me throughout the writing of this thesis.

To my advisor, Amalia Leifeste: this thesis and its topic would not have been conceivable without you. Thank you for listening from the first day of classes and for often decoding the thoughts I could not put into coherent sentences. I am grateful for your encouragement and enthusiasm in my topic, as well as your patience and expert criticism.

To my readers, Amy Elizabeth Uebel, Katherine Pemberton and Ralph Muldrow: thank you for your knowledge of and enthusiasm in my topic. Your comments, questions, and support were invaluable. Special gratitude to Amy Elizabeth for being a guiding hand with unending patience – laser scanning would not have been possible without your help.

To my friends, both old and new: without your encouragement, sass and generous hearts, I would not be where I am today.

To my family: you have done more for me than words can accurately convey and I am eternally grateful. Thank you for your love, support, guidance and prayers. Your unwavering confidence in my abilities and your encouragement sustained me. I owe my love for historic structures and their mystery to you.

To the MSHP program: the knowledge you have instilled in us will be invaluable to our careers; I am proud to join the alumni of this program.

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CHAPTER ONE

INTRODUCTION

While traditional documentation methods are still very much a part of preservation practice, the concept of digitizing cultural heritage has been employed increasingly in the historic preservation field. Digitization is the process of converting the representation of an object, image, sound or document to an electronic format.[1] Digitization is often undertaken as a measure of long-term protection and public accessibility. Seen this way, digitization is a valuable tool for the charges of the historic preservation movement in terms of making cultural heritage sites available for posterity, and sometimes a wider contemporary audience. UNESCO - the United Nations Educational, Scientific and Cultural Organization – defines cultural heritage as "the legacy of physical artifacts and intangible attributes of a group or society that are inherited from past generations, maintained in the present and bestowed for the benefit of future generations."[2] Prompted by the recent destruction of cultural heritage and enabled by advances in technology, preservationists have demonstrated an increased interest in digitizing heritage sites and historic structures, as is seen in historic preservation literature.[3] Consistent advances in equipment and software capabilities, as

[1] "Digitize," *Merriam-Webster*, accessed February 10, 2016, http://www.merriam-webster.com/dictionary/digitize.

[2] Within the *Convention Concerning the Protection of the World Cultural and Natural Heritage* (1972), the United Nations Educational, Scientific and Cultural Organization (UNESCO) defines cultural heritage as monuments, groups of buildings and sites. Monuments are further delineated as architectural works, works of monumental sculpture and painting, archaeological elements, inscriptions and cave dwellings. Groups of buildings by definition can either be separate or connected, and sites according to the Convention are works of humans or the combined works of nature and humans. Architectural heritage is a particular avenue of cultural heritage, which addresses the built environment, specifically historic buildings, structures and spaces. Architectural heritage is studied in terms of single structures, or towns and cities, and often functions as a symbol of culture. Frequently discussed through styles, architectural heritage can be observed at national, regional or local importance. "Tangible Cultural Heritage," *United Nations Educational, Scientific and Cultural Organization*, accessed February 10, 2016, http://www.unesco.org/new/en/cairo/culture/tangible-cultural-heritage/.

[3] The topical literature will be discussed in the following chapter, the literature review.

well as a greater level of refinement and an increased number of open source platforms have afforded greater use of digital documentation tools for the preservation discipline. The rapid development of three-dimensional imaging and processing platforms has made it possible to create digital copies of cultural and architectural heritage through computer-generated three-dimensional representations.[4]

The creation of digital representations of architectural heritage has not only benefited the preservation field, but has also profited adjacent disciplines such as urban planning, academia, conservation and heritage tourism. Software advancements in the architecture and preservation curriculum have allowed for the integration of image-based documentation – beyond conventional two-dimensional drawings – with multifaceted user interfaces, revolutionizing the manner in which researchers and preservation enthusiasts experience cultural heritage.[5] Photographic and graphic documentation tools are merging into a singular process. Imagery documentation, accomplished with digital technologies is often the base for cultural heritage recordation. Popular avenues for digital documentation include laser scanning, photogrammetry, Building Information Modeling (BIM), three-dimensional modeling, geographic information systems (GIS) and total station technology. These technologies and the resulting photorealistic three-dimensional models

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[4] Three-dimensional imaging, the process of combining scans computationally to create a manipulatable model, was adopted by preservationists from medical, automotive design and forensic disciplines. Facility managers and city planners initially employed geographic information systems. Survey tools, such as the total station were used in civil engineering and the oil industries. Photogrammetry and other aerial documentation technologies were previously employed for defense purposes and atmospheric sciences. The processing platforms – the underlying computer system and environment for which these applications are designed to run with – vary widely. For digital documentation technologies, the processing platform is specific to the documentation technique and the form of data captured. This topic constitutes a significant portion of discussion among literature. Robert Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation," *APT Bulletin* 40, no. 3/4 (January 1, 2009): 5–6, doi:10.2307/40284498.

[5] User interface refers to the human-computer interaction, or the user experience. A multifaceted user interface is the visual part of a computer application or operating system that engages multi-level adaptation capabilities to support a wider range of people. This framework is a way to bridge the gap between universal design for people with minimal computer knowledge and explicit design for people with elevated experience.

now supplement two-dimensional drawings, previously the standard for documentation campaigns.

To some in the preservation field, 'digital' and 'historic' are contradictory adjectives. There are professionals within the discipline who rely on what are proving more antiquated means for recording historic structures and sites. Conventional means for documenting structures relies on direct survey and the manual acquisition of accurate dimensions. Traditionally, to produce a measured drawing the documenter would hand measure and record the historic surface with conventional tools. Field notes would then be used to produce final drawings, either in the form of hand drafting or through computer-aided design (CAD) programs.[6] While this traditional method is still widely incorporated into preservation practice, digital technologies have been employed increasingly in the historic preservation field. In *Towards a New Era of Cultural-Heritage Recording and Documentation,* author Robert Warren contends that although the contemporary documentation process has changed drastically, the core goals of architectural heritage documentation remain the same. Warren states that preservationists still look to conserve construction knowledge and material heritage, as well as promote cultural heritage awareness.[7]

However, the process of documenting architectural heritage as a part of the physical environment has entered the Digital Era. Authors argue that the Industrial Revolution in the United States set the milieu for a cultural outlook framed by machines that personified the modern mentality. Literature further argues that it was this mentality paired with the promise of reduced labor that set into motion the Digital Revolution of the second half of the twentieth century.[8] A greater upsurge of technology, later to impact the preservation

[6] The Historic American Buildings Survey (HABS) has standard guidelines for the measured drawings of historic structures. The guidelines specifically address field sketches and measurements, as well as final deliverable specifications.
[7] Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation," 7.
[8] *Ibid*. 5.

field, emerged in the 1980s; however this was a trivial advancement compared to the developments of the late 1990s into the early twenty-first century. CAD programs took a foothold in the 1980s allowing practitioners to represent large buildings at full scale on the computer. Surveying by total stations and photogrammetry saw an increased use in the 1990s, and laser scanning, although present since the 1970s in other fields, progressed into heritage documentation by the late 1990s.[9] By 2000, most university programs and professional offices retained a form of CAD in their workflow.[10] Copious literature agrees that the tools used today for digital documentation by preservationists were already on the market and being employed by other disciplines, but this second wave of the Digital Revolution made them more economically feasible for the cultural heritage field.[11]

While Autodesk's AutoCAD – the prominent commercial software application for two-dimensional drafting – and other computer-aided design programs were once the forerunners in documentation, this avenue is now being replaced or combined with more sophisticated software platforms. The axiom of a heritage documentation project is to retrieve maximum information through recording.[12] Digital technologies such as laser scanning, photogrammetry, multimedia geographic information systems (GIS) and three-dimensional modeling are expediting efforts to record and interpret historic places.[13] The acceptance of these tools is due in part to their ability to rapidly capture data, their high level of accuracy and their nonintrusive character. Scale and irregular forms, two obstacles

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[9] George C. Skarmeas, "From HABS to BIM: Personal Experiences, Thoughts, and Reflections," *APT Bulletin* 41, no. 4 (January 1, 2010): 47, http://www.jstor.org.libproxy.clemson.edu/stable/41000038; Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation," 5-7.

[10] Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation," 6.

[11] Serra Akboy, "The Mediated Environment of Heritage Recording and Documentation," *Preservation Education & Research* 6 (2013): 7–23, http://www.ncpe.us/wp-content/uploads/2014/11/PER2013-offprint-AKBOY-ILK.pdf; Skarmeas, "From HABS to BIM: Personal Experiences, Thoughts, and Reflections"; Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation."

[12] Akboy, "The Mediated Environment of Heritage Recording and Documentation," 7.

[13] As prevailing methods of recordation, these four categories of digital documentation technologies will become the dominant subjects of analysis in this thesis. Each will be later addressed and evaluated in terms of efficacy for the documentation of architectural heritage.

commonly present for traditional methods of hand measurements, are no longer a restriction with the implementation of digital tools. Additionally, digital documentation tools contain a level of detail – materiality, ornamentation, weathering and deterioration data – seen as too labor intensive to depict by conventional recordation means.[14] Previously inaccessible surfaces are now feasible for recording. The use of digital documentation technologies allows preservationists to measure architectural elements that are considered unreachable, unsafe or too fragile to measure by hand.

Although the objectives of cultural heritage preservation have not changed, the attainable scale for a documentation campaign has significantly increased. However, instead of a large-scale architectural documentation effort, practitioners primarily document objects, monuments and single buildings. These singular entities do not represent the relationship of architecture and streetscapes found in a historic urban landscape. Digital documentation techniques present preservationists with a viable opportunity for undertaking large-scale documentation measured in blocks and communities, as opposed to individual structures. As a greater initiative, preservationists should adopt available technology and software platforms recognizing them as important tools with which to accomplish the objectives of recording, understanding, monitoring and protecting the architectural heritage of neighborhoods, districts and cities. The authors of *With Heritage So Rich* expressed larger-scale preservation best by stating:

> Preservation must look beyond the individual building and individual landmark and concern itself with the historic and architecturally valued areas and districts, which contain a special meaning for the community. A historic neighborhood, a fine old street of houses, a village green, a colorful marketplace, a courthouse square, an aesthetic quality of the town scape -- all must fall within the concern of the preservation movement. It makes little sense to fight for the preservation of a historic house set between two service stations, and at the same time to ignore

[14] Akboy, "The Mediated Environment of Heritage Recording and Documentation," 20.

> an entire area of special charm or importance in the community, which is being nibbled, away by incompatible uses or slow decay.[15]

Digital documentation technologies provide organizations and cities with a method to record a greater magnitude of historic urban landscapes. These tools allow city-scaled documentation, presenting and recording urban architectural patterns, rather than the commonly seen explicit concentration on single historic structures. Stefano Brusaporci, the author of *Issues of Historic Town Surveying: Visualizing Urban Values* (2014) explains that the preservation field is transitioning to a new objective regarding the "awareness of extending the concept of cultural heritage."[16] With this new drive, he asserts that not only do a greater number of historic structures need to be protected, but also their interrelationship should be better portrayed, because an association between the buildings is ineluctable.[17] The author further asserts that architectural heritage cannot "derive from one specific building" since a city is not a simple abstract of buildings, but a series of spatial relationships.[18] This initiative to document expansive areas of historic urban cores and architecture, rather than particular structures can be seen through CyArk's 'Historic Cities' laser scanning campaign.

CyArk is a nonprofit organization renowned for demonstrating large-scale heritage documentation through digital technologies. The organization's mission is to digitally document and preserve world heritage sites, ensuring that these historic places are available for future generations. The company attributes their initiative to the alarming rate at which heritage sites and structures are being lost to natural disaster, population growth and human

[15] National Trust for Historic Preservation, *With Heritage So Rich* (Preservation Press, 1966): 193.
[16] Stefano Brusaporci, "Issues of Historic Town Surveying: Visualizing Urban Values," *Scientific Research and Information Technology* 4, no. 2 (2014): 63.
[17] *Ibid, 64-65*.
[18] *Ibid*, 65.

conflict.[19] In 2013, the organization began the CyArk 500 Challenge, an ambitious goal to digitally document 500 cultural heritage sites within five years. Through this campaign, the organization established the 'Historic Cities' project and has successfully undertaken citywide digital documentation. The organization has documented the streetscapes of both New Orleans and Philadelphia through laser scanning, with the intention to scan Boston, San Francisco and Chicago as well.[20] CyArk has proven that digital documentation technologies are capable of recording and preserving large-scale endeavors such as historic cities and urban areas.

Today, the preservation discipline is equipped with a wide range of advanced technologies for recording and preserving cultural heritage. The concept of digitally documenting architectural heritage at a citywide scale is a growing movement. By employing digital documentation tools, organizations have begun to record historic urban landscapes to achieve a range of preservation-related objectives including conservation, city planning, education and heritage tourism applications. Recent case studies representing large-scale architectural heritage documentation are seen globally. Three-dimensional modeling was employed to depict the downtown historic district of Savannah, Georgia. CyArk recently used laser scanning technology to document the historic streets of New Orleans, Louisiana and Philadelphia, Pennsylvania. Both Paris and Marseille in France have been documented through aerial photogrammetry. Columbia, South Carolina, Los Angeles, California and Gainesville, Florida are among a selection of local level initiatives to create multimedia GIS platforms.

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[19] "CyArk," accessed September 11, 2015, http://www.cyark.org/.

[20] Katia Chaterji, "Historic Cities Program Announced to Map Cities in 3D," *CyArk*, October 31, 2014, http://www.cyark.org/news/historic-cities-program-announced-to-map-cities-in-3d; Ian Delaney, "HERE and CyArk Partner to Save Historic Areas – with Lasers," *HERE 360*, October 7, 2014, http://360.here.com/2014/10/07/cyark-partner-save-historic-areas-lasers/; Katherine Sayre, "Digital Archive Group CyArk Captures New Orleans in 3-D Using Laser Beams," *The Times-Picayune*, October 7, 2014, http://www.nola.com/business/index.ssf/2014/10/digital_archive_group_captures.html.

Charleston, however, is absent from this list despite having a highly reputed inventory of historic structures, a closely guarded historic district and a long history as a pioneer in new historic preservation tools. The lack of a digital preservation movement for Charleston's architectural heritage is surprising considering the city's past success with preservation campaigns.[21] In 1931, Charleston became the first city in the United States to enact a zoning ordinance for the historic district, leading other cities in this crusade.[22] However, Charleston's rich architectural history is primarily confined to textbooks and archives, with concentration on specific, preeminent structures, not large-scale architectural documentation.[23] Addressing this deficiency, the focus of this thesis endeavors to answer the question of how a detailed understanding of the major types of digital documentation and a parallel comparison of their efficacy can inform the selection of a specific method when a city, such as Charleston, embarks on a digital architectural heritage documentation

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[21] Several endeavors, initiated at a local level, have attempted to generate a multimedia GIS platform for Charleston. These projects include the Alfred O. Halsey Map Preservation Research Project; the Charleston Map sponsored by the Luxury Simplified Group; and several interactive GIS platforms available through the Historic Charleston Foundation. These platforms display buildings, sites and events significant to Charleston's urban development. Map overlays include building development, building age, the evolving waterfront and peninsula shape change, historic fires and fortifications. Although significant resources for research, these platforms do not document or preserve the architectural heritage of the city.

[22] The City Council adopted Charleston's preservation ordinance in October of 1931. The opening sentence of the ordinance clearly stated its purpose: "In order to promote general welfare through the preservation and protection of historic places and areas of historic interest..." This was the first time an area of buildings was designated as significant and worthy of protection. Charleston's Board of Architectural Review (BAR) was also established at this time. It was established for the "preservation and protection of the old historic or architecturally worthy structures and quaint neighborhoods which impart a distinct aspect to the city and which serve as visible reminders of the historical and cultural heritage of the city, the state, and the nation." The blending of planning and preservation goals was a revolutionary concept for its time. Charles Edwin Chase, "CHARLESTON: Guarding Her Customs, Buildings, and Laws," *Preservation Forum*, 1998, National Trust for Historic Preservation.

[23] The digital documentation of singular structures is an undertaking that has already been initiated at numerous historic sites. Academic publications and case studies primarily evaluate the documentation of distinct structures and archaeological complexes. These structures and sites are privileged for their size, grandiosity or related significance. Charleston is not an exception to this site-specific documentation campaign. A limited selection of historic structures in Charleston and the greater Lowcountry area has already been digitally documented. This list includes Drayton Hall, the Aiken Rhett House, the Nathaniel Russell House, Castle Pinckney and Fort Sumter, among others. These structures were documented with an assortment of digital documentation technologies involving laser scanning, photogrammetry, three-dimensional modeling and Historic Building Information Modeling (HBIM).

campaign.

Only after the advantages and shortcomings of technologies have been identified and discussed can a successful integration of architectural recordation and digital tools be accomplished. While "digital tools have a home in historic preservation", documentation technologies are powerful and sophisticated, requiring significant investments in hardware, software and training for institutions.[24] There are however, documentation technologies that require less technical expertise and generate more straightforward products. It is imperative that the capacities and potential obstacles of a documentation technology are established and understood before the method is selected for implementation. Through the analysis and investigation of four categories of digital documentation techniques – laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling – as well as through an evaluation of corresponding case studies, this thesis will dissect the effectiveness of the digital documentation platforms available and their applicability to the Charleston Historic District and other cities.

To understand if digital documentation technologies are applicable to the preservation field for architectural heritage recordation, it is necessary to first determine acceptable practices for available platforms. Following this introduction, the thesis commences with a literature review providing a brief overview to the current academic discussions regarding digital documentation technologies presently used to record cultural heritage. Knowledge of how the digital documentation methods are employed with regard to architectural heritage, as well as current dialogue regarding equipment and platforms used for endeavors similar to this thesis, are incorporated within this section. Perspective from the literature review, looking towards the apparent strengths, weaknesses, expected deliverables and capacities of the digital documentation techniques provides insight as to

[24] Akboy, "The Mediated Environment of Heritage Recording and Documentation," 19.

how these technologies have been previously used for preservation and what outcomes practitioners have generated, providing a foundation of expectations for the data to be generated and analyzed within the thesis.

Through the literature review, it is understood that practitioners seldom employ just one digital documentation technique for recordation. Academic discussions and published case studies demonstrate, and often argue for, the overlap and integration of the documentation methods. Few case studies represent a "pure" application of the technology and literature does not provide an equal assessment of the four techniques. However, this thesis asserts that a parallel comparison of the digital documentation technologies employed for recording architectural heritage cannot be established if hybrid methods are used and categories are not established. Therefore, the first step in analyzing the efficacy of popular digital documentation tools was to review the categories of the techniques as established by the body of literature. This step provides guidance for both the selection of the case studies to be analyzed and the techniques to be undertaken in the investigative trials. Literature establishes four prominent categories of digital documentation tools for recording architectural heritage: laser scanning, photogrammetry, multimedia geographic information systems (GIS) and three-dimensional modeling. From the review of published works, this appears to be a standard division of technological platforms. A comparative analysis of these four technologies, as presented in this thesis, makes it possible for cities to understand the most applicable technique for their preservation objectives. The published works and the arguments of their respected authors regarding the implementation of laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling for heritage documentation are discussed at great length in Chapter Two, the literature review.

The third chapter of the thesis, the methodology, communicates the process undertaken to evaluate the case studies and the investigative trials. Within this section, the reasoning for the inclusion of each case study, as well as the parameters used to assess their success is established. The methodology chapter also describes the procedure undertaken for each investigative trial – laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling. The investigative trials provide an opportunity to analyze the four digital documentation technologies against a series of parameters established in this chapter. This section provides a brief background for the data accumulation, data processing and data post-processing phases for the four documentation techniques. The unit of analysis for the trials – a sample block on Church Street between Queen and Chalmers streets in Charleston, South Carolina – is also established in the methodology.

Apart from published literature, case studies provide an opportunity to examine the use of the digital documentation technologies for citywide architectural heritage documentation. The fourth chapter of the thesis examines four case studies that employ applications of the four digital documentation technologies. The case studies are analyzed to further understand the potential deliverables of the documentation platforms. The case studies chosen for analysis include: the Virtual Historic Savannah Project, the Historic New Orleans laser scan, Historic Columbia Foundation's Interactive Neighborhood Tours and the University of Maryland Baltimore County photogrammetry project. The data accumulated from the analysis of the case studies, in conjunction with available publications, helps to understand why cities undertake architectural heritage documentation campaigns. The case studies foster a comprehensive understanding of the requirements of a digital model for a city, as well as the successes and failures of each technology.

The case studies were chosen for their variety of architecture, as well as their involvement in or potential involvement with the preservation movement. In addition, the case studies were selected for their "purity" in methodology; the case studies chosen for analysis engage only one of the digital documentation techniques being studied in the thesis. In contrast, many case studies recognized within the literature review were accomplished through multiple, overlapping methods. The data for the analysis of the four case studies is generated almost entirely from interviews with the sponsoring organization. Newspaper, journal and magazine articles, as well as conference papers and presentations generate secondary, supportive material; these sources generally address the success and acceptance of the programs.

Following the analysis of the case studies, a trial model of each of the four documentation methods being studied – laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling – was generated. The fifth chapter of the thesis describes the data accumulation, data processing and data post-processing stages for each investigative trial. Each methodology and the corresponding trial employ separate data accumulation equipment and processing platforms. To record the unit of analysis through laser scanning, the FARO Focus^{3D} X 330 laser scanner was employed. FARO's proprietary software, SCENE was utilized to process the data. To capture and process the photogrammetric data, an off-the-shelf digital camera and the Agisoft PhotoScan platform were used. ESRI's ArcGIS web-mapping application was employed to create a multimedia GIS project. A three-dimensional model of the trial block was created through a combination of the City of Charleston's GIS data and Trimble's SketchUp program. The capabilities of the hardware and software for the trials are further explained in Chapter Five.

The objective of the investigative trials is to generate a documentation deliverable from each of the four technologies to aid in the creation of a parallel comparison of the digital documentation techniques available. To accomplish this, ten hours were dedicated to working within each program to develop a digital documentation product of the unit of analysis, the sample block on Church Street within the Charleston Historic District. The results of the investigative trials are used to inform the selection of a specific method when a city embarks on a digital architectural heritage documentation campaign. A parallel comparison of the technologies is described in the following section, Chapter Six.

Through the investigative trials, with supplemental support from the literature and case studies, the thesis works towards answering the question of how a detailed understanding of the major types of digital documentation and a parallel comparison of their efficacy can inform the selection of a specific method when a city, such as Charleston, embarks on a digital architectural heritage documentation campaign. A concluding analysis of the documentation technologies is formed in Chapter Six. The apparent capacities and outcomes of each of the four techniques are analyzed according to a series of parameters including: audience, application, efficacy in recordation, refinement, expertise required, manageability of the product, labor intensity and necessary institutional capacity. A concluding matrix will quantify the capacity of each of the technologies – laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling – in terms of the parameters. This method furnishes a parallel comparison of the techniques and their efficacy in architectural heritage documentation within cities and communities.

Digital documentation will increasingly be fundamental to the understanding, appreciation and management of heritage places. The studies undertaken through this thesis will expectantly encourage cities to expand their commitment to preservation beyond single historic buildings to a broader documentation of historic neighborhoods and districts. Digital documentation techniques present preservationists with a viable opportunity for undertaking large-scale documentation of historic urban landscapes, fostering a representation of the relationship of architecture and streetscapes. However, it is not until the capacities and limitation of the technologies are understood can an organization successfully select and employ a digital documentation technology for architectural heritage recordation in a city or community.

CHAPTER TWO

LITERATURE REVIEW

This literature review addresses the current academic discourse regarding digital documentation technologies applicable to historic preservation. Literature has been assembled that specifically addresses the expected capacity, generated outcomes, criticism and approval for laser scanning, photogrammetry, three-dimensional modeling and multimedia geographic information system (GIS) that pertains to architectural heritage documentation. Additionally, studies directly comparing these digital documentation techniques provide significant insight for arguments for and against their use in the cultural heritage discipline. Due to rapidly developing advances of the platforms and equipment, reports on specific software within this review are restricted to the past five years. This restriction was initiated as scholarship is slow to catch up to evolving documentation technologies. Works have primarily been compiled from abstracts, case studies and conference presentations discussing preservation use of these technologies.

The subject of digital documentation technology applicable to historic sites and structures has generated immense conversation in the past two decades. Much of the literature pertaining to digital heritage documentation is presented in the form of case studies. These publications are frequently predisposed towards depicting success. Case studies often focus on the author's accomplishments, the final deliverable and generally promote the digital documentation method employed in the specific project. These publications typically present the project expectations, means of data accumulation, methodology and visual outcomes for the documentation undertaken by the author.[25] Only rarely do the essays and publications present a detailed explanation of realizations or inefficiencies.[26] Very little literature assumes a neutral position disengaged from personal projects, offering an equalized analysis of various digital documentation technologies.[27]

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[25] Hung-Ming Cheng, Wun-Bin Yang, and Ya-Ning Yen, "BIM Applied in Historical Building Documentation and Refurbishing," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 25th International CIPA Symposium, XL (2015): 85–90; "Applications of Digital Photogrammetric Methods for Preservation Documentation of Historic Homes," Narrative Final Report, The Georgia O'Keeffe Museum (National Center for Preservation Technology and Training, October 24, 2012), http://ncptt.nps.gov/wp-content/uploads/2012-11.pdf; Surendra Pal Singh, Kamal Jain, and V. Ravibabu Mandla, "Image Based 3D City Modeling: Comparative Study," vol. XL– 5 (ISPRS Technical Commission V Symposium, Riva del Garda, Italy: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2014), 537–46; F. Fiorillo et al., "3D Digitization and Mapping of Heritage Monuments and Comparison with Historical Drawings," vol. 11–15/W1 (2013 XXIV International CIPA Symposium, Strasbourg, France: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2013), 133–38; R. Quattrini et al., "From TLS to HBIM. High Quality Semantically-Aware 3D Modeling of Complex Architecture" (2015 3D Virtual Reconstruction and Visualization of Complex Architectures, Avila, Spain: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2015); A. Guarnieri, F. Remondino, and A. Vettore, "Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modeling" (Institute of Geodesy and Photogrammetry), accessed September 11, 2015, http://www.castorc.cyi.ac.cy/system/files/Guarnieri_etal_ISPRSV06.pdf; Sara Gonizzi Barsanti, Fabio Remondino, and Domenico Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues" (University of Trieste, Italy, n.d.); W. Boehler and A. Marbs, "3D Scanning and Photogrammetry for Heritage Recording: A Comparison" (12th International Conference on Geoinformatics, University of Gavle, Sweden: Geoinformatics, 2004).

[26] These publications include a detailed methodology for the procedures undertaken through the case studies, as well a more thorough explanation for the outcome of the documentation project. Typically, the results of the study are presented in the form of comparative tables, delineating the equipment and software used, as well as the capacities a user could expect from each. Singh, Jain, and Mandla, "Image Based 3D City Modeling: Comparative Study"; "Applications of Digital Photogrammetric Methods for Preservation Documentation of Historic Homes"; Moulay Larbi Chalal and Riccardo Balbo, "Framing Digital Tools and Techniques in Built Heritage 3D Modelling: The Problem of Level of Detail in a Simplified Environment," *The International Journal of the Constructed Environment* 4 (2014): 40–52; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues."

[27] The authors in these publications offer a neutral outlook on the outcomes and capacities of the explored digital documentation technologies. These essays are comparable to technical specifications for the equipment and software required for the digital documentation techniques. Findings and summarizations are most typically presented in the form of detail tables, comparing parameters such as application, strengths, weakness, developer, brand, range and data input. Fabio Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning," *Remote Sensing* 3, no. 6 (May 30, 2011): 1104–38, doi:10.3390/rs3061104; Singh, Jain, and Mandla, "Image Based 3D City Modeling: Comparative Study"; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues."

Publications of case studies analyzing the concepts of multi-block architectural recordation and digital documentation use within cities and historic districts are rare. Essays primarily evaluate the documentation of single structures or objects, and archaeological complexes.[28] While there are several instances where blocks of cities or the facades of multiple buildings have been documented, there is not widespread publication on this application.[29] Where cities have engaged in large-scale documentation, both capturing entire metropolitan areas and at the scale of districts, the case studies have generally employed unmanned aerial vehicles (UAV) generating isometric views of the architecture.[30] These technologies do not provide clear representation of the façade of the buildings, and this is of limited value to architectural heritage documentation. The majority of these examples and discussions are from European cities; UAV face legal limitations and public distrust in the United States. Several publications have suggested difficulties undertaking façade-specific digital documentation. This group of literature is highly applicable to the

[28] Quattrini et al., "From TLS to HBIM. High Quality Semantically-Aware 3D Modeling of Complex Architecture"; Renju Li, Tao Luo, and Hongbin Zha, "3D Digitization and Its Applications in Cultural Heritage," in *Digital Heritage*, ed. Marinos Ioannides et al., Lecture Notes in Computer Science 6436 (Springer Berlin Heidelberg, 2010), 381–88, http://link.springer.com/chapter/10.1007/978-3-642-16873-4_29; Fiorillo et al., "3D Digitization and Mapping of Heritage Monuments and Comparison with Historical Drawings"; Guarnieri, Remondino, and Vettore, "Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modeling."

[29] "CyArk," accessed September 11, 2015, http://www.cyark.org/; Franz Leberl et al., "Automated Photogrammetry for Three-Dimensional Models of Urban Spaces," *Optical Engineering*, February 2012, http://www.researchgate.net/publication/258224670_Automated_photogrammetry_for_three-dimensional_models_of_urban_spaces?enrichId=rgreq-b30575d6-c268-4804-ad28-25f9e56e8ea3&enrichSource=Y292ZXJQYWdlOzI1ODIyNDY3MDtBUzoyNTg2ODUxMjk3MTk4MDhAMTQzODY4Njc0OTQyMQ%3D%3D&el=1_x_2.

[30] The authors of *Automated Photogrammetry for Three-Dimensional Models of Urban Spaces* contend that façade imaging is typically associated with street-side photography. While UAV and LiDAR technologies have been utilized to document facades, the aerial data is steep and the pixels on the facades are not square. Through a case study, the number of recognized floors and windows on 104 buildings were compared between terrestrial scanning and LiDAR. With LiDAR only 93% of floors and 86% of windows were recognized by the scanning data. Leberl et al., "Automated Photogrammetry for Three-Dimensional Models of Urban Spaces."

feasibility study of certain technologies undertaken through this thesis.[31]

Much of the literature addressing the rapidly increasing use of digital documentation technology has argued that while the physical process of recording cultural heritage has changed, the objective from initial preservation documentation remains the same.[32] Authors prefaced their publications stating that the means portrayed and methodology discussed were for the common purpose of preserving sites and structures through digital representations.[33] Consistent arguments made by practitioners and proponents for recording heritage, such as loss due to on-going wars, natural disasters, climate change and human negligence, were seen throughout.[34] Most frequently expressed was the concern that cultural heritage sites

[31] This group of publications specifically addresses architectural heritage and the documentation of building facades. The essays discuss the methodology and platforms best used and most successful for the data capture of building facades from the street. G. Saygi and M. Hamamcioglu-Turan, "Documentation of a Historical Streetscape with Close Range Digital Photogrammetry" (22nd CIPA Symposium, Kyoto, Japan, 2009); Conor Dore and Maurice Murphy, "Integration of Historic Building Information Modeling (HBIM) and 3D GIS for Recording and Managing Cultural Heritage Sites" (18th International Conference on Virtual Systems and Multimedia, Milan, Italy: Dublin Institute of Technology, 2012), 369–76; Boehler and Marbs, "3D Scanning and Photogrammetry for Heritage Recording: A Comparison"; Stefano Brusaporci, "Issues of Historic Town Surveying: Visualizing Urban Values," *Scientific Research and Information Technology* 4, no. 2 (2014): 63–80.

[32] Robert Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation," *APT Bulletin* 40, no. 3/4 (January 1, 2009): 5–10, doi:10.2307/40284498; Naif Adel Haddad, "From Ground Surveying to 3D Laser Scanner: A Review of Techniques Used for Spatial Documentation of Historic Sites," *Journal of King Saud University - Engineering Sciences* 23, no. 2 (June 2011): 109–18, doi:10.1016/j.jksues.2011.03.001.

[33] In *Towards a New Era of Cultural-Heritage Recording and Documentation*, Robert Warden argues that contemporary heritage documentation projects have retained the goals common to heritage recordation from previous decades. These driving objectives include "conservation of design and construction knowledge, conservation of material and aesthetic heritage, [and] promulgation of cultural awareness." The author argues that while the documentation goals have not significantly altered over the past two decades, the processes of recordation differ greatly. Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation." 7.

[34] John Ristevski, Anthony Fassero, and John Loomis, "Historic Preservation through Hi-Def Documentation," *CyArk*, February 7, 2007, http://cyark.org; Serra Akboy, "The Mediated Environment of Heritage Recording and Documentation," *Preservation Education & Research* 6 (2013): 7, 13, 20, http://www.ncpe.us/wp-content/uploads/2014/11/PER2013-offprint-AKBOY-ILK.pdf; Renju Li, Tao Luo, and Hongbin Zha, "3D Digitization and Its Applications in Cultural Heritage," in *Digital Heritage*, ed. Marinos Ioannides et al., Lecture Notes in Computer Science 6436 (Springer Berlin Heidelberg, 2010), 381, http://link.springer.com/chapter/10.1007/978-3-642-16873-4_29; Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation." 6.; Fabio Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning," *Remote Sensing* 3, no. 6 (May 30, 2011): 1104, doi:10.3390/rs3061104.

are being lost faster than they can be preserved. Tangible representations of the past are at an elevated risk; while artifacts can be safely housed in collections and museums, cultural heritage sites are exposed to the degradation of human and natural forces.[35] Elizabeth Lee, the Vice President of CyArk, a nonprofit organization with the mission of using new technologies to create a library of the world's cultural heritage sites, truthfully summarized the field's desire for digital preservation by stating, "There are so many incredible heritage sites – many still unknown to the wider public – that tell compelling stories about our human history but are at risk of being lost and could benefit from being digitally preserved."[36]

Though it would be easy to view the literature as polarized between advocates for traditional recording techniques, like hand measuring and hand drafting, and the voices generating excitement about digital documentation of architectural heritage, several authors fall in a position between the three-dimensional and two-dimensional documentation advocates.[37] This segment of the literature argues that increased use of digital documentation technology has "created a tension between three-dimensional recording tools and the final two-dimensional product."[38] Authors argue that two-dimensional plans, elevations and sections are the desired final product of documentation, and contend that three-dimensional

[35] Maria Doyle, "3D Scanning Gives World's Historic Sites New Life," *Product Lifecycle Report*, December 20, 2013, http://blogs.ptc.com/2013/12/20/3d-scanning-gives-worlds-historic-sites-new-life/; D. Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage" (J. Paul Getty Conservation Institute, World Monuments Fund, 2012).

[36] Doyle, "3D Scanning Gives World's Historic Sites New Life."

[37] Traditionally, to produce a measured drawing of a historic structure, the documenter was required to hand record the historic surface. Field notes were created on graph paper and final drawings were produced, by hand or through computer-aided design software, from these field measurements. Serra Akboy-Ilk in *The Mediated Environment of Heritage Recording and Documentation* argues that practitioners have shifted away from traditional means of recording and now increasingly rely on digital tools to "define, treat and interpret historic structures". Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation"; Akboy, "The Mediated Environment of Heritage Recording and Documentation."

[38] Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation." 6.

models are generated, then subsampled or reduced to a two-dimensional drawing.[39] This diminution of the documentation data is argued to be the result of both the requested deliverable, typically a two-dimensional product, as well as a lack of knowledge of handling three-dimensional data by non-experts.[40] This position questions if it is practical to document digitally if most organizations still seek two-dimensional drawings as the final output. It appears that a standardized compromise has yet to be developed to bridge the gap between two and three-dimensional documentation.

While the majority of the authors writing on documentation methods seem to be in favor of utilizing digital methods for documentation, there is a camp that argues that digital technologies foster less "direct engagement with the heritage environment" and that the use of these tools has altered the way the documenter connects with cultural heritage.[41] These authors, such as Serra Akboy-Ilk in *The Mediated Environment of Heritage Recording and Documentation*, argue that there is disconnect from heritage and lack of intimate

[39] Two-dimensional drawings have continued to be the standard practice at leading institutions like the National Park Service's Historic American Buildings Survey. Robert Warden, in T*owards a New Era of Cultural-Heritage Recording and Documentation* describes the push from two-dimensional to three-dimensional, but contends that two-dimensional drawings have remained the desired final deliverable due to reasons of archival stability. Warden further explains that technological innovations have changed the expectations for final heritage documentation projects. Traditionally, a drawing was a two-dimensional presentation. The drawing constituted the act of extracting important information from the real object, a historic building in this case, and displaying it in a different way. However, Warden contends that drawings as two-dimensional interpretations were challenged by three-dimensional modeling as a normative product. With this mindset, software offerings began to develop that operated primarily in three-dimension with the assurance of secondary products in two-dimension. With this development, two-dimension deliverables were extracted from the three-dimensional model. Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation." 6-7.; Akboy, "The Mediated Environment of Heritage Recording and Documentation." 7-9.

[40] Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning"; Akboy, "The Mediated Environment of Heritage Recording and Documentation"; Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation."

[41] Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation"; Akboy, "The Mediated Environment of Heritage Recording and Documentation."

knowledge with the subject when digital technologies are employed for recording.[42] Typically, this literature stems from the belief that teaching hand documentation techniques is a valuable pedagogical exercise.[43] In contrast to traditional hand recording methodology, practitioners in favor of digital documentation technologies assert that digital data is a "critical component to permanently record[ing]" significant cultural heritage for the posterity of future generations.[44] Both camps uphold the opinion that hand recording is a valuable scholastic exercise, yet it cannot be denied that with the popularity of digital documentation methods, the culture of historic building documentation and the expectations for deliverables have been significantly altered. Additionally, the concept of accuracy counters the argument for traditional hand documentation methods. With hand recording, authors like Serra Akboy-Ilk contend that the documenter is engaged in the concepts of amplification and reduction, thus reducing the accuracy of the documentation. The final drawings represent the documenter's view of what to draft, potentially not comprising all the physical qualities of the structure and therefore not relating an accurate depiction

[42] Serra Akboy-Ilk argues that digital documentation technologies foster less human-heritage interaction during the data gathering and production phases leading to a diminished involvement of the documenter with the historic environment. Additionally, she contends that the movement away from traditional means of recording lessens the abstract architectural thinking skills required of practitioners. The documenter is no longer immersed in the historic environment and the demand of careful scrutiny that hand measuring and drawing places on the documenter is absent. Akboy, "The Mediated Environment of Heritage Recording and Documentation." 8-9.

[43] Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation." 7.

[44] John Ristevski, Anthony Fassero, and John Loomis, "Historic Preservation through Hi-Def Documentation," *CyArk*, February 7, 2007, http://cyark.org; Renju Li, Tao Luo, and Hongbin Zha, "3D Digitization and Its Applications in Cultural Heritage," in *Digital Heritage*, ed. Marinos Ioannides et al., Lecture Notes in Computer Science 6436 (Springer Berlin Heidelberg, 2010), 381, http://link.springer.com/chapter/10.1007/978-3-642-16873-4_29; Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning." 1104.

of the architecture.[45] Certain aspects are revealed while others are eliminated, reducing the truthfulness of the depictions.[46] The accuracy, precision and reliability of digital documentation technology support the arguments of practitioners in favor of a transition from hand recording to digital documentation.

The digital documentation technologies being analyzed through this thesis have been divided into four categories: three-dimensional laser scanning, photogrammetry, three-dimensional modeling and multimedia GIS. These technologies were divided according to their similarities in input requirements, as well the final product generated for digital preservation applicable to a city or community. While this appears to be a standard division of technological platforms, several authors have posed interesting alternatives worth noting. Rather than dividing digital documentation tools by equipment and software platforms, an argument was made for categorizing according to final application; these classifications were argued to be digital archiving, three-dimensional line drawing, virtual restoration and virtual display.[47] Robert Warden, in *Towards a New Era of Cultural-*

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[45] Akboy-Ilk further explains her discussion of amplification and reduction stating that through hand recording, the documenter selects important architectural information, gathering the field measurements that he or she deems significant for the project. Compiling the field measurements into plans and elevations, the documenter may amplify certain aspects of the structure yet eliminate other details. In places were no data was collected during the fieldwork, elements of the structures are never portrayed in the two-dimensional drawings. Additionally, Akboy-Ilk argues that the quality of the record is determined by the drawing standards, as well as the documenter's drafting and interpretation skills. Such a significant reliance on the interpretative manner and competency of the documenter further illuminates the highly accurate manner in which digital documentation technologies record cultural heritage. Akboy, "The Mediated Environment of Heritage Recording and Documentation." 14-15.
[46] Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation"; Akboy, "The Mediated Environment of Heritage Recording and Documentation." 14-15.
[47] The authors of *3D Digitization and Its Applications in Cultural Heritage* divide digital documentation technologies according to their applications within the cultural heritage field. The digital archiving category encompasses a broad range of methods and is generally described as a means of permanently preserving three-dimensional data for later management and analysis. The publication argues that three-dimensional line drawings are an essential component of archaeological reports, and offer a less expensive alternative to line drawings by hand. Digital restoration is argued to be important where parts of cultural heritage are missing and restoration is requested. The authors argue that virtual display solves the contention between heritage protection and display, allowing the enjoyment of a digital model from any viewpoint without damage to the object or site. Li, Luo, and Zha, "3D Digitization and Its Applications in Cultural Heritage."

Heritage Recording and Documentation (2009), categorized digital documentation tools as GIS tools, survey tools and aerial tools; GIS was confined to the geographic information system, paradigms of surveys tools were global positioning systems and total stations and aerial tools constituted photogrammetry, laser scanning and LiDAR technology.[48] The authors of *Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling* have an approach that emphasizes archaeology, and categorizes documentation tools as either direct survey, measuring in direct contact with the object, or indirect survey. The authors argued that indirect survey could be further classified as passive techniques, recognized as image-based methods such as photogrammetry, or active sensors, acknowledged as range-based methods such as laser scanning.[49] Fabio Remondino in *Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning* (2011) further developed this categorical division by addressing both passive sensors, active sensors, classical surveying and modeling from two-dimensional maps.[50] Several publications took a more traditional approach offering categories that encompass documentation in a broader sense, not just the digital techniques. This assemblage consists of written documentation, graphic or non-photographic documentation and photographic documentation; the technological methods discussed through this thesis would fall within the photographic documentation category.[51]

[48] Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation." 6-7.
[49] Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues." 1-2.
[50] Fabio Remondino's categorical division of digital documentation techniques is more aligned with architectural heritage and more thorough than other authors' interpretations. In this publication, both passive and active sensors are addressed as non-invasive optical recording sensors; passive sensors are distinguished by the image data they deliver for processing, while active sensors provide data directly for three-dimensional information. The author discusses active optical sensors as laser scanners or radars. Remondino further divides this category into airborne and terrestrial laser scanners, arguing for separate treatment as they differ in terms of employed sensors. Passive sensors, generating image data are discussed in terms of the photogrammetry technique. Classical surveying is not widely discussed in the publication, but is acknowledged as documentation by means of total stations and the global navigation satellite system (GNSS). Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning." 1106-1111.
[51] Haddad, "From Ground Surveying to 3D Laser Scanner."

Much of the literature and conversation regarding digital documentation methods engages the position of comparing platforms and techniques. Several publications have attempted to address the lack of, and need for, parallel and systematic comparisons between the digital technologies available for documentation of architectural heritage. However, this avenue of exploration seems to generate one of the largest shortcomings within the available literature. Naif Adel Haddad et. al. in *From Ground Surveying to 3D Laser Scanning* (2011) present a comparative table evaluating linear measurements taken simultaneously by a tape measure, photogrammetry software and a laser scanning platform.[52] This comparative analysis recognized the differences in accuracy of the tools, but failed to provide the reader with a broader sense of the strengths and confines of the three techniques.[53] In *Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning,* Remondino presents nine separate tables addressing digital documentation methods such as terrestrial laser scanning, LiDAR, terrestrial digital cameras and mobile mapping systems. The tables address parameters concerning the measuring principle, range, accuracy, frequency and acquisition mode for each technology. These comparisons generate a detailed analysis of the technical components and equipment necessary for photogrammetry and laser scanning, however, these appraisals fall short of comparing the broader spectrum of technology available for heritage documentation. Remondino

[52] The authors of this publication used the ancient theatres of Jerash, the Southern Theatre and the Northern Theatre, as a case study to perform a comparison of traditional means of recording heritage, three-dimensional scanning and photogrammetry through the PhotoModeler platform. Different typical objects were chosen and characteristically like parts of them were recorded by tape measure, total station, photogrammetry and three-dimensional scanning. The results of the case studies were presented and compared with the objective of providing non-geodetic users with recommendations for suitable applications of the techniques. A comparative evaluation of the accuracy of the techniques in data capture and modeling of the northern gate of the Southern Theatre were presented in a comprehensive table. The authors concluded that hand surveying was labor intensive and that photogrammetry provided the simplest means of producing drawings. However, the authors further concluded that the effort to generate accurate and detailed models by means of photogrammetry was considerably high when compared to that of laser scanning. The publication stated that cost would inevitably be a deciding factor and that integration of the methods was often the recommended solution.

[53] Haddad, "From Ground Surveying to 3D Laser Scanner."

compares software within each documentation category, but does not produce a cohesive evaluation by equating the individual technologies. The author acknowledges a noteworthy fact stating the information provided will soon be obsolete; he asserts the predominant issue with collecting these characteristics for users is the lack of standards and common terminology within the three-dimensional documentation community.[54] He argues that technical standards, comparative data and best practice suggestions must be created for cohesiveness within the digital preservation movement.[55]

The most relevant comparative study on modeling techniques was *Image Based 3D City Modeling: Comparative Study* presented at the ISPRS Technical Commission V Symposium in 2014. Through this study the authors argued that the demand for three-dimensional documentation was increasing and a comparative study evaluating three-dimensional city modeling did not previously exist. The paper provides a comparative assessment of four image based three-dimensional modeling techniques: sketch based modeling, procedural grammar based modeling, close range photogrammetry based modeling and computer vision techniques. SketchUp, CityEngine, PhotoModeler and Agisoft Photoscan were chosen as the probationary software platforms. The study includes an introduction to the four techniques, as well as each method's strengths and weaknesses, but primarily addresses data acquisition methods, data processing techniques and output products. Commentary presents what the software platforms can and cannot do. The study provided tips for each of the documentation techniques and use of the software platforms; however, the authors did not delve into detailed methodology for either the capture of

[54] Remondino asserts that new users are approaching digital documentation methodologies, especially those involving range sensors, and a clear statement about the optical three-dimensional measurement systems is not available. He contends that technical standards, similar to those available for traditional surveying, should be created and adopted by the vendors of scanning and image data equipment. Remondino argues that common terminology is often internal to companies, but has not be implemented by the greater digital documentation field.

[55] Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning." 1126.

the data and images, nor the processing. As a strong reference, the publication provides multiple tables affording comparative summaries of strengths, weaknesses, input and output facilities. While this inclusion is an incredibly compelling comparative, a method similar to a checklist would provide a more concise and interpretable comparison where similar and dissimilar characteristics of the techniques could be more easily observed. Overall, this study produces a strong publication relatable to the objective of this thesis.[56]

There is a strong theme within the literature that to gain adequate knowledge, analysis and preservation of cultural heritage, many of the methods of documentation discussed are best used in combination. The combination of digital documentation methods for larger, more complex sites is highly supported by the literature. It is argued that a partnership between digital surveying and modeling methods allows for reaping the strengths of each technique, while making up for the potential weaknesses of others. Through this interdisciplinary work a new level of detail and accuracy is achieved in modeling.[57] While many practitioners address the overlap of three-dimensional documentation technologies for heritage, this topic of the literature focuses primarily on the direct assimilation of

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[56] Singh, Jain, and Mandla, "Image Based 3D City Modeling: Comparative Study."

[57] Fiorillo et al., "3D Digitization and Mapping of Heritage Monuments and Comparison with Historical Drawings"; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues"; Boehler and Marbs, "3D Scanning and Photogrammetry for Heritage Recording: A Comparison"; Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning"; Guarnieri, Remondino, and Vettore, "Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modeling"; C. Santagati, L. Inzerillo, and F. Di Paola, "Image-Based Modeling Techniques for Architectural Heritage 3D Digitization: Limits and Potentials" (2013 XXIV International CIPA Symposium, Strasbourg, France: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2013); Ristevski, Fassero, and Loomis, "Historic Preservation through Hi-Def Documentation"; Jason Church, "Close Range Photogrammetry vs. 3D Scanning for Archaeological Documentation" (Lecture, 3D Digital Documentation Summit, Presidio, San Francisco, CA, July 10, 2012), http://ncptt.nps.gov/blog/close-range-photogrammetry-vs-3d-scanning-for-archaeological-documentation/.

photogrammetry and active sensors, or laser scanning.[58] Significantly fewer studies are available that evaluate the integration of scanning and image-based techniques with three-dimensional modeling or GIS-based platforms. Where other studies do analyze the integration of three-dimensional modeling and multimedia GIS, it is typically limited to the specific integration of these two techniques.[59] Limited case studies or publications evaluate how three-dimensional modeling or metadata accumulation visible through GIS software could be further developed and integrated with laser scanning and photogrammetry models.

Interestingly, in the cases where photogrammetry and laser-scanning techniques are combined, the project more often entails an archaeological component with less emphasis

[58] Guarnieri, Remondino, and Vettore, "Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modeling"; Fiorillo et al., "3D Digitization and Mapping of Heritage Monuments and Comparison with Historical Drawings"; Boehler and Marbs, "3D Scanning and Photogrammetry for Heritage Recording: A Comparison"; Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning"; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues."

[59] Publications discussing the integration of three-dimensional models with GIS are limited compared to those available discussing photogrammetry and laser scanning. In *Integration of BIM and GIS: The Development of the CityGML GeoBIM* Extension, the authors argue that while there is an increasing interest in the integration of three-dimensional models with GIS, the modeling "people" and the GIS "people" still live in different worlds. The two programs use different technologies, standards and syntax. The authors assert that previous attempts to incorporate GIS and massing models has led to a focus on one or the other, rather than equal assimilation. With GIS integration, the three-dimensional aspect is typically Building Information Modeling (BIM) or Historic Building Information Modeling (HBIM). Essays discussing integration of other modeling software, such as SketchUp or Rhino are limited. Within the publications, three-dimensional GIS analysis is done using CityGML. CityGML is an international framework for three-dimensional city modeling. This platform has been adopted as it provides an interoperable foundation for modeling three-dimensional masses, topology and appearance properties. Current applications of this program are focused on city planning and disaster management. Limited publications on this topic can be attributed to the challenge of integrating the semantics between BIM and HBIM with GIS. The GeoBIM extension was developed to aid in addressing this issue. Leon van Berlo and Ruben de Laat, "Integration of BIM and GIS: The Development of the CityGML GeoBIM Extension" (5th International 3D GeoInfo Conference, November 3-4, 2010, Berlin, Germany, Berlin, Germany, 2010), http://www.academia.edu/1477477/Integration_of_BIM_and_GIS_The_development_of_the_CityGML_GeoBIM_extension; Conor Dore and Maurice Murphy, "Integration of Historic Building Information Modeling (HBIM) and 3D GIS for Recording and Managing Cultural Heritage Sites" (18th International Conference on Virtual Systems and Multimedia, Milan, Italy: Dublin Institute of Technology, 2012), 369–76.

placed on architectural heritage documentation.[60] However, there is a growing assertion through historic architectural organizations that photogrammetry and laser scanning are as valuable to the preservation field as they are to archaeology. In *The Mediated Environment of Heritage Recording and* Documentation (2013), Serra Akboy-Ilk states that photogrammetry and laser scanning technologies "have been utilized increasingly in historic preservation" over the past two decades and that "digital tools have a home in historic preservation."[61] Substantial literature does address the use of these platforms for architectural purposes and these documentation techniques are highly linked in terms of popularity, acceptance among users, deliverables and application.[62] However, in regards to the focus of this study, there are fewer pieces of literature and case studies specific to documenting streetscapes and blocks of historic architecture through photogrammetry and laser scanning than as seen through three-dimensional modeling and GIS.[63] Example case

[60] Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning"; Church, "Close Range Photogrammetry vs. 3D Scanning for Archaeological Documentation"; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues"; Li, Luo, and Zha, "3D Digitization and Its Applications in Cultural Heritage."

[61] Akboy, "The Mediated Environment of Heritage Recording and Documentation." 8,19.

[62] Other digital architectural documentation techniques include three-dimensional modeling, GIS applications and total station technology. However, the products generated from these technologies are less comparable to the deliverables experienced with laser scanning and photogrammetry. The difference in required data input and processing techniques renders it more difficult for practitioners to combine these technologies with laser scan or photogrammetric data. In contrast, the use of laser scanning and photogrammetry are more widely discussed due to overlapping characteristics desirable for a preservation documentation campaign. These technologies' ability to rapidly capture data, their high level of accuracy and their non-intrusive character during data accumulation links the laser scanning and photogrammetry technologies and fosters their popularity. Boehler and Marbs, "3D Scanning and Photogrammetry for Heritage Recording: A Comparison"; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues"; Li, Luo, and Zha, "3D Digitization and Its Applications in Cultural Heritage"; Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation"; Doyle, "3D Scanning Gives World's Historic Sites New Life"; Logan Ward, "The Preservationist's New Superpowers - National Trust for Historic Preservation," National Trust for Historic Preservation, *PreservationNation Blog*, (Summer 2012), http://www.preservationnation.org/magazine/2012/summer/the-preservationists-new.html?utm_source=facebook&utm_medium=like&utm_campaign=The Preservationist's New Superpowers.

[63] This publication is one of few to specifically discuss the documentation of cities' streetscapes. The authors discourse the use of photogrammetry for street side documentation in contrast to the more popular digital documentation method of LiDAR. Leberl et al., "Automated Photogrammetry for Three-Dimensional Models of Urban Spaces."

studies are represented through CyArk's documentation of New Orleans and Philadelphia; however, academic sources have yet to thoroughly evaluate these projects due to their relative newness.[64] Instead of a broader architectural model, practitioners primarily study the documentation of objects, single buildings and monuments; single entities that do not relate to their historic surroundings as facades arguably do. An exception to the documentation of single structures can be made in the field of archaeology, where landscapes and cultural ruins have been digitally documented through integrated photogrammetry and laser scanning.[65] However, these studies do not provide a comparable analysis to the documentation of historic streetscapes of cities this thesis pursues.[66]

Similar to the literature discussing digital documentation technologies, publications examining the benefits and drawbacks of software packages for photogrammetry and laser scanning are typically supported through case studies. General conclusions are formed that are consistent through the literature, but the capacities and limitations argued of the software

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[64] CyArk is a non-profit organization founded in 2003 with the goal of ensuring that heritage sites are available to future generations, while making the sites and structures uniquely accessible for today's generation. The organization uses new digital documentation technologies to create three-dimensional replications of cultural heritage. CyArk's 500 Challenge is an ambitious goal to digitally document 500 cultural heritage sites within the next five years. Within this program, the organization has established a project group referred to as "Historic Cities". Partnering with HERE, a branch of the Nokia Corporation, CyArk has digitally documented the streetscapes of both New Orleans and Philadelphia through laser scanning. "CyArk."

[65] Boehler and Marbs, "3D Scanning and Photogrammetry for Heritage Recording: A Comparison"; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues."

[66] Doyle, "3D Scanning Gives World's Historic Sites New Life"; Ward, "The Preservationist's New Superpowers - National Trust for Historic Preservation"; Li, Luo, and Zha, "3D Digitization and Its Applications in Cultural Heritage"; Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation"; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues"; Boehler and Marbs, "3D Scanning and Photogrammetry for Heritage Recording: A Comparison."

packages are specific to the project being addressed.[67] Prevalent software acknowledged for data processing includes Geomagic, Cyclone and Polyworks for laser scanning data, and Autodesk 123D Catch, Agisoft PhotoScan and PhotoModeler Scanner for photogrammetry imagery.[68] When comparing software platforms for the data processing phase of digital documentation, authors reach a general consensus on valued software characteristics. The literature states that processing and rendering software packages are chosen based on the quality of results desired, budget, time and required hardware.[69]

There is a general understanding and argument throughout the literature that photogrammetry is suitable for the documentation of structures and archaeological sites, as it contains detailed information about the surface of the structure and can be more easily interpreted than drawings.[70] When tested against laser scanning for the recordation of facades, laser scanning did not sufficiently record degradation in the surface materials; however, texture mapping produced through photogrammetry impressively displayed

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[67] Through their published case study, the authors of *From Ground Surveying to 3D Laser Scanner: A Review of Techniques Used for Spatial Documentation of Historic Sites* were proponents for the PhotoModeler and Scene software platforms. While the authors of *Image-Based Modeling Techniques for Architectural Heritage 3D Digitalization: Limits and Potentialities* acknowledge a variety of applicable processing platforms for photogrammetry, Autodesk's 123D Catch was referenced throughout the methodology and conclusions. In contrast, *Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling – Some Critical Issues* not only addressed multiple software platforms for laser scanning and photogrammetry, but also employed all the programs for various phases of the processing and rendering stages. Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues"; Santagati, Inzerillo, and Di Paola, "Image-Based Modeling Techniques for Architectural Heritage 3D Digitization: Limits and Potentials"; Haddad, "From Ground Surveying to 3D Laser Scanner"; Guarnieri, Remondino, and Vettore, "Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modeling"; Chalal and Balbo, "Framing Digital Tools and Techniques in Built Heritage 3D Modelling: The Problem of Level of Detail in a Simplified Environment."

[68] Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues."

[69] Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning." 1106, 1115.; Church, "Close Range Photogrammetry vs. 3D Scanning for Archaeological Documentation."

[70] Haddad, "From Ground Surveying to 3D Laser Scanner."

the weathering patterns of the structure's surface.[71] A more widespread acceptance of photogrammetry for preservation is attributed to an increase in the availability of low cost open source software programs for image-based modeling. The authors of *Generating Precise and Accurate 3D City Models Using Photogrammetric Data* support this with the conclusion that "photogrammetry appears to provide the only economic means to acquire truly three-dimensional city data."[72] Authors propose that photogrammetry offers characteristics such as ease of use, high visual quality of the reconstructed model and ability to interact and edit the results.[73]

Photogrammetry, used within the preservation field, is typically well received. However, several publications denounce its use, arguing it is a program that requires significant processing experience, and can result in multiple campaigns of image documentation to gather adequate data.[74] Author Naif Adel Haddad asserts in *From Ground Surveying to 3D Laser Scanner: A Review of Techniques Used for Spatial Documentation of Historic Sites* (2011) that successful photogrammetry documentation requires "high-skilled photographers."[75] The authors of *Applications of Digital Photogrammetric Methods for Preservation Documentation of Historic Homes* (2012) contend that while photogrammetry

[71] The authors of this publication used the ancient theatres of Jerash, the Southern Theatre and the Northern Theatre, as a case study to perform a comparison of three-dimensional scanning and photogrammetry to record architectural heritage. Characteristically like parts of the structures were recorded by both photogrammetry and laser scanning. Images in the publication provide a comparison of the level of detail and visuals obtainable through the two documentation technologies. The authors noted that while laser scanning was precise in measurements, the technique had difficulties with the portrayal of the material surfaces. On the other hand, the authors observed that documentation by photogrammetry contained adequate information about the surface detail of the structure. *Ibid*.

[72] O. Emem and F. Batuk, "Generating Precise and Accurate 3D City Models Using Photogrammetric Data" (YTU, Division of Photogrammetry and Remote Sensing, n.d.), http://www.isprs.org/proceedings/XXXV/congress/comm4/papers/386.pdf.

[73] Akboy, "The Mediated Environment of Heritage Recording and Documentation"; Santagati, Inzerillo, and Di Paola, "Image-Based Modeling Techniques for Architectural Heritage 3D Digitization: Limits and Potentials."

[74] "Applications of Digital Photogrammetric Methods for Preservation Documentation of Historic Homes"; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues"; Haddad, "From Ground Surveying to 3D Laser Scanner."

[75] Haddad, "From Ground Surveying to 3D Laser Scanner." 112.

is possible for cities to adopt, the technique requires "the right amount of training and expertise" and "takes time to build the skill set necessary…to implement." Several authors argue that if images are not properly acquired, the resulting data and three-dimensional model will be incorrect.[76] Literature points out several limitations of the technique, such as application to architecture on narrow streets, as the user is prevented from obtaining suitable distance from the subject. Several authors also express that photogrammetry is not well matched for objects with irregular surfaces lacking a clearly defined structure; arguably, laser scanning would be a better technique with this application.[77] This is supported by literature stating that while photogrammetry is still widely used, it has seen recent pressure from laser scanning technologies.[78]

Users have generally divided laser scanning into the categories of airborne laser scanning (ALS, LiDAR), terrestrial laser scanning (TLS) and handheld scanners.[79] In both publications and case studies, terrestrial laser scanning is argued to have the most prominent

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[76] These assertions seem to be especially true with what the authors refer to as "fully automated black-box tools" used for processing the image data. "Applications of Digital Photogrammetric Methods for Preservation Documentation of Historic Homes." 15.; Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues." 8.

[77] Santagati, Inzerillo, and Di Paola, "Image-Based Modeling Techniques for Architectural Heritage 3D Digitization: Limits and Potentials"; Haddad, "From Ground Surveying to 3D Laser Scanner."

[78] G. Forlani, R. Roncella, and C. Nardinocchi, "Where Is Photogrammetry Heading To? State-of-Art and Trends." (Geodesy and Geomatics, Accademic Nazionale dei Lincei in Rome: DICATeA, 2014).

[79] Airborne laser scanning (ALS) involves data captured through use of an aircraft; the technology evolved as the hardware became utilized for airborne terrain modeling, specifically within the forestry industry. LiDAR is a term attributed to the same hardware, but favored in the United States. An integral part of ALS or LiDAR is that the hardware applies filters to separate the "ground" from the '"non-ground" data strikes. Terrestrial laser scanning (TLS) uses the same principles as LiDAR, but is ground based. TLS is most useful for capturing small, relative to those captured from an aircraft, irregular objects, such as buildings and landforms. The author of *3D Laser Scanners: History, Applications, and Future* contends that TLS is a new and efficient method for digitizing large objects and scenes. Hand-held laser scanners create a three-dimensional image as a laser is projected onto an object and the distance to its surface is measured. This method of scanning is less applicable to cultural heritage sites and structures. Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning"; Mostafa Ebrahi, "3D Laser Scanners: History, Applications, and Future" (Assiut University, October 2011).

place in architectural heritage documentation.[80] Arguments for the use of laser scanning technology all address the characteristics of speed and reliability. Authors stress the value of laser scanning to heritage as it produces point cloud data accurate to millimeters and impossible to match in speed, resulting in high resolution, detailed models.[81] Arguments made through case studies assert that complex surfaces can easily be captured with lasers, and if needed, converted to two-dimensional applications.[82] Although decreasing, a major disadvantage of laser scanners remains their price. Economics of laser scanning have been argued as both expensive and cost-efficient in different reports. While the scanning equipment and software costs more than manual surveying, literature argues that lasers capture data quickly and accurately, and depending on the size of the structure, these

[80] Author Serra Akboy-Ilk asserts that laser scanning has revolutionized cultural heritage documentation, allowing practitioners the opportunity to now comfortably scan all types of historic surfaces, some not feasible with hand recording. Mark Schara of the National Park Service reiterates this assertion, stating that with laser scanning technologies, the Historic American Buildings Survey (HABS) now has the ability to undertake large documentation projects. HABS welcomed the introduction of laser scanning technology in the 1990s. Schara explains that the scale of structures and sites, as well as their irregular and organic forms created difficulties during hand recording that are now obsolete with laser scanning. Ebrahi, "3D Laser Scanners: History, Applications, and Future." 29.; Akboy, "The Mediated Environment of Heritage Recording and Documentation." 12, 16.

[81] In *3D Laser Scanners: History, Applications, and Future*, the author asserts that laser scanning produces a reliable and accurate survey for preservation and restoration of heritage sites. Laser scanning accurately measures points in a matter of seconds, creating a point cloud that is incredibly precise compared to that of hand recording and modeling. With scanning technology, the pace of recording has been transformed from weeks of fieldwork to several days' labor. Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning." 1106, 1115.; Ebrahi, "3D Laser Scanners: History, Applications, and Future." 31, 41.; Akboy, "The Mediated Environment of Heritage Recording and Documentation." 16.

[82] Laser scan data may be converted to CAD or other imaging programs for use in conservation, management, restoration, virtual tourism or education. Ebrahi, "3D Laser Scanners: History, Applications, and Future." 41.; Akboy, "The Mediated Environment of Heritage Recording and Documentation." 12.

characteristics can reduce the billable hour cost compared to that of manual documentation.[83]

Hardware and data storage appear to be the greatest arguments against the use of laser scanning technology for architectural heritage documentation. To efficiently utilize this documentation technique, the user must have the correct computer hardware and sufficient memory for data.[84] Processing data requires extensive editing and is time consuming; the resulting three-dimensional model is data heavy and often cannot be run on computers and laptops with medium characteristics.[85] While this is not typically a challenge for firms employing commercial grade software, small organizations, such that you might find in towns, mid-sized cities or non-profits, may be limited within the processing phase of the technology.

Speaking broadly, the implementation of a purpose-built multimedia GIS was regularly referenced as a digitized version of an inventory or historic structures survey

[83] Several authors argue that laser scanning provides three-dimensional data that is more economically produced than that of traditional means of surveying. The authors argue that traditional means are "slow and cumbersome", while laser scanning produces accurate as-built models with very little time. In terms of service fees and billable time, laser scanning costs more than traditional means of manually surveying; however, the author of *3D Laser Scanners: History, Applications, and Future* argues that depending on the nature of the project, the cost to manually survey may exceed the cost of scanning. While improvements in software and the processing workflow have reduced the labor costs of laser scanning, the costs for the scanning equipment, labor to execute the scan, and labor for post processing are still relatively high compared to the techniques of photogrammetry and three-dimensional modeling. Ebrahi, "3D Laser Scanners: History, Applications, and Future"; Haddad, "From Ground Surveying to 3D Laser Scanner"; George C. Skarmeas, "From HABS to BIM: Personal Experiences, Thoughts, and Reflections," *APT Bulletin* 41, no. 4 (January 1, 2010): 51, http://www.jstor.org.libproxy.clemson.edu/stable/41000038.

[84] Ebrahi, "3D Laser Scanners: History, Applications, and Future." 36.

[85] While the data volume for photogrammetry documentation is dependent on the number of images and the images' resolution, laser scanning data generally produces a dense point cloud. The detailed accuracy of the scanning documentation method creates a dataset, which the authors contend is unsuitable for management due to its large size. Barsanti, Remondino, and Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues." 8.

throughout the literature.[86] Sources argue that creating an inventory is a critical step of a city endeavoring to be a good cultural heritage steward. These sources further contend that the program should not be limited to the GIS platform, but should additionally incorporate ontology to manage the relationships of the heritage data.[87] A component of the platform that analyzes the network of relationships within the historic metadata, rather than working solely in standard GIS layers was claimed by several authors, Carlisle, Avramides, Dalgity,

[86] GIS has traditionally been used with two-dimensional mapping as a cartographic tool to store, visual and analyze geographic data over large areas. Spatial data within GIS is not considered as accurate or detailed as data created through CAD systems. When applied to historical buildings, there is a prejudice regarding GIS, as the term geographical is interpreted as referring only to X, Y, Z coordinates. However, GIS does not have to be bounded to position coordinates; it can be used to refer to spatial relations. Juna Goda Papajorgji, "Merging Historic Preservation with Web Technologies: A Model for a GIS and Multimedia Historic Information System in Alachua County, Florida" (2nd Annual URISA 2003 Public Participation GIS (PPGIS) Conference, Portland, Orgeon, USA: URISA, 2003), 1–7; Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage"; Adena Schutzberg, "The Arches Project: Turning Open Source GIS into a Heritage Inventory and Management System," *Directions Magazine*, February 25, 2013, http://www.directionsmag.com/entry/the-arches-project-turning-open-source-gis-into-a-heritage-inventory-a/310721; David Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System," *Conservation Perspectives*, Fall 2013, 28.2 edition, http://www.getty.edu/conservation/publications_resources/newsletters/28_2/changing_heritage.html; P.K. Carlisle et al., "The Arches Heritage Inventory and Management System: A Standards-Based Approach to the Management of Cultural Heritage Information" (English Heritage, World Monuments Fund, J. Paul Getty Trust, 2014), http://www.getty.edu/conservation/our_projects/field_projects/arches/Carlisle_Dalgity_et_al_2014_Arches_Heritage_CIDOC.pdf; Dore and Murphy, "Integration of Historic Building Information Modeling (HBIM) and 3D GIS for Recording and Managing Cultural Heritage Sites." 370-371.; F. Remondino et al., "Evaluation of GIS and BIM Roles for the Information Management of Historical Buildings," vol. II– 5/W1 (XXIV International CIPA Symposium, Strasbourg, France: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2013), 284-285.

[87] Ontology within the GIS platform allows users to explore spatial relationships or demographic, cultural, economic and geographic areas. Schutzberg, "The Arches Project"; Carlisle et al., "The Arches Heritage Inventory and Management System: A Standards-Based Approach to the Management of Cultural Heritage Information"; Schutzberg, "The Arches Project"; Remondino et al., "Evaluation of GIS and BIM Roles for the Information Management of Historical Buildings." 285.

Myers and Wuthrich to be most successful and effective for recording heritage.[88] Literature drafted by the proponents for multimedia GIS applications typically argued that planning efforts within cities is the largest drive for this documentation technique, stating that for authorities tasked with managing numerous heritage entities, a digital inventory is the "most essential tool for decision making."[89] While city planning appears to have a much larger role in utilizing historic multimedia GIS platforms than was seen with laser scanning and photogrammetry, risk of destruction from natural disasters, an objective of laser scanning and photogrammetry, remains a prominent function of documentation through this methodology.[90]

Arguments for the creation of multimedia GIS-based web applications are easily relatable to cities, and sources contend that GIS is applicable at "national, regional, local or site scales" as well.[91] Authors and developers argue that the GIS method of recordation can be used by anyone with "basic to no knowledge of computer operations" and that it

[88] These authors argue that the GIS platform should provide for the association with "historical periods, cultures, and events", and whether the structures incorporate particular architectural styles or building technologies. The essays argue that the platform should be geospatially aware, but house customizable definitions for searching through the heritage information. These definitions and the inherent formal structure should provide for describing implicit and explicit concepts and relationships included with the architectural heritage documentation. The authors argue that an inclusion of this type allows for user to define the relationships they desire to track. With Arches specifically, a heritage inventory platform sponsored by the Getty Conservation Institute and the World Monuments Fund, the database represents the relationship of a "site to its name, period, location, actors, activities [and] architectural heritage." Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage"; Carlisle et al., "The Arches Heritage Inventory and Management System: A Standards-Based Approach to the Management of Cultural Heritage Information"; "The Arches Project Puts A Semantic And Geo-Spatial Spin On Cultural Heritage," *DATAVERSITY*, accessed September 12, 2015, http://www.dataversity.net/the-arches-project-puts-a-semantic-and-geo-spatial-spin-on-cultural-heritage/.
[89] Papajorgji, "Merging Historic Preservation with Web Technologies: A Model for a GIS and Multimedia Historic Information System in Alachua County, Florida"; Schutzberg, "The Arches Project"; Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage."
[90] Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System."
[91] Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage." 817.

is relatively inexpensive for organizations.[92] Additional arguments state that the program provides simple means for users to interact with the data through a web browser without abnormal platform requirements or downloads. With constant software development advances and high priced proprietary software licenses and upgrades, the implementation of a web-based multimedia GIS program was previously seen as too expensive for smaller cities and organizations. However, recent developments of digital information technologies, specifically GIS, as well as increased global access to the Internet has significantly improved the effectiveness and affordability of digital heritage inventories.[93] Case studies are available where a purpose-built GIS was implemented utilizing a lightweight technological solution due to limited budgets; developers support this choice stating that historic data does not change often, and a more advanced system would not be necessary for districts and cities.[94] Additionally, regarding affordable development, several publications have suggested that suitable platforms are available at no cost, providing a solid foundation for heritage institutions to customize to their objective and application.[95] Supporting the initiative for inexpensive platforms for heritage documentation through GIS, several companies have created templates for inventories emphasizing preservation context. Arches, supported by the Getty Conservation Institute and the World Monuments

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[92] Papajorgji, "Merging Historic Preservation with Web Technologies: A Model for a GIS and Multimedia Historic Information System in Alachua County, Florida"; Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage." 817, 819.

[93] Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage"; Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System."

[94] The implementation of a lightweight GIS solution was undertaken through a partnership between the GIS Division at the Department of Growth Management in Alachua County, Florida and the Department of Urban and Regional Planning at the University of Florida. The project consisted of a multimedia GIS based application for information regarding historic structures in Alachua County. This project was initiated to support preservation activities and related planning efforts of the local government. Authors of the publication argue that the GIS platform created for the county can serve as a prototype model to be implemented at minimal costs in other counties. Papajorgji, "Merging Historic Preservation with Web Technologies: A Model for a GIS and Multimedia Historic Information System in Alachua County, Florida."

[95] Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage." 817.

Fund, and the Environmental Systems Research Institute (ESRI) have led this enterprise. In 2012, ESRI published a Historic Buildings and Districts Conservation and Preservation Web Map template with editing capabilities for managing historical information about buildings.[96] Arches is creating a similar publication through their work with the City of Los Angeles.[97] Several avenues of literature contend that branded GIS software rarely fits the objectives of the cultural heritage field, resulting in organizations spending significant resources to customize inventory information systems. While this may be a concern for large undertakings of digital inventories, advocates argue that foundational templates can

[96] The Environmental Systems Research Institute, or ESRI is an internationally recognized supplier of Geographic Information System (GIS) software. ArcGIS is the application most commonly used of the ESRI products. The platform is acknowledged for integrating, storing, editing, analyzing, sharing and displaying geographic information. The 2012 addition of ArcGIS historic conservation and preservation resources has propelled the company further into the preservation field. The Historic Buildings and Districts Conservation and Preservation Web Map is a ArcMap editing template with a set of workflows for creating and managing historical information about structures. The Scanned Map Services for Historic Conservation and Preservation template is an ArcMap editing map with a georeferencing workflow for creating image services from scanned historic maps. "GIS Mapping Software, Solutions, Services, Map Apps, and Data," *ESRI*, accessed November 8, 2015, http://www.esri.com; Charlie Frye, "Historic Conservation and Preservation Web Map Templates | ArcGIS Blog," ESRI, *ArcGIS Resources*, accessed August 5, 2015, http://blogs.esri.com/esri/arcgis/2012/05/23/historic-conservation-and-preservation-web-map-templates/.

[97] Arches, developed by the Getty Conservation Institute and the World Monuments Fund is a new "open-source geospatial software system for cultural heritage inventory and management." The organizations used the perspectives of heritage professionals to create a purpose-built software platform, freely available, for the management of heritage information. The authors argue that with increasing threats to the cultural heritage, the need for a functional heritage inventory grew immensely over the last decades. Arches provides a common platform that does not rely on the costly proprietary software that many companies employ. The platform is intended for use in the international cultural heritage field and is freely available to use and customize, providing a valuable option for organizations on a budget. Applications for Arches include: identification and inventory, research and analysis, monitoring and risk mapping, planning for investigation, management and conservation activities, raising awareness among the public, all in regards to heritage places. Los Angeles, through their HistoricPlacesLA project, is the first United States city to implement the platform. The project serves as a historic resource inventory system for the City and includes detailed information on many designated resources. "Los Angeles Historic Resource Inventory," *HistoricPlacesLA*, accessed October 15, 2015, http://historicplacesla.org; "What Is Arches?," *Arches*, accessed September 12, 2015, http://archesproject.org/what-is-arches/; "Arches Project," *The Getty Conservation Institute*, accessed September 12, 2015, http://www.getty.edu/conservation/our_projects/field_projects/arches/arches_overview.html.

be sufficient for the architectural heritage of cities and communities.[98]

In addition to the broad conversation of platforms, several publications discuss design principles necessary for creating a successful open source, web-based GIS for heritage management. Reoccurring principles include incorporating international standards; making the platform broadly accessible, freely available, user friendly and efficient with minimal training; ensuring the system is economical to both sponsors and users; and permitting flexibility and customization. Arguably, through these principles, the primary objective to function as an inventory, as well as monitor threats to sites, record change over time, assess potential impacts of planning initiatives, and provide an avenue for research should be effectively accomplished.[99] The authors of *Changing the Heritage Inventory Paradigm* (2013) argue that for success in public education, research and heritage tourism, the multimedia system should address size, location, significance, appraisal of integrity and a means of categorization of the architectural heritage. Consistency in these principles should enable a comparison of historically significant structures, "appraisal of authenticity and integrity, and determination of relative significance."[100] While multimedia data to be included within the program seemed to vary throughout the published case studies, in *Changing the Heritage Inventory Paradigm*, the authors assert that to achieve an effective inventory, data can be structured in four categories: immovable heritage, historical events, historical people and documents. Theoretically, with these categories, the user should be able to discern relationships and observe overlap within the cultural heritage.[101]

Unlike the literature presented concerning photogrammetry and laser scanning

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[98] Papajorgji, "Merging Historic Preservation with Web Technologies: A Model for a GIS and Multimedia Historic Information System in Alachua County, Florida"; Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System"; Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage."
[99] Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System"; Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage." 819.
[100] Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System."
[101] *Ibid.*

documentation, publications concerning open-source multimedia GIS platforms for the documentation of architectural and archaeological heritage addressed a broad range of international standards. Publications assert that the standards identify essential items of information to be included in a digital inventory, helping to facilitate data sharing across political boundaries.[102] The International Committee for Documentation (CIDOC), sponsored by the International Council of Museums created the Conceptual Reference Model (CRM), a highly supported matrix within the literature.[103] The Conceptual Reference Model provides definitions and a formal structure for describing the concepts and relationships in cultural heritage documentation. The model is intended to provide a common semantic framework customizable for various heritage documentation endeavors, as well as be a common language serving as a guide for data modeling.[104] Semantic mapping, or a logical language for establishing relationships among heritage, was another more broad standard contended to be significant for multimedia GIS platforms. Advocates for the concept argued that semantics make it simpler for users to comprehend the value of culturally significant objects, allowing for the interpretation of the relationships between structures, names, periods, locations and architectural descriptions.[105] Additionally the Open Geospatial Consortium (OGC) has published technical documents that detail interfaces for software developers. The literature generally supports compliance with OGC standards as they assist in ensuring that the developed metadata system is compatible with

[102] Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System."
[103] Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage"; Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System"; Schutzberg, "The Arches Project"; Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning"; "The CIDOC Conceptual Reference Model," *International Council of Museums*, accessed September 12, 2015, http://www.cidoc-crm.org; Carlisle et al., "The Arches Heritage Inventory and Management System: A Standards-Based Approach to the Management of Cultural Heritage Information."
[104] "The CIDOC Conceptual Reference Model."
[105] Schutzberg, "The Arches Project"; Carlisle et al., "The Arches Heritage Inventory and Management System: A Standards-Based Approach to the Management of Cultural Heritage Information."

other GIS applications such as Google Earth and ArcGIS.[106] In summation, the literature encourages the inclusion of standards within multimedia GIS programs and argues that interoperability, or the ability of information technology systems and software applications to communicate and exchange data, is crucial to the cultural heritage field.[107]

While three-dimensional modeling is a recognized and accepted category of digital documentation for architectural heritage, compared to photogrammetry and laser scanning, this technique receives the least attention in the literature. The majority of the literature discussing the application of three-dimensional modeling for cultural and architectural heritage is concentrated on the excitement of Building Information Modeling (BIM) or Historic Building Information Modeling (HBIM); this is especially true because of the five-year control established for the literature review.[108] BIM serves as a parametric database model for a building's lifecycle, and is most often discussed in terms of semantic purposes, providing opportunity to integrate building component information within the model.[109] While BIM is most often used as a semantic tool, this thesis is looking only into the creation

[106] Schutzberg, "The Arches Project"; Myers et al., "Arches: An Open Source GIS for the Inventory and Management of Immovable Cultural Heritage"; Myers, "Changing the Heritage Inventory Paradigm: The Arches Open Source System."
[107] Schutzberg, "The Arches Project."
[108] Hung-Ming Cheng, Wun-Bin Yang, and Ya-Ning Yen, "BIM Applied in Historical Building Documentation and Refurbishing," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 25th International CIPA Symposium, XL (2015): 85–90; David M. Foxe, "Building Information Modeling for Constructing the Past and Its Future," *APT Bulletin* 41, no. 4 (January 1, 2010): 39–45, doi:10.2307/41000037; Dore and Murphy, "Integration of Historic Building Information Modeling (HBIM) and 3D GIS for Recording and Managing Cultural Heritage Sites"; van Berlo and Laat, "Integration of BIM and GIS"; F. Remondino et al., "Evaluation of GIS and BIM Roles for the Information Management of Historical Buildings," vol. II– 5/W1 (XXIV International CIPA Symposium, Strasbourg, France: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2013), 283–88.
[109] BIM is a recent advancement in computer-aided design (CAD) systems. BIM is a process where software is employed to create a single virtual model of a building's geometry; this becomes a visual representation of a database that contains information about the building's materials and assemblies. BIM and HBIM are different from traditional CAD systems and simpler three-dimensional modeling systems in that the platform is based on information enhanced parametric building elements. Foxe, "Building Information Modeling for Constructing the Past and Its Future." 40.; Dore and Murphy, "Integration of Historic Building Information Modeling (HBIM) and 3D GIS for Recording and Managing Cultural Heritage Sites." 370.

of massing and geometry of three-dimensional models. BIM, as well as other platforms such as Autodesk Revit Architecture, Google SketchUp and Autodesk 3D Studio Max are capable of creating three-dimensional massing models of architectural heritage without incorporating parametric data, although minimal literature is devoted to this application.

In comparison to photogrammetry or laser scanning, literature discussing three-dimensional modeling is more architecturally concentrated and involves significantly less influence of cultural and archaeological heritage. Overlap of the digital documentation technologies is again observed, primarily where the creation of a three-dimensional model through BIM is used alongside laser scanning and photogrammetry data.[110] While practitioners seem to be largely infatuated with BIM and HBIM and the complex constructions they create, others argue for the employment of Google SketchUp. Multiple publications claim SketchUp is easy to learn and easy to use for digitization.[111] Additionally, the platform is free and available to a large number of non-technical users, contrary to BIM.[112] SketchUp is argued to be a good option for "normal visualization projects."[113] In *Digitization and Preservation of City Landmarks Using Limited and Free Web Services* (2013), the author argues that a significant advantage of the SketchUp platform is that

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[110] Cheng, Yang, and Yen, "BIM Applied in Historical Building Documentation and Refurbishing"; Quattrini et al., "From TLS to HBIM. High Quality Semantically-Aware 3D Modeling of Complex Architecture."

[111] SketchUp, previously a product of Google, but now owned by Trimble, is a three-dimensional computer graphics program that follows the sketch-based modeling approach. While the authors of *Digitization and Preservation of City Landmarks Using Limited and Free Web Services* contend that more complex methods exist for three-dimensional documentation of cultural and architectural heritage, they assert that SketchUp is an effective solution to creating a three-dimensional city model. Fotis Lazarinis and Sotiris Georgiou, "Digitization and Preservation of City Land-Marks Using Limited and Free Web Services," *Digital Presentation and Preservation of Cultural and Scientific Heritage* 3 (2013): 176–82; Singh, Jain, and Mandla, "Image Based 3D City Modeling: Comparative Study."

[112] Lazarinis and Georgiou, "Digitization and Preservation of City Land-Marks Using Limited and Free Web Services." 181.

[113] As a sketch tool, SketchUp is accurate in producing building massing models and is recognized by the authors for its fast processing speed. However, the simplicity of the software makes its deliverables incomparable to that of laser scanning or photogrammetry. SketchUp models lack textured quality and high-resolution renderings, and do not contain the three-dimensional point cloud available with other digital documentation technologies. Singh, Jain, and Mandla, "Image Based 3D City Modeling: Comparative Study." 542-543.

models can be created through two methods of data: by knowing their shape and dimensions or by having photographs of the surfaces. Additionally, the option to link the structure to coordinates on Google Earth has arguably made this a popular platform.[114] Generally, the literature argues that for three-dimensional architectural models there is a plethora of software available.

An argument was posed that a downfall of creating a three-dimensional model, rather than utilizing laser scanning or photogrammetry is the ongoing refinement of the model and the question of completeness. Literature contends that generating a three-dimensional model could be an endless task of modeling details, whereas laser scanning and photogrammetry capture all surface details through data.[115] Some publications explain the more user-friendly three-dimensional modeling options used in organizations with modest operating budgets result in low detailed models useful for virtual tourism, but not adequate for long-term preservation.[116] Following this theme, the case has been considered that the success of a three-dimensional model relies on the quality of the model and reliability of the geometry, a contention not necessarily applicable to laser scanning and photogrammetry.[117] While the generation of three-dimensional models has become a larger conversation in recent years, authors attributed this to more widespread use and

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[114] Lazarinis and Georgiou, "Digitization and Preservation of City Land-Marks Using Limited and Free Web Services." 176-181.

[115] Through this publication, the author poses the question of "how complete is complete". David M. Foxe, "Building Information Modeling for Constructing the Past and Its Future," *APT Bulletin* 41, no. 4 (January 1, 2010): 45, doi:10.2307/41000037.

[116] In *Framing Digital Tools and Techniques in Built Heritage 3D Modelling: The Problem of Level of Detail in a Simplified Environment,* when discussing the generation of low resolution and low detailed models, the authors reference Fabio Remondino in *Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning* to further explain that "…when a three-dimensional model is generated, it is often subsampled or reduced to a two-dimensional drawing due to the lack of software or knowledge in properly handling three-dimensional data." Moulay Larbi Chalal and Riccardo Balbo, "Framing Digital Tools and Techniques in Built Heritage 3D Modelling: The Problem of Level of Detail in a Simplified Environment," *The International Journal of the Constructed Environment* 4 (2014): 40.

[117] Quattrini et al., "From TLS to HBIM. High Quality Semantically-Aware 3D Modeling of Complex Architecture."

integration with laser scanning and photogrammetry.

The state of literature concerning digital documentation of historic architecture is fragmentary. There seems to be substantial implied overlap between cultural, archaeological and architectural heritage documentation. These preservation initiatives are collected together with greater emphasis on the cultural faction of the division, significantly less literature addresses exclusively architectural heritage. Directly addressing this thesis question, several avenues of the literature argued that while there are immense amounts of digital documentation platforms available for the architectural heritage discipline, the field lacks common terminology, specifications and performance benchmarks, making it challenging for non-specialists to select an efficient technique for the application. Robert Warden asserts, "technology at this point is outpacing methodology", as practitioners see new platforms frequently entering the market, but the data processing software available is slower in evolution.[118] Insufficient literature is available that systematically compares, with neutral position, the categories of digital techniques and platforms for architectural heritage recordation. Employment of the systems is generally observed through published case studies, where the method and platform seem to have been chosen by personal preference. The wide support for integration of the digital methods poses an additional obstacle for potential users when gauging a parallel comparison of laser scanning, photogrammetry, three-dimensional modeling and multimedia GIS. In response, this thesis will be directed towards producing a more evenhanded comparison of the digital technologies utilized for architectural heritage documentation within cities and historic communities. Emphasis on the façade-level of the buildings, a rare theme in the literature, as well as the efficacy of the technologies, will be further explored in this study.

[118] Warden, "Towards a New Era of Cultural-Heritage Recording and Documentation." 8.

CHAPTER THREE

METHODOLOGY

Data necessary for the thesis involves three separate types of sources. Publications addressed through the literature review provide academic perspective on the digital documentation technologies presently used to record cultural and architectural heritage. Analysis of four case studies, correlating to the documentation techniques being analyzed, furnishes the second avenue of data. The third, and largest source of data is generated through a trial of each of the digital documentation technologies being addressed within the thesis. Through the documentation trials, with supplemental support from the literature and case studies, the thesis works towards answering the question of how a detailed understanding of the major types of digital documentation and a parallel comparison of their efficacy can inform the selection of a specific method when a city, such as Charleston, embarks on a digital architectural heritage documentation campaign.

Primary Research & Establishment of Categories

To understand if digital documentation technologies are applicable to the preservation field for architectural heritage recordation, it is necessary to first determine acceptable practices for available platforms. The thesis commences with a literature review providing a brief introduction to the current academic discussions regarding digital documentation technologies in the historic preservation field. Knowledge of how the digital documentation methods are employed with regard to architectural heritage, as well as current dialogues regarding equipment and platforms used for endeavors similar to this thesis, are incorporated within this initial section. Perspective from the literature review, looking towards the apparent strengths, weaknesses, expected deliverables and capacities of the digital documentation techniques provides insight as to how these technologies were previously used within the preservation field and what outcomes practitioners have generated, providing a foundation of expectations for the data to be generated and analyzed within the thesis.

Beyond the initial literature review, the initial methodological step of this thesis was to establish categories relating to the digital documentation technologies utilized within the historic preservation field. This step is significant as it provided guidance for not only literature to be reviewed and discussed, but also guided the selection of case studies to be analyzed and the programs to be undertaken as a trial. The digital documentation technologies being analyzed through this thesis for use in recording architectural heritage have been divided into four categories: laser scanning, photogrammetry, three-dimensional modeling, and multimedia geographic informational systems (GIS). These technologies were chosen for their application to both the preservation field for documentation of architectural heritage, as well as application and potential feasibility for a city or historic community. The documentation techniques were divided according to their similarities in input data requirements, equipment and platforms utilized, as well the likeness of the final product generated. Through research, this appears to be a standard division of technological platforms for preservation objectives.

Through the literature review, it was recognized and acknowledged that practitioners seldom employ just one digital documentation technique for recordation. Academic discussions and published case studies demonstrated, and often argued for, the overlap and integration of the technological documentation methods; few case studies representing "pure" applications of the technology were available. However, this thesis asserts that an effective and parallel comparison of the digital documentation technologies employed for recording architectural heritage by cities cannot be established if hybrid methods are used and categories are not established. Thus, the division of techniques into laser scanning, photogrammetry, three-dimensional modeling and multimedia GIS was determined.

Case Study Analysis

Four case studies, corresponding with the four digital documentation technologies, are analyzed to further understand the potential deliverables of these platforms. The case studies chosen for analysis include: the Virtual Historic Savannah Project, Historic New Orleans, Historic Columbia Foundation's Interactive Neighborhood Tours and the University of Maryland Baltimore County.

The case studies were chosen for specific unifying elements concerning both the locality's size and the technology employed for documentation. Savannah, Georgia; New Orleans, Louisiana; and Columbia, South Carolina are all mid-sized cities - comparable to Charleston - with recognized historic neighborhoods. The University of Maryland Baltimore County campus was selected for its comparable size to a historic district of a city, as well as its similar area to the other case studies. The similarity of size makes the projects comparable to Charleston, South Carolina. Additionally, it was important that the case studies chosen for analysis had a variety of architecture, and were either involved in or could potentially become involved in the preservation movement. These considerations define prototype documentation projects with similar architectural sizes and types, city layouts and underlying city preservation objectives. In addition to the parameter of size, the case studies were chosen for their "purity" in methodology; the case studies selected for analysis engage only one of the digital documentation techniques being studied in the thesis. Many case studies recognized within the literature review were accomplished through multiple, overlapping methods. As this thesis concentrates on a parallel comparison of technologies, corresponding case studies were chosen for their singular use and portrayal of a digital documentation technique. Case studies that employed integrated or hybrid methods of documentation were not selected, as this would not support the objective of creating a comparative analysis of documentation methods. This defining feature of pureness is critical, as it significantly aids in the analysis of the case studies, providing further substantiation for the successes, applications and obstacles of the digital documentation technologies to be potentially encountered by cities documenting architectural heritage.

Due to the restraints of available publications, the data for the analysis of the four case studies is generated almost entirely from interviews with the sponsoring organization and/or the platform developer, if applicable. Newspaper, journal and magazine articles, as well as conference papers and presentations generate secondary, supportive material; these sources generally address the success and acceptance of the programs. A formal questionnaire was not issued since each of the case studies employs different means of data accumulation and processing; however, the same prompts were discussed with each of the case studies, allowing for further explanation should the interviewee have decided to elaborate.[119] The prompts developed to generate data for the case study analysis include:

- Who are, or have been the key people involved with the project? Who helped with the initial design; who accumulated the data; who processed the data; who has been in charge of platform maintenance; and what were their backgrounds and relationship to the historic preservation field?
- Who are the primary users and viewers of the program? Were these the intended users?
- In regards to your project, where have you seen the successes and benefits of this digital documentation technique?
- What have been the obstacles or failures involved with this digital documentation method?
- In terms of efficacy, how did the digital documentation method perform in your opinion; has this method adequately documented the city's architectural heritage, and do you think for posterity it will be successful displaying the city's architectural evolution?

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[119] Transcripts of the interviews for the case studies are included in the appendices of the thesis.

•In terms of cost, was this a feasible undertaking or would you describe it as feasible for a city or community?

•How did ease-of-use rank specifically during the data accumulate phase? And specifically the data processing phase?

•Generally, was the digital documentation campaign successful?

•Would you employ the same digital documentation technology again, or would you employ a different method?

Evaluation of the case studies provides a comparison and generates an introduction to each category of the digital documentation methods. As stated, data primarily came from the prompts generated for the sponsoring organizations and creative developers of each case study. This data, in conjunction with available publications, helps to understand why cities undertake architectural heritage documentation campaigns. This section generates a discussion of the apparent successes and shortcomings in efficacy, user-friendliness, primary application and users, and engagement of visuals. To further understand why each of the case study projects was developed, this section of the thesis provides a brief explanation of each case study analyzed including a description of the digital documentation technology utilized, the data processing program employed, a description of the display mechanisms used and a summation of the undertakers, noting whether the project was fulfilled by a nonprofit organization, creative developer or city officials.

Trial Documentation

A trial of each digital documentation technique is undertaken following analysis of the case studies. These trials are analyzed and evaluated according to pre-established parameters. This investigative trial generates the primary data to establish a more parallel comparison of the technologies' efficacy for use by cities for architectural heritage documentation.

The objective of the investigative trial is to generate a digital documentation deliverable from each of the four documentation technologies selected, to aid in the creation of a parallel comparison and inform the selection of a specific method when a city embarks on a digital architectural heritage documentation campaign. Within this section of the thesis, a trial model of each of the four methods being studied – laser scanning, photogrammetry, three-dimensional modeling and multimedia GIS – is generated. The intention of the trial is not to create a professional grade product, but rather to create a model representative of a selection of the city's architecture, completed as best as possible under the time restriction established. The purpose of the study is to inform the selection of a technique for the documentation of a city's architectural heritage, not the documentation of singular structures acknowledged for their historic significance.[120] A block of architecture, rather than a singular structure has been chosen to represent the evolving architectural heritage of Charleston. The use of a city block in Charleston for documentation serves as

[120] The documentation of singular structures is an undertaking that has already been initiated at numerous historic sites. Academic publications and case studies primarily evaluate the documentation of single structures and archaeological complexes. These structures and sites are privileged for their size, grandiosity or related significance. Seldom seen is the documentation of blocks of urban centers or the facades of multiple buildings. Examples of digital documentation initiated at well-recognized historic structures include, Drayton Hall in Charleston, South Carolina; Montpelier in Orange, Virginia; and the Notre Dame Cathedral in Paris. Preservation technicians at Drayton Hall have recently begun a digital restoration project of the interior of the house circa 1765. This virtual restoration includes original paint colors and furnishings. Laser scanning is being used at Notre Dame in Paris to discover the anomalies of the Cathedral's structure. Through the Digital Montpelier Project, three models have been created of the structure that trace the Mansion's evolution from 1764 to 1812. F. Fiorillo et al., "3D Digitization and Mapping of Heritage Monuments and Comparison with Historical Drawings," vol. 11–15/W1 (2013 XXIV International CIPA Symposium, Strasbourg, France: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2013), 133–38; Renju Li, Tao Luo, and Hongbin Zha, "3D Digitization and Its Applications in Cultural Heritage," in *Digital Heritage*, ed. Marinos Ioannides et al., Lecture Notes in Computer Science 6436 (Springer Berlin Heidelberg, 2010), 381–88, http://link.springer.com/chapter/10.1007/978-3-642-16873-4_29; "The Digital Montpelier Project," *Digital Montpelier*, accessed July 8, 2015, http://www.digitalmontpelier.org; Aria Danaparamita, "Coming to Drayton Hall: Historic Preservation in 3D," National Trust for Historic Preservation, *Saving Places*, (July 22, 2013), https://savingplaces.org/stories/coming-to-drayton-hall-historic-preservation-in-3d; Rachel Hartigan Shea, "Historian Uses Lasers to Unlock Mysteries of Gothic Cathedrals," *National Geographic*, June 22, 2015, http://news.nationalgeographic.com/2015/06/150622-andrew-tallon-notre-dame-cathedral-laser-scan-art-history-medieval-gothic/.

the unit of analysis; data was accumulated from the public right-of-way and through public documents; full house models were not produced.

The block chosen for the digital documentation trial is on Church Street between Queen Street and Chalmers Street, located within the Old and Historic District of Charleston, South Carolina. This block of structures was chosen with several parameters in mind. This block was selected for its representation of Charleston's architectural heritage; the widely recognized Charleston single house type is prominent in this area. Its central location within Charleston's Historic District lends an enormous amount of history and architectural interest that will likely be pursued through future generations. A block that incorporates both shorter and taller buildings was selected for the purpose of determining how the height of structures to be documented would be a factor in the digital documentation methods.[121] The notion of gathering data at an angle serves as a predetermined obstacle placed on the trial for means of generating a strong comparison against the three-dimensional modeling and multimedia GIS technologies.[122]

Several other parameters were considered when choosing the block for the trial documentation. For the multimedia GIS data accumulation, it was necessary to verify that historic data would be readily available, so labor could be expended on developing the program, rather than discovering historic documents and photographs. With application to

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[121] The presence of taller buildings will most likely be a feature in all cities; in Charleston, presumably as well as in other cities, for trial purposes, the presence of a taller structure could typically be accomplished by including a steeple in the documentation block. However, it was discovered that in Charleston specifically, the majority of churches span the entirety of the block and are typically flanked by churchyards and parking lots, limiting the variety of architecture to be documented. To ensure recording architectural diversity larger than a single church property for the investigative trial, taller buildings have been established at a height of approximately four stories or greater. Within this documentation trial, this parameter is being achieved through the inclusion of the French Huguenot Church.

[122] Naif Adel Haddad, "From Ground Surveying to 3D Laser Scanner: A Review of Techniques Used for Spatial Documentation of Historic Sites," *Journal of King Saud University - Engineering Sciences* 23, no. 2 (June 2011): 109–18, doi:10.1016/j.jksues.2011.03.001; C. Santagati, L. Inzerillo, and F. Di Paola, "Image-Based Modeling Techniques for Architectural Heritage 3D Digitization: Limits and Potentials" (2013 XXIV International CIPA Symposium, Strasbourg, France: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2013).

the laser scanning and photogrammetry technologies, the amount of vehicle and pedestrian traffic on the block, as well as the expanse of tree coverage was considered. Although not imperative characteristics, these factors, as well as the height of the buildings being documented, are potential obstacles in documenting architectural heritage. Church Street between Queen Street and Chalmers Street does not have expansive tree coverage; trees do line parts of the sidewalk, however, adequate views of the building facades are still available. Typical of the central core of any downtown digital documentation campaign, the trial block affords the obstacles of parked vehicles, moving vehicles and pedestrians. However, this aspect is unavoidable in other cities' main streets and a likely reality in any application of digital documentation.

In the investigative trial for the four digital documentation technologies being evaluated, the time allocated for the field capture and data accumulation, data processing and data post-processing or rendering was limited to ten hours for each method. This time allocation was formed through an educated estimate.[123] The division of labor and time into data accumulation, data processing and rendering for the laser scanning, photogrammetry, three-dimensional modeling and multimedia GIS documentation are anticipated to be different. By including the overall time cap of ten hours, flexibility can be established within each of the data phases. The trial block on Church Street was chosen to establish boundaries for the documentation, providing an equal area for the concluding analysis. Time required

[123] The ten-hour time allocation was determined with guidance from practitioners who are familiar with both the documentation technologies being employed, as well as the trial block. It was suggested that data accumulation time be budgeted roughly the same for laser scanning and photogrammetry. These methodologies are assumed to potentially be the most time consuming of the four technologies being explored. An average laser scan takes approximately fifteen minutes. With this in mind, it was surmised that two hours would be reasonable for scanning the trial block. As a rule of thumb, for every hour spent on site, approximately three hours should be planned for processing and rendering. These guidelines helped to establish the ten-hour time cap. Time required for the three-dimensional modeling and multimedia GIS techniques generally depends on the level of detail to be modeled and the amount of historic data to be incorporated into the GIS platform, and therefore were limited to the ten-hour restriction. Amy Elizabeth Uebel, Thesis Methodology Questions, Email, October 26, 2015.

for the capture and processing of data for each of the technologies is different; however, the overall time is the same for each, establishing a means for comparable analysis of labor and produced deliverable.

Data Accumulation and Field Capture

Data is accumulated to allow for the digital documentation of the sample block on Church Street within Charleston's Old and Historic District. Field capture and data accumulation are distinct for each of the four methods of digital documentation being undertaken and are addressed individually.

Trial One: Laser Scanning

Raw data for the terrestrial laser scanning documentation trial was captured with the help of the Clemson University Warren Lasch Conservation Center and the organization's FARO Focus^{3D} X 330 laser scanner. The FARO Focus scanner was chosen principally for the availability of the equipment and corresponding software, as well as guidance from the staff at the Warren Lasch Conservation Center. FARO is a company internationally recognized for three-dimensional measurement, imaging and realization technology employed in a variety of applications, with architectural heritage being one of them. The FARO Focus^{3D} X 330 is ideal for this trial and the objective of this thesis due to its compact, lightweight and portable characteristics, specifically being designed for outdoor applications. The FARO Focus^{3D} X 330 takes measurements up to a distance of 330 meters, with accuracy up to two millimeters.[124] Raw data was captured of the trial block through the scans and presented in the form of a data point cloud to be used for processing and modeling.

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[124] "FARO Focus3D Overview," *FARO*, accessed October 20, 2015, http://www.faro.com/en-us/products/3d-surveying/faro-focus3d/overview.

Trial Two: Photogrammetry

Raw data for the photogrammetry portion of the trial stemmed from a series of digital images taken of the street-fronting façades of the structures on the trial block. The block of structures cannot be captured in one photograph; the compilation of a large number of photographs is required to capture the block as a whole. The method in which the images are captured has the most significant impact on the success of the output file and generated product. During the processing phase, the photographs are processed in the order in which they were taken. Therefore the methodology used to capture the images needs to be systematic with cohesive camera settings. Overlap of at least fifty percent should be present between the photographs to ensure successful stitching and recognition of matching points. Additionally, the images should be taken as perpendicular as possible to the structures' planes.[125] The Nikon D7000 digital SLR camera belonging to the Clemson University – College of Charleston Graduate Program in Historic Preservation was used to capture the digital data required for later processing. Images were taken as a RAW file format, and then converted to a high-resolution .JPEG file to be utilized for later processing.

Trial Three: Multimedia GIS

Data for the multimedia GIS method of architectural documentation was accumulated from local archives including that of the Historic Charleston Foundation, the South Carolina Room at the Charleston County Public Library on Calhoun Street, as well as previously generated documents including *The Buildings of Charleston* by Jonathan Poston

[125] G. Saygi and M. Hamamcioglu-Turan, "Documentation of a Historical Streetscape with Close Range Digital Photogrammetry" (22nd CIPA Symposium, Kyoto, Japan, 2009); "Applications of Digital Photogrammetric Methods for Preservation Documentation of Historic Homes," Narrative Final Report, The Georgia O'Keeffe Museum (National Center for Preservation Technology and Training, October 24, 2012), http://ncptt.nps.gov/wp-content/uploads/2012-11.pdf.

(1997), *This is Charleston* by Samuel Gaillard Stoney (1960) and the *City of Charleston Tour Guide Training Manual*. The Library of Congress's Historic American Buildings Survey collection was referenced as well. Data was limited to architecturally associated documents directly related to the unit of analysis. Data for this technology may include, but is not limited to, historic photographs of the structures, historic maps, plats and drawings, descriptions detailing construction phases or additions, and information pertaining to relevant architects for the structures on the trial block. Raw data for this documentation technique was compiled from both paper and scanned copies of historic documents and photographs, as well as digital files of historic maps and images. Data editing was achieved through the Adobe Photoshop CC photo editing computer application. Adobe Photoshop is a raster graphics editor developed and published by Adobe Systems. It has become the industry standard in raster graphics editing and was chosen for its recognition as a design toolset with a variability of editing capabilities.[126] Adobe Photoshop CC 2015 is the latest version of the program; graphic file formats, by default, are saved as Photoshop's.PSD or .PSB file formats; however, raw data for this trial was exported in the form of high-resolution .JPEG files, allowing for easy integration into the GIS software platform during the processing stage. This documentation method required only minimal time on site. This time was used to capture exterior photographs, from the public right-of-way, of the buildings on the block. These images serve as contemporary comparison for posterity. The Nikon D7000 digital SLR camera belonging to the Clemson University – College of Charleston Graduate Program in Historic Preservation was used to capture these photographs.

[126] Martin Evening, *Adobe Photoshop CC for Photographers*, Revised (Boca Raton: CRC Press, 2015); "Adobe Photoshop CC," *Adobe*, accessed October 15, 2015, www.adobe.com; Scott Onstott, *Enhancing Architectural Drawings and Models with Photoshop*, 2nd ed. (San Francisco: Sybex, 2011).

Trial Four: Three-Dimensional Modeling

Raw data for the three-dimensional modeling application of documentation is presented in the form of a base layout of the building footprints representative of the unit of analysis. This data denotes the general masses of the structures depicting the relationship of the buildings to one another. Data portraying the building outlines was developed from the Charleston County GIS data set. Sanborn Fire Insurance maps were not utilized as they potentially portray an outdated representation of the structures on the block; GIS records from the City provide a more complete and reliable means of modeling.[127] Data communicating the roof forms of the structures was derived from aerial photography approaches, such as Google Earth and Google Street View. The data accumulation stage of the three-dimensional modeling method predominantly required time assembling the appropriate base map. However, at the start of the accumulation phase, time was spent on site capturing one photograph and one base measurement of every structure to be used for measuring building height. The photographs were rectified using Adobe Photoshop CC 2015. The base measurement was used to accurately scale the photographs in Autodesk's AutoCAD 2015, with the objective of obtaining the height of the roof and relative roof pitches. Equipment required to accumulate data for this technique largely developed from computer drafting sources; however, the Nikon D7000 digital SLR camera belonging to the Clemson University – College of Charleston Graduate Program in Historic Preservation was used to capture the façade photographs and a standard measuring tape was utilized in

[127] Sanborn Fire Insurance maps are historical maps of cities delineating the location of structures, as well as the construction materials and the number of stories for the purpose of establishing insurance risk costs. These maps document over a century of urban development and prove useful when researching building evolutions and lost structures. However, the maps are not accurate for modeling current-day building footprints. Sanborn Fire Insurance maps exist for Charleston from 1884 to 1964. The potential for building changes in the fifty-year gap to present-day renders the use of the Charleston County GIS data most reliable for the three-dimensional modeling phase. "Sanborn Fire Insurance Maps" (University of South Carolina University Libraries), South Caroliniana Library, Digital Collections, accessed November 12, 2015, http://digital.tcl.sc.edu/cdm/search/collection/SFMAPS/searchterm/Charleston/field/0/mode/all/conn/and/order/date.

the field to capture the base dimension of each structure.

Data Processing

Raw data accumulated during phase one is processed to allow for visual representations of the sample block on Church Street. The manipulation of the generated data is distinct for each of the four methods of digital documentation being undertaken, and therefore is addressed individually.

Trial One: Laser Scanning

SCENE, a proprietary product of FARO, is a three-dimensional laser scanning software that is specifically designed for use with the FARO Focus^{3D} X 330 laser scanner. This software platform was used in the processing phase of the laser scanning documentation trial. SCENE processes the raw scan files and manages the generated point cloud data; the software automatically recognizes target objects and scan positions, registering or stitching together the multiple scans.[128] Autodesk Recap and Innovmetric Polyworks are software platforms also used for the registering of the data. However, the SCENE platform was chosen principally for the availability of both the software and resources through the Clemson University Warren Lasch Conservation Center. During the processing phase, registration of the multiple scans produced a laser scan point cloud similar to a mesh, representation of the scanned architecture. The processed data was cropped and refined during this phase as well. The processing of this data took place on a Warren Lasch Conservation Center computer; the hardware capabilities of the computers belonging to Warren Lasch greatly exceed that of the desktop computers at the Clemson University – College of Charleston Graduate Program in Historic Preservation. This obstacle is

[128] "SCENE, FARO's 3D Documentation Software," *FARO*, accessed October 20, 2015, http://www.faro.com/en-us/products/faro-software/scene/overview.

discussed within the concluding comparison of technologies and may play a role in the analytical argument for or against the application of laser scanning.

Trial Two: Photogrammetry

There are multiple software platforms available for the processing of photogrammetric data, the most recognized of these including Autodesk Recap 360, Autodesk 123D Catch, AgiSoft PhotoScan, Pix4D and PhotoModeler.[129] For data processing of the digital images captured for the photogrammetry documentation trial, Agisoft PhotoScan was employed. This software is an imaging processing platform with the capabilities of converting thousands of images into georeferenced three-dimensional models.[130] While Autodesk is a highly recognized supplier of digital documentation software, with more widely recognized products than the AgiSoft and PhotoModeler companies, neither Recap 360 nor 123D Catch were chosen for several significant reasons. 123D Catch has a black box nature that does not allow for the manipulation of the photographs during the processing phase. The software was originally generated towards iPhone and iPad application users, not professional solutions, and likely would not be high-powered enough for this application. 123D Catch limits photographs to 70 images, which may prove difficult with the objective of capturing a block of architecture in the historic district of a city or community.[131] Recap 360 was initially a software platform designed for laser scanning data. Recent versions are now compliant with both laser scanned and photogrammetric data; however, Recap is still principally used by practitioners for the processing of point clouds.[132] The PhotoScan

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[129] Sara Gonizzi Barsanti, Fabio Remondino, and Domenico Visintini, "Photogrammetry and Laser Scanning for Archaeological Site 3D Modeling - Some Critical Issues" (University of Trieste, Italy, n.d.).

[130] "Agisoft PhotoScan," *Agisoft*, accessed November 30, 2015, http://www.agisoft.com.

[131] C. Santagati and L. Inzerillo, "123D Catch: Efficiency, Accuracy, Constraints and Limitations in Architectural Heritage Field," *International Journal of Heritage in the Digital Era* 2, no. 2 (2013): 263–89; Uebel, Thesis Methodology Questions.

[132] "Autodesk ReCap: Design in-Context with Accurate Dimensions," *Autodesk ReCap*, accessed October 21, 2015, https://recap.autodesk.com.

platform automatically processes digital imagery based on image content, converting photographs into highly precise, timely and customizable deliverables.[133] The processing of this data took place on the desktop computers of the Clemson University – College of Charleston Graduate Program in Historic Preservation; for the documentation of a single block of architecture, principally composed on single facades, the hardware capabilities of these computers were sufficient. The processing phase of the photogrammetry data alternated between active and non-supervised work as the software platform imported, aligned and rendered the captured data.

Trial Three: Multimedia GIS

Following the accumulation of historic documents and photographs, the processing stage of the multimedia GIS trial was generated chiefly through ESRI's ArcGIS platform. ArcGIS is a geographic information system used for the creation of maps, the compilation of data, and the management and sharing of geographic information. The ArcGIS platform, as well as its multiple applications provides an infrastructure for the organization of field data.[134] ArcGIS was chosen for its internationally recognized mapping applications, multiple levels of implementation and detail, potential for a variety of uses by a city and immense amount of online user forums. ESRI has recently made available two map templates that feature historic preservation and conservation content – the Historic Buildings and Districts Conservation and Preservation Web Map Template and the Scanned Map Services for Historic Conservation and Preservation template.[135] Through ArcGIS, these map

[133] "Agisoft PhotoScan."

[134] "Put Your Maps to Work," *ArcGIS*, accessed October 7, 2015, https://www.arcgis.com/features/; "GIS Mapping Software, Solutions, Services, Map Apps, and Data," *ESRI*, accessed November 8, 2015, http://www.esri.com.

[135] Charlie Frye, "Historic Conservation and Preservation Web Map Templates | ArcGIS Blog," ESRI, *ArcGIS Resources*, accessed August 5, 2015, http://blogs.esri.com/esri/arcgis/2012/05/23/historic-conservation-and-preservation-web-map-templates/.

templates, in conjunction with a web mapping application, help to manage the historic information gathered and create a dataset for the trial. ArcGIS allows for the organization of field data principally through a base map. The accumulated data of historic documents and photographs were uploaded to this platform through the combination of images in the form of .JPEG file and textual narratives. Using an ArcGIS application allowed for the mapping of the architectural heritage along the Church Street unit of analysis, producing a representation similar to that of Google Maps. Processing time for the GIS media depended on the amount of historic documents gathered for the application.

Trial Four: Three-Dimensional Modeling

SketchUp, previously recognized as Google SketchUp but now owned by Trimble Navigation, is the computer graphics platform chosen to process the raw data for the three-dimensional modeling technique of this trial. SketchUp is an open source, three-dimensional modeling computer program with a wide range of drawing applications.[136] For this trial, 2015 SketchUp Make, the freeware version of the platform, was employed; cities or communities completing documentation with this platform may purchase SketchUp Pro for additional functionality. The SketchUp modeling platform was chosen for its availability of instructive resources, affordability, efficacy in mass modeling and

[136] "The Easiest Way to Draw in 3D," *SketchUp*, accessed September 23, 2015, www.sketchup.com; Fotis Lazarinis and Sotiris Georgiou, "Digitization and Preservation of City Land-Marks Using Limited and Free Web Services," *Digital Presentation and Preservation of Cultural and Scientific Heritage* 3 (2013): 176–82.

potential to integrate with Google Earth.[137] The processing phase of this documentation technique involved modeling the mass of the structures on the Church Street trial block. The previously accumulated data, an Autodesk AutoCAD file of Charleston County's GIS map, provided the building footprints of the structures to be modeled. Processed data resulted in building masses and roof forms depicting the relationship of the architecture on the block. Roof shapes were obtained from aerial photography available through Google Earth and roof pitches were modeled from the rectified photographs captured at street level.[138] The level of detail of the modeling was confined to massing; fenestrations and major architectural features were not accounted for. Processed data through SketchUp was generated in an .SKP file. However, further processing resulted in scenes of the model in a .JPEG file format. Processing time for the three-dimensional modeling consumed the majority of the inclusive time limitation.

Data Post-Processing & Rendering

Following the initial processing of data accumulated during phase one, the processed data is rendered for a finished visual representations of the trial block on Church Street. Data post-processing and rendering is distinct for each of the four methods of digital

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[137] "Main Streets Using Google SketchUp for Historic Preservation," *SketchUpdate*, accessed October 21, 2015, http://sketchupdate.blogspot.com/2010/10/main-streets-using-google-sketchup-for.html; Lazarinis and Georgiou, "Digitization and Preservation of City Land-Marks Using Limited and Free Web Services"; Kent Morrison, "Visualizing Your Community with Google Earth and Google SketchUp," *PreservationNation Blog*, February 2010, http://www.preservationnation.org/main-street/main-street-now/2010/januaryfebruary/visualizing-your-community.html?utm_source=facebook&utm_medium=like&utm_campaign=Visualizing Your Community with Google Earth and Google SketchUp; Surendra Pal Singh, Kamal Jain, and V. Ravibabu Mandla, "Image Based 3D City Modeling: Comparative Study," vol. XL– 5 (ISPRS Technical Commission V Symposium, Riva del Garda, Italy: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2014), 537–46.

[138] In this modeling phase, major assumptions will be generated regarding the roof forms and roof pitches of the structures on the trial block. Acknowledging the pre-established parameter and concept of collecting data only from the public right-of-way and public documents, roof pitches will be modeled according to rectified photographs. Standard pitches for the roof forms present on the trial block will be applied accordingly. This aspect of data accumulation and processing provides a major limitation to the accuracy of the documentation objective and will be addressed in the analysis of the digital documentation technique.

documentation being undertaken and is addressed individually.

Trial One: Laser Scanning

The processing phase of the laser scan data through the SCENE platform produced a project point cloud compiling all present scans. The scan data was refined during the processing phase; a textured model was created and unwanted scan points were removed. The post-processing phase is primarily a stage for exporting the completed point cloud model. SCENE has several file format options for exporting the scan points depending on the requirements of the deliverable. The exported data can also be further manipulated in the rendering phase with external software platforms such as Autodesk's 3D Studio Max, Rhino 3D Modeling, Nevercenter's Silo 3D and Blender. For the analytical purposes of this trial, the final form of the data was exported as high-resolution .JPEG files for comparison with the other digital documentation technologies.

Trial Two: Photogrammetry

Following the semi-automated processing of the photogrammetric data through the PhotoScan platform, the final phase of rendering exported the textured three-dimensional model of the buildings on the trial block. This stage affords the opportunity of exporting the model for additional editing procedures; integration of the model can be accomplished through a .3DS file, an Autodesk .DWF file or a .KML file for GIS applications. The photogrammetry project is typically saved to PhotoScan's standard .PSZ file. For the study, the final photographic model of the data was exported to a high-resolution .PDF file for comparable visualization to the other digital documentation technologies. Exporting to this format also allows greater accessibility for navigating the model, as the PhotoScan platform is not necessary for viewing.

Trial Three: Multimedia GIS

The post-processing stage of the multimedia GIS technique continued within the ArcGIS platform. This phase of the trial was a non-supervised element as the maps and data were formally rendered and exported; minimal labor and time was expended for this stage. The final deliverable for analysis and presentation included an interactive GIS project generated through ESRI's ArcGIS application and accessible through a shared HTML link. The outcome from this stage of the methodology was a base map, similar to that of Google Maps, with connected articles of historic data and photographs relating to each of the structures on the Church Street trial block.

Trial Four: Three-Dimensional Modeling

The post-processing phase of the data continued to use the SketchUp platform. Rendering the data of the three-dimensional model predominately involved creating "scenes" or screen captures through the SketchUp platform. The layouts created within the platform allowed the modeled data to be captured at various adult eye-height positions, creating perspective presentations of the modeled block. Additionally, isometric or bird's eye views of the architecture were generated. Once the SketchUp scenes of the model were captured and rendered, the images were exported as raster images in a .JPEG file format. The images resulting from this post-processed data allow for the three-dimensional model to be analyzed and compared to the other digital documentation technology deliverables.

Trial Analysis

Following the trial of each digital documentation technique, the technologies and their respected documentation process, as well as the visuals generated are analyzed to produce a parallel comparison of the four digital documentation technologies, with focus on the specific application of architectural heritage documentation in cities.

The analysis of the digital documentation techniques primarily addresses the capacity and outcome of each of the four methods; analysis does not explain how to use each technology and program, although a discussion of these steps is integrated within each section of the methodology during the trials. The analysis portion reveals and provides understanding of the strengths and weaknesses of each of the platforms, addressing the parameters that cities and communities should acknowledge when embarking on a digital architectural heritage documentation campaign. This study is not an attempt to measure the success of each of the digital documentation techniques analyzed; with the adequate amount of time, knowledgeable expertise and appropriate equipment, each of the documentation methods can be successful in an architectural heritage application. This is an argument efficaciously observed through both literature and case studies. This study is being undertaken to generate and establish a more parallel comparison between laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling, for a wholesome interpretation, devoid of hybrid techniques, for cities.

The apparent capacities and outcomes of each of the four digital documentation technologies are analyzed according to a series of parameters gathered through various publications and input from preservation practitioners. The parameters for analysis are as follows:

- Perceived Target Audience – Intended Users
- Effective Application – Preservation Objectives Accomplished
- Ability to Record Urban and Architectural Features
    - Solid versus Void
    - Height, Scale, Mass
    - Roof Form
    - Fenestrations
    - Surface Texture
- Degree of Refinement
    - Accuracy

- •Level of Detail
- •Resolution
- •Perspective Views
- •Rectified Views

•Technical Expertise Required
- •Accumulation
- •Processing
- •Post-Processing
- •For Manipulation
- •To Derive Information

•Manageability
- •Extensibility
- •File Size

•Labor Intensity
- •Accumulation
- •Processing
- Post-Processing

•Institutional Capacity
- •Cost
- •Equipment Access
- •Software Access
- •Access to Training
- •Hardware Requirements

•Potential Obstacles and Areas of Failure

In conclusion, a matrix quantifying the capacity in terms of each parameter for the four digital documentation technologies is generated. This presents a parallel comparison of the techniques and their efficacy in architectural heritage documentation within cities and historic communities.

CHAPTER FOUR

CASE STUDIES DIGITALLY RECORDING ARCHITECTURAL HERITAGE

New Orleans Laser Scanning

CyArk, a non-profit foundation based out of Oakland, California is using laser-scanning technology to create "three-dimensional models of cultural heritage sites."[139] The organization was formed following the destruction of the Buddhas of Bamiyan in Afghanistan in 2001. CyArk's mission is to utilize laser-scanning technology to record historic sites, ensuring that while the political stability in countries decline, their cultural heritage will not be lost. Elizabeth Lee, vice president of CyArk stated that the vocation of CyArk was to "digitally record and share the world's heritage" by capturing "as many of these heritage sites as possible, before they're lost to the passage of time." CyArk established the CyArk 500 Challenge with the objective of digitally preserving, through laser scanning, 500 heritage sites in five years.[140] New Orleans was one of the cities chosen for the Historic Cities Project, a component of the documentation challenge.[141] Following back-to-back hurricanes Katrina and Rita, New Orleans was "at the top of the list of cities

Figure 4.1 *- CyArk 500 Challenge Logo.*
Image courtesy of CyArk, used with permission

[139] Alison Gregor, "CyArk Is Bringing Historical Architecture Back to Life in Digital," *Architect*, March 2, 2015, http://www.architectmagazine.com/technology/cyark-is-bringing-historical-architecture-back-to-life-in-digital_o.
[140] *Ibid*.; Ian Delaney, "HERE and CyArk Partner to Save Historic Areas – with Lasers," *HERE 360*, October 7, 2014, http://360.here.com/2014/10/07/cyark-partner-save-historic-areas-lasers/.
[141] Gregor, "CyArk Is Bringing Historical Architecture Back to Life in Digital."

targeted for this type of digital preservation."[142]

For the New Orleans laser scan, CyArk partnered with HERE, a global leader in mapping and navigation, and a subsidiary of the Nokia Corporation to create the Historic Cities Project, launched at the CyArk Annual Summit in Washington, D.C. in October of 2013.[143] This recent partnership with HERE has allowed CyArk to increase the scope and scale of the architectural heritage documentation beyond individual landmarks to a whole district, broadening their digital archive.[144] Through the Historic Cities Project, the companies are creating virtual three-dimensional replicas of selected historic cities through laser scanning. Their scans provide street-view and aerial perspectives of the architecture.[145] Arguably, these replicas will allow future generations to see realistic visualizations of the cities in three-dimensional detail, aiding in preservation and conservation efforts.

The objective of the Historic Cities Project is to digitally document five historic American cities: New Orleans, Philadelphia, Chicago, San Francisco and Boston.[146] One criterion presented by CyArk when selecting a site for documentation is the likelihood of its destruction.[147] New Orleans, chosen as a historic city with rich history expressed through the architecture was the first city on the list to be documented by CyArk and HERE. Brinker Ferguson, Digital Production Manager at CyArk emphasized, "New Orleans is part of a larger narrative that is going on in the history of world culture."[148] The historic city was a highly prioritized candidate for digital documentation due to its vulnerability to

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[142] Katy Reckdahl, "Group Working to Digitally Preserve New Orleans' Historic Architecture," *The Advocate*, October 6, 2014, http://theadvocate.com/news/neworleans/10459772-148/group-working-to-digitally-preserve.
[143] Katia Chaterji, "Historic Cities Program Announced to Map Cities in 3D," *CyArk*, October 31, 2014, http://www.cyark.org/news/historic-cities-program-announced-to-map-cities-in-3d.
[144] Gregor, "CyArk Is Bringing Historical Architecture Back to Life in Digital"; Delaney, "HERE and CyArk Partner to Save Historic Areas – with Lasers."
[145] "CyArk," accessed September 11, 2015, http://www.cyark.org/.
[146] Brinker Ferguson, CyArk's Laser Scan of New Orleans, Phone, November 13, 2015.
[147] Alex Davies, "Stunning 3-D Maps Form a Digital Copy of New Orleans," *WIRED*, August 29, 2015, http://www.wired.com/2015/08/stunning-3-d-maps-form-digital-copy-new-orleans/.
[148] Ferguson, CyArk's Laser Scan of New Orleans.

natural disasters, precarious position below sea level and proximity to surrounding levees. With laser scanning technology, CyArk and HERE digitally documented the architectural heritage of the historic city, recording its streets for posterity and creating a "guide to rebuilding" should it be necessary.[149]

CyArk's field manager, Ross Davidson, worked with HERE in January of 2014 to create a site map of New Orleans, delineating the most strategic points along the streets to capture adequate data of the architecture for the documentation project.[150] To capture the data, HERE used advanced laser scanning technology known as LiDAR or Light Detection and Ranging technology. The LiDAR machine, a small cylindrical instrument, was mounted to HERE's true mapping vehicles and tilted at an angle to allow for the capture of a 360-degree imprint.[151] CyArk and HERE chose to mount the equipment to a vehicle rather than to a satellite or airplane to ensure that facades of the structures were effectively detailed through the documentation endeavor. The true mapping vehicles traveled at a normal speed collecting the street-level data needed to digitally model the architectural heritage. CyArk chose to use LiDAR technology, as opposed to standard camera photography, as it arguably provides more information than photographs.[152] Through the laser scanning technology, CyArk and HERE were able to model the structures to an accuracy of two centimeters.

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[149] Davies, "Stunning 3-D Maps Form a Digital Copy of New Orleans"; Pino Bonetti, "10 Years after Katrina: HERE Helps to Digitally Preserve Historic Sites like New Orleans," *HERE 360*, August 31, 2015, http://360.here.com/2015/08/31/here-helps-to-digitally-preserve-historic-sites-like-new-orleans/.

[150] Ferguson, CyArk's Laser Scan of New Orleans.

[151] HERE uses laser scanners affixed to a fleet of about 200 cars, known as the HERE true mapping vehicles. HERE's true mapping vehicles were purpose-built for creating highly detailed, accurate models of cites through LiDAR technology. The vehicles capture approximately 700,000 data points per second, emitting 32 lasers. The company's technology can achieve a range of data capture up to 230 feet. The data captured by the true mapping vehicles is typically used in automobile navigation systems, but HERE donated the data to CyArk, arguably "extending [the] information's use beyond [their] normal business of maps and navigation, and into preservation, education and historical research." Gregor, "CyArk Is Bringing Historical Architecture Back to Life in Digital"; Delaney, "HERE and CyArk Partner to Save Historic Areas – with Lasers"; Gwennie Poor, "Pssst! Our 'Secret Sauce' Is LiDAR," *HERE 360*, March 24, 2015, http://360.here.com/2015/03/24/lidar/; Bonetti, "10 Years after Katrina."

[152] The engineering-grade data produced from the laser scans could have been transferred into a computer-aided drafting (CAD) program for more detailed analysis should that have been an objective of the project.

Additionally, each data point captured had an X, Y and Z coordinate allowing for the model to be synchronized with a global positioning system.[153]

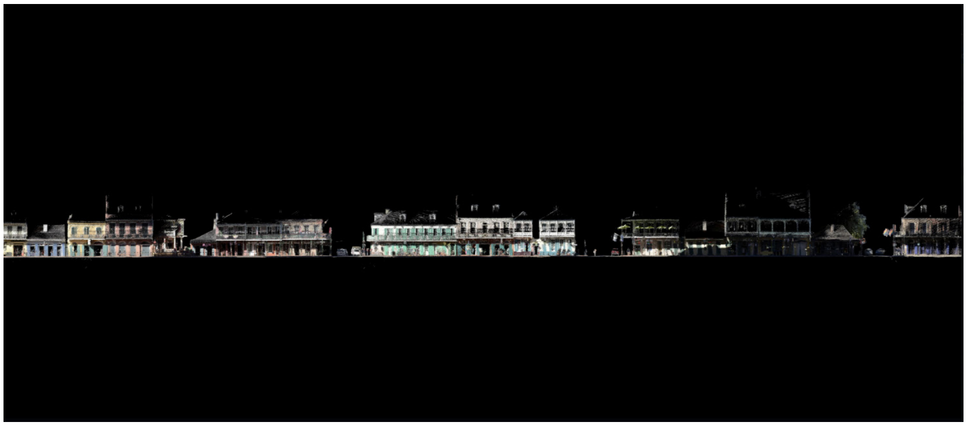

Figure 4.2 *- 3D Perspective Showing a Section of New Orleans' Bourbon Street.*
The image above depicts a rectified view from the laser scan generated of the architectural heritage of the city's historic districts.
Image courtesy of CyArk and HERE, used with permission

Data collection for the New Orleans laser scan began in September of 2014. Utilizing the true mapping vehicles and LiDAR technology, HERE scanned 277 miles of the city's streets in three days. Raw data was accumulated for four historic districts of the city: the Garden District, Faubourg Marigny, the French Quarter and Esplanade Ridge. After the initial scan, HERE released the LiDAR data from the historic neighborhoods to CyArk. CyArk's technicians uploaded the raw data to a processing software to begin the stitching process. By stitching the scanned data and point clouds together, a three-dimensional mesh of the streetscapes and building exteriors was created. LiDAR technology does not export images of the buildings. To colorize the structures, the CyArk team overlaid photographs taken simultaneously with the data points.[154] Over 150 man-hours were spent digesting the 15 billion data points. The finished product is a "panoramic street-front image" that is

[153] Delaney, "HERE and CyArk Partner to Save Historic Areas – with Lasers"; Poor, "Pssst! Our 'Secret Sauce' Is LiDAR"; Chaterji, "Historic Cities Program Announced to Map Cities in 3D."
[154] Reckdahl, "Group Working to Digitally Preserve New Orleans' Historic Architecture"; Katherine Sayre, "Digital Archive Group CyArk Captures New Orleans in 3-D Using Laser Beams," *The Times-Picayune*, October 7, 2014, http://www.nola.com/business/index.ssf/2014/10/digital_archive_group_captures.html.

miles long, representing 5.71 square miles of the approximately 350 square miles of New Orleans.[155]

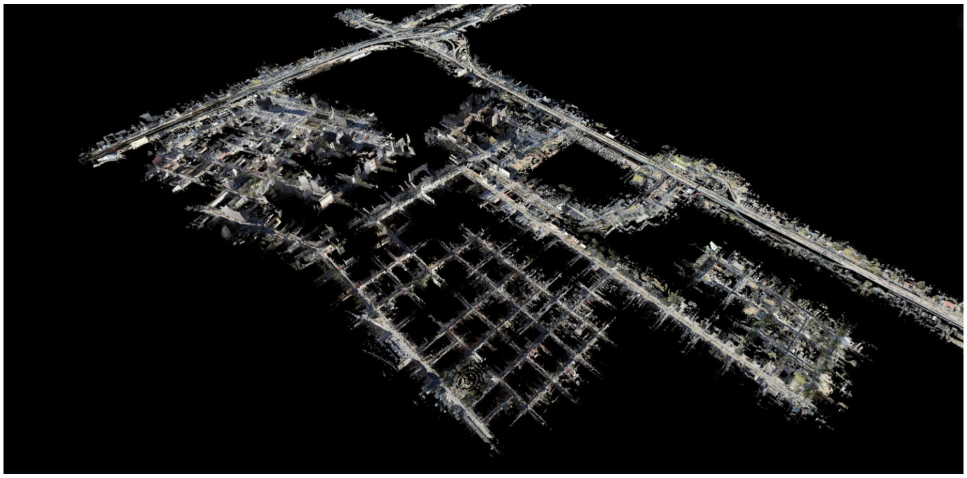

Figure 4.3 *- Aerial Perspective of the New Orleans French Quarter.*
The image above is a compilation of the point cloud data for 5.71 square miles of New Orleans. This image depicts 277 scanned miles of the city's architectural heritage.
Image courtesy of CyArk and HERE, used with permission

The New Orleans laser scan, as well as CyArk's other digital documentation projects, can be explored by the general public through a free, online library on CyArk's website. Brinker Ferguson, the digital production manager for CyArk explained that the site is primarily used for educational initiatives and that the organization works specifically with elementary, middle and high school faculty to develop curriculum. The organization's objective is to "tell a story through the architecture" with the future proposal of creating a 360-degree video of the historic city. In addition to educational uses, the digital documentation of New Orleans provides future opportunities for reconstructing destroyed architectural heritage within the city.[156] CyArk vice president, Elizabeth Lee, said a big part of the CyArk's mission is to "get people excited about the historic environment" of New Orleans and show why "it is important to preserve and care for these places."[157]

155 Davies, "Stunning 3-D Maps Form a Digital Copy of New Orleans."
156 Ferguson, CyArk's Laser Scan of New Orleans; Gregor, "CyArk Is Bringing Historical Architecture Back to Life in Digital."
157 Sayre, "Digital Archive Group CyArk Captures New Orleans in 3-D Using Laser Beams."

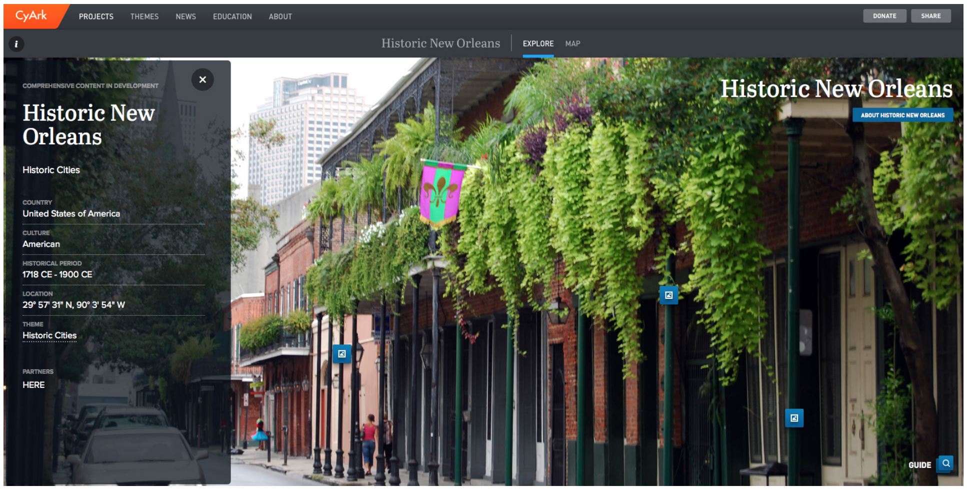

Figure 4.4 *- Initial Platform View.*
The image above portrays the home platform for the New Orleans Laser Scan Project accessible through CyArk's free, online library.
Image courtesy of CyArk, used with permission

The documentation team at HERE expressed that laser scanning within the preservation field for cataloging at-risk historic sites in New Orleans was a "fascinating and unexpected application."[158] The partnership between CyArk and HERE was successful in allowing future generations to see realistic visualizations of the city in three-dimensional detail. Additionally, the effort between the two companies has set a precedent for an increase in the scope of digital documentation beyond individual landmarks to whole districts at a citywide scale. Directly addressing the team's New Orleans scan, the digital documentation project successfully generated digital blueprints, with an accuracy of two centimeters of four of New Orleans's historic districts.[159] With this modeled data, the city is prepared for future restoration and reconstruction projects should the architecture by affected by a natural disaster. CyArk explains that they typically work with local groups to document the architectural heritage, so the groups are able to use the models created in ongoing restoration and conservation efforts.[160] The LiDAR technology was especially

[158] Poor, "Pssst! Our 'Secret Sauce' Is LiDAR."
[159] Sayre, "Digital Archive Group CyArk Captures New Orleans in 3-D Using Laser Beams."
[160] Delaney, "HERE and CyArk Partner to Save Historic Areas – with Lasers."

effective in the New Orleans applications as it created an "unbelievably fast" and "highly detailed, accurate model" of the historic city.[161] Through laser scanning technology, the New Orleans architecture was frozen "as [it] were at a specific point in time."[162] The architectural heritage of the city is now digitally preserved for posterity through streetscape scans.

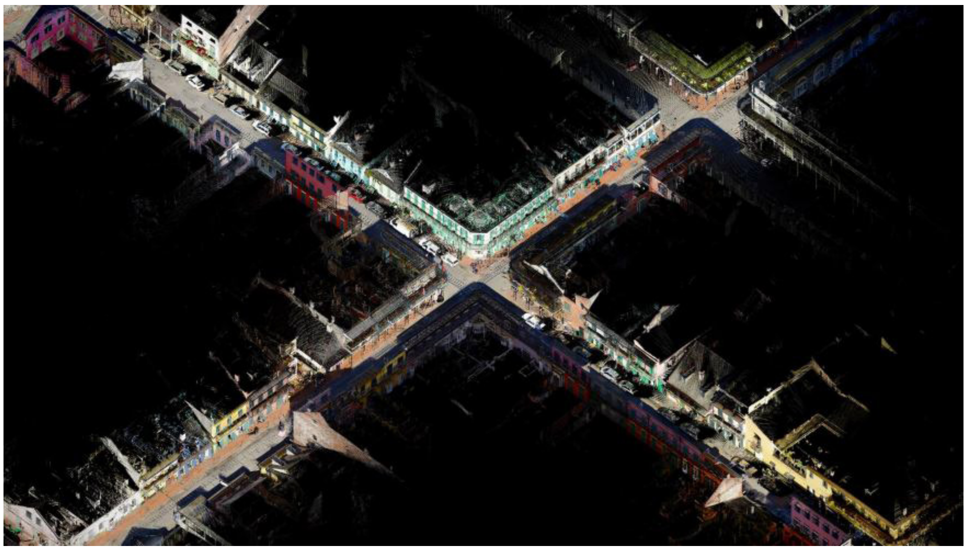

Figure 4.5 *- Detail of the Aerial Perspective of the New Orleans French Quarter.*
The image above is an enlarged detail of the aerial perspective generated from the laser scan data of the New Orleans French Quarter.
Image courtesy of CyArk and HERE, used with permission

This case study did present several obstacles for laser scanning's application within New Orleans. By mounting the LiDAR technology to HERE's true mapping vehicles, the team was restricted to terrestrial scanning. Documenting the upper portions of the structures was difficult, as was obtaining the desired three-dimensional aerial perspectives of the historic districts. This visual aspect of the project may have been more successful with the implementation of drones and photogrammetry. The specialization of CyArk's documentation work demands that the organization employ a full time three-dimensional modeler and a full time production specialist. Brinker Ferguson, the digital production

[161] Bonetti, "10 Years after Katrina."
[162] Delaney, "HERE and CyArk Partner to Save Historic Areas – with Lasers."

manager for CyArk asserts that laser scanning is less user-friendly than photogrammetry and that users need to be educated on how to use the technology to minimize user error. Additionally, data collection and processing, as well as software restrictions made the New Orleans project an expensive undertaking. CyArk's funding primarily evolves from partnerships with larger technology companies and Ferguson believes that, in terms of economics, a city wanting to document their architectural heritage through laser scanning would need to partner with a large institution or organization in order for the project to be feasible. She explains that the scanners utilized by CyArk and HERE range in cost from $15,000 to $300,000, and the software required to read, display and visualize the data poses a sizeable expense.[163]

While not interactive, the New Orleans laser scan project provides street-view and aerial perspectives of the historic city. The project showcases digital preservation; the platform and technology employed do not allow for tracking the change over time of the city's architectural heritage. The objective of the initiative was not to document the evolution of the city, but to create a time capsule of New Orleans circa February 2015. Ferguson argues that the project could not showcase architectural evolution unless the team was to rescan and digitally document the city every five years.[164] The resulting product, visually similar to a video game, provides a digital representation of the city's historic districts through aerial and streetscape imagery.

University of Maryland Photogrammetry

The case study chosen to demonstrate the application of photogrammetry for the digital documentation of architectural heritage assumes a different approach than the three other case studies discussed. A photogrammetric scan of the University of Maryland

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[163] Ferguson, CyArk's Laser Scan of New Orleans.
[164] *Ibid*.

Baltimore County campus was selected as the case study for this technology. The case study represents aerial, rather than close-range or ground-based photogrammetry. Aerial photogrammetry employs unmanned aerial vehicles (UAV) to generate isometric views of the environment. The use of UAV is more prominent in European cities than in the United States, as UAV face legal limitations and public distrust in the United States. The majority of European examples commissioning UAV engaged in large-scale documentation and captured entire metropolitan areas.[165] The University of Maryland Baltimore County photogrammetric case study was ultimately selected for its comparable size to a documentation campaign likely undertaken by a mid-sized city such as Charleston, as well as its comparable acreage of scan capture to the other case studies presented in this thesis.

The photogrammetric trial described later in this thesis will use close-range photogrammetry, while the University of Maryland Baltimore County photogrammetric scan employs aerial photogrammetry. Although close-range and aerial photogrammetry result in distinctive deliverables, this aerial photogrammetry case study was chosen as it more closely aligns with citywide documentation endeavors explored by this thesis. Additionally, aerial photogrammetry has become an increasingly popular documentation method for large-scale environmental recordation. Although aerial photogrammetry maintains less concentration on a detailed documentation of facades, this avenue of photogrammetry is still pertinent to historic preservation and architectural heritage, as seen through the scanning campaigns initiated in Europe's historic cities. Arguably though, the University of Maryland Baltimore County full campus scan more closely corresponds with the current practices of unmanned aerial vehicles (UAV) in the United States.

[165] Franz Leberl et al., "Automated Photogrammetry for Three-Dimensional Models of Urban Spaces," *Optical Engineering*, February 2012, http://www.researchgate.net/publication/258224670_Automated_photogrammetry_for_three-dimensional_models_of_urban_spaces?enrichId=rgreq-b30575d6-c268-4804-ad28-25f9e56e8ea3&enrichSource=Y292ZXJQYWdlOzI1ODIyNDY3MDtBUzoyNTg2ODUxMjk3MTk4MDhAMTQzODY4Njc0OTQyMQ%3D%3D&el=1_x_2.

The case study is unique in that it was initiated by the Laboratory for Anthropogenic Landscape Ecology at the University of Maryland Baltimore County; the project was not specifically proposed by an organization with an interest in historic preservation or architectural heritage.[166] The initial objective of the photogrammetry scan was to create an aerial orthophotograph of the campus for research purposes.[167] As both the data capture and the data processing technology were relatively new to the team, the University of Maryland Baltimore County photogrammetric scan was more or less undertaken as an opportunity to explore the technologies available to digitally document large expanses for three-dimensional constructions.[168] The University of Maryland Baltimore County is a small public research university with less than 15,000 students and staff. The University is located in the suburbs of Baltimore and its campus occupies approximately five hundred acres. Although the university was established in 1966, the land the campus occupies has an extensive past with several historically significant buildings. These include a farmhouse and the 1920s Hillcrest Building.[169] Hilltop Circle creates a complete loop encompassing the campus; this feature defines the area of the photogrammetry documentation.[170]

A full campus scan of the University of Maryland Baltimore County was conducted

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[166] "About Anthropogenic Landscapes," *Laboratory for Anthropogenic Landscape Ecology*, accessed January 15, 2016, http://ecotope.org.

[167] An orthophotograph is an aerial photograph geometrically connected, or orthorectified, so that it possesses a uniform scale. Orthophotographs lack distortion and resemble maps. Jonathan P. Dandois and Erle C. Ellis, "High Spatial Resolution Three-Dimensional Mapping of Vegetation Spectral Dynamics Using Computer Vision," *Remote Sensing of Environment* 136 (September 2013): 259–76, doi:10.1016/j.rse.2013.04.005.

[168] Stephen Zidek, "Full Campus Scan With Octo," *Ecosynth - 3D Tools for Ecology*, February 4, 2014, http://ecosynth.org/profiles/blogs/full-campus-scan-with-octo?id=6524404%3ABlogPost%3A7324&page=2; Stephen Zidek, "Aerial Scan," *Agisoft*, accessed January 15, 2016, https://sketchfab.com/models/733719d35b564814a8e3269b268c2637/embed?autostart=0&transparent=0&autospin=0&controls=1; "Ecosynth: 3D Tools for Ecology," *Laboratory for Anthropogenic Landscape Ecology*, accessed January 15, 2016, http://ecotope.org/projects/ecosynth/.

[169] "UMBC: An Honors University in Maryland," *UMBC*, accessed November 28, 2015, http://www.umbc.edu.

[170] Zidek, "Full Campus Scan With Octo."

in February of 2014 as an initiative of the University's Ecosynth Project.[171] The University of Maryland Baltimore County Ecosynth Research Team, sponsored by the Laboratory for Anthropogenic Landscape Ecology, piloted the project. Grants from the National Science Foundation and the United States Department of Agriculture Forest Service funded the research of the team. The Ecosynth Research Team developed a suite of tools for the mapping and measuring of three-dimensional environments. The initiative uses off-the-shelf digital cameras and open-source software to generate three-dimensional scans at low altitudes.[172]

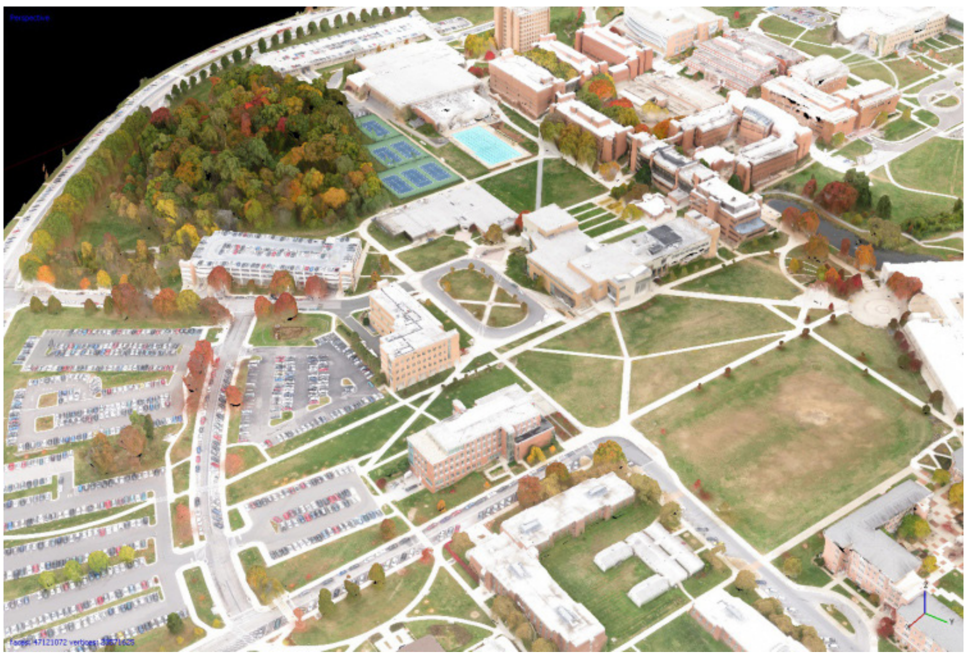

Figure 4.6 *- Aerial Perspective from the Photogrammetric Model of the UMBC Campus.*
The image above portrays a section of the final textured model created through the Photoscan software of the University of Maryland Baltimore County campus.
Image produced by Stephen Zidek and the Ecosynth Research Team, used with permission

The Ecosynth team at the University of Maryland Baltimore County includes a variety of both professors and students from the Computer Science and Electrical Engineering program, as well as the Geography and Environmental Systems program. The

[171] *Ibid*.
[172] "Ecosynth: 3D Tools for Ecology."

team, in this ongoing project at the time of writing, is composed of principal investigators, postdoctoral researchers, graduate students, research technicians, undergraduate students and research collaborators.[173] The full campus photogrammetry scan of the University of Maryland Baltimore County was primarily generated by Stephen Zidek.[174] The creation of the ortho-photogrammetric model did not stem from preservation related objectives. Rather, the project team used the photogrammetric model for analytical purposes. Through the scanned data, Zidek and his team was able to measure the percentage of green space on the campus. Additionally, the team used the deliverable to evaluate building conditions, primarily the roofs.[175]

Zidek led the Ecosynth team on the generation of a colorized three-dimensional rendition of the campus through aerial photogrammetry scanning. Everything within the Hilltop Circle – or what the team refers to as the "loop" – was included in the scanning procedure. For the aerial photography segment of the scan, data was captured utilized an OktoXL-framed MikroKopter.[176] The control structure for drone was through an Arducopter.[177] This system was employed for its characteristic as an open-source platform with free software; the low cost and availability of this control system makes it highly used

[173] *Ibid*.
[174] Zidek is an aerial systems engineer and one of the two research technicians for the Ecosynth Project team.
[175] "Ecosynth: 3D Tools for Ecology"; Zidek, "Full Campus Scan With Octo"; Zidek, "Aerial Scan."
[176] MikroKopters are battery powered and radio controlled unmanned aerial vehicles (UAV). MikroKopter is German-based company and subsidiary of HiSystems. MikroKopters are hobby-helicopters or drones equipped with GPS data and altitude control. MikroKopters are popular, and arguably employed for this case study, as they are able to automatically maintain their current altitude and position, as well as automatically fly back to their starting position. Additionally, the MikroKopter can be programmed to fly to waypoints (as seen in this case study). The MikroKopter company produces multiple drone models including the OktoXL. The OktoXL is the frame and flight system employed for the University of Maryland Baltimore County campus scan. This frame was specifically created for photographic and film purposes. The flight equipment can safely fly for thirty minutes at a maximum linear distance of five miles. Zidek, "Full Campus Scan With Octo"; "MikroKopter," *MikroKopter - Universal UAV*, accessed January 16, 2016, http://www.mikrokopter.de/en/home.
[177] An Arducopter is an autopilot system and open-source control platform for drones. The software is most often used with micro air vehicles. "Open Source Autopilot," *ArduPilot*, accessed January 16, 2016, http://ardupilot.com.

equipment for hobbyists.[178] The combination of these flight systems constructed for this case study is recognized as a miniature unmanned aircraft vehicle (UAV).[179]

The digital camera equipment employed for the capture of the raw data was a Canon PowerShot ELPH 520.[180] A waterproof case surrounding the camera was used to provide a stable and consistent mount for the Canon PowerShot's attachment to the underside of the drone. Additionally, rubber vibration dampers were included to minimize motion blur in the images resulting from the UAV's pulsations. For data capture and the flight time, the camera was programmed in a sequential shooting mode resulting in the capture of two still frames per second.[181] The University of Maryland Baltimore County campus is approximately 500 acres in size.[182] Due to the size of the campus and the flight distances involved for adequate data capture, the campus was systematically divided into three endeavors. Each of the three undertakings resulted in approximately three and one-half miles of flight distance. During the flights and data capture period, the UAV was maintained approximately 330 feet above ground level; this height ensured that the equipment remained well above the structures' roofs, while allowing for detailed data capture of the ground and buildings below. The systematic flight paths planned by the Ecosynth team placed each path of the drone approximately 130 feet apart. This methodology resulted in seventy-five percent overlap between the accumulated photographs, ensuring that the project's developers had sufficient data for the processing of the photogrammetric scan.

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[178] *Ibid*.
[179] Zidek, "Full Campus Scan With Octo."
[180] The Canon PowerShot ELPH 520 is a digital camera modeled after Canon's original ELPH design; however, this camera showcases the company's technical advances. The ELPH 520 is only 0.76 inches thick, making it the world's thinnest 12x zoom camera. This characteristic – its slimness – makes the camera a suitable choice for UAV photography. Although it features a compact body, the image processor and lens technologies of the camera allows for the capture of clear, detailed images. The camera employs a 12mm wide-angle lens fostering greater depth and perspective during data capture. "PowerShot ELPH 520 HS with 4GB Memory Card," *Canon*, accessed January 16, 2016, http://www.canon.ca/inetCA/en/products/method/gp/pid/13403#_020.
[181] Zidek, "Full Campus Scan With Octo."
[182] "UMBC: An Honors University in Maryland."

By employing the Arducopter platform in conjunction with the MikroKopter, the flights were fully automatic. The project team was only directly involved in the data capture at the initial launch and then again when the equipment was disabled when the drone landed.[183]

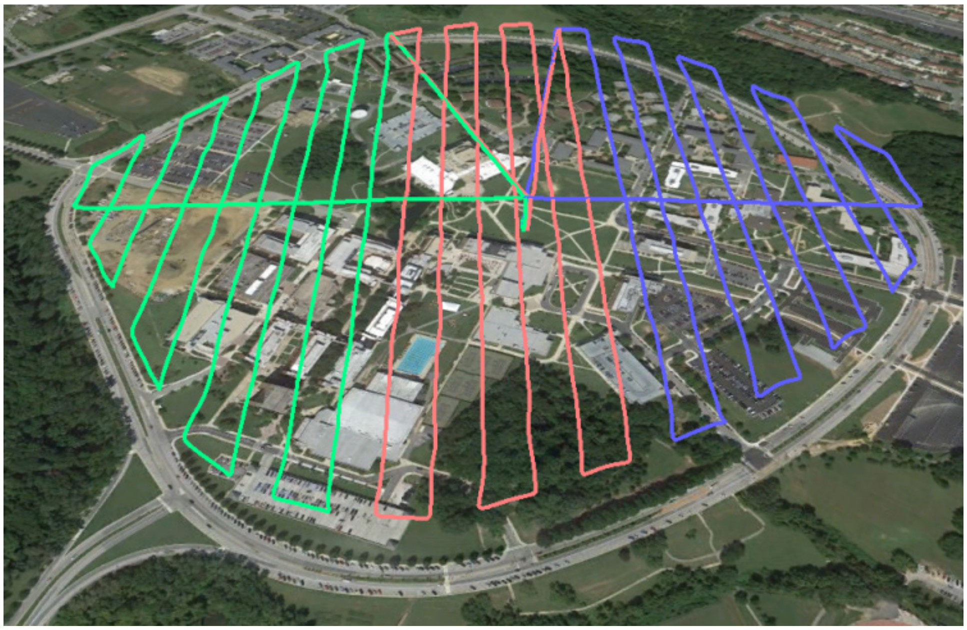

***Figure 4.7** - Flight Paths.*
The image above depicts the three 6km flight missions used to capture photogrammetric data of the campus for rendering.
Image produced by Stephen Zidek and the Ecosynth Research Team, used with permission

In total, 5443 photographs were captured during the flights and transferred to the photogrammetry software. Extraneous images captured at the ascent and the landings were discarded; capture of these images was unavoidable since the camera settings were established at a continuous data capture rate (two per second) and capture was initiated before UAV liftoff. Only the photographs taken along the pre-established vertical tracks and the horizontal connecting tracks – at maximum altitude – were retained. Zidek explained that the majority of the images captured were slightly blurred. The project team attributed this inaccuracy to the overcast lighting conditions, which consequently triggered

[183] Zidek, "Full Campus Scan With Octo."

a longer exposure time through the automatic camera settings.[184] Zidek believes the data capture may have been more successful with brighter lighting. Additionally, he suggested that greater vibration damping and the use of a higher quality camera might have remedied this issue.[185]

The three-dimensional photogrammetric model was produced through the Agisoft PhotoScan platform. Prior to importing the data into PhotoScan, the team employed the Python platform to convert the global positioning system (GPS) and altitude data that was captured along with the photographs; through this program, GPS data was assigned to individual images.[186] After assigning GPS and altitude data to the photographs, the images were then uploaded to the Agisoft PhotoScan platform.[187] Zidek explained that the computer vision system generated a three-dimensional point cloud by building geometry from matching features identified in the multiple overlapping photographs. The mass of the three-dimensional point clouds were then georeferenced for analytical and measurement purposes. Within the PhotoScan platform, the team processed both a height map and arbitrary geometry mesh model. Texture was applied to both. The textured mesh model

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[184] Conceivably, the issue of blurred photographs would be absent from close-range photogrammetry. If the images had been captured from the ground – with a camera and tripod – the camera settings could have been more readily controlled. Ideally the camera settings – the ISO, aperture and shutter speed – would be consistent for all photographs. Manual settings may result in some images being lighter or darker than others. However, capturing the images from the ground gives the opportunity for a trial of the settings, ensuring that the shutter speed is quick enough. Aerial photogrammetry relies on automatic camera settings, as the opportunity for a trial shoot is unobtainable.

[185] Zidek, "Full Campus Scan With Octo"; Zidek, "Aerial Scan."

[186] Python is a computer-programming platform with a variety of applications. The platform is open-source and allows for the effective integration of multiple data systems. In the University of Maryland Baltimore County case study, Python was used to assign GPS coordinates and altitude data to the images captured with the Canon PowerShot. "Python Is Powerful... and Fast," *Python*, accessed January 16, 2016, https://www.python.org.

[187] Agisoft PhotoScan is a software product utilized to perform photogrammetric processing of digital images. PhotoScan is a stand-alone, advanced image-based product that generates three-dimensional spatial data from still digital photographs to be used in GIS applications. The photogrammetric platform is an off-the-shelf tool used for both aerial and close-range photogrammetry. The platform utilizes three-dimensional reconstruction technology; by processing at least two photographs in which the object is visible a three-dimensional model can be produced. The software platform is capable of processing up to tens of thousands of photographs and produces deliverables with a high degree of accuracy.

resulted in a full resolution orthophotograph.[188]

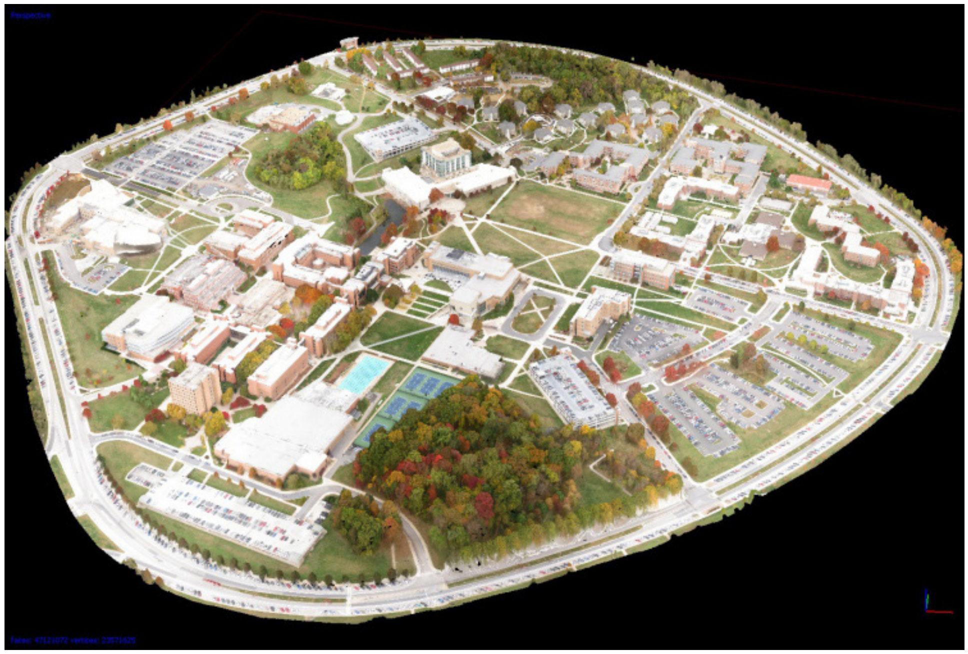

Figure 4.8 *- Full Campus Photogrammetric Scan.*
The image above depicts the final textured photogrammetric model produced of the 0.78 square mile University of Maryland Baltimore County campus.
Image produced by Stephen Zidek and the Ecosynth Research Team, used with permission

As a point cloud, visually, the roofs of the structures, as well as the green space of the campus are so dense that they appear to be solid. In contrast, the facades of the buildings appear much less detailed. Zidek asserted that the roofs and lawns – the planes parallel to the image capture equipment – possess more data points than the facades of the buildings.[189] Observable holes on a significant number of the building sides are apparent. These holes represent areas that were not wholly visible and adequately captured during the UAV's flights. Arguably, close-range photogrammetric scanning, rather than the aerial scanning employed would have captured the structures' details more effectively. However, this method would not have generated the orthophotograph desired by the team, nor was façade capture central to the team's objectives.

[188] Zidek, "Full Campus Scan With Octo."
[189] *Ibid*.

Figure 4.9 *- UMBC Physics Building.*
The image above was captured from the sparse point cloud with the final texture applied.
Rendered areas of transparency and light hues encompass less geometry.
Image produced by Stephen Zidek and the Ecosynth Research Team, used with permission

The PhotoScan platform provides the opportunity to generate a dense point cloud. The processing of a dense point cloud typically results in more detailed geometry; however, this also requires greater RAM for processing.[190] Due to this impediment, the Ecosynth team elected to leave the majority of the model as a sparse point cloud. For analytical purposes, however, they did chose to process the campus's library building as a dense point cloud. Zidek explained that this allowed the project team to compare the results of the sparse point cloud geometry to that of the dense point cloud geometry without overwhelming the hard drive of the computer.[191] The structures and areas of the campus left as sparse point clouds had significantly less geometry. Components seemed to be fused together and the edges of the facades were less defined. The sparse point cloud had a larger amount of holes. Zidek contends that all the buildings included in the scan could be developed to the level of the library by applying the dense point cloud, however, he explains that it is an incredibly time

[190] "Agisoft PhotoScan," *Agisoft*, accessed November 30, 2015, http://www.agisoft.com.
[191] Zidek, "Full Campus Scan With Octo."

consuming process.[192] Additionally, processing the entirety of the model to be a dense point cloud would require a computer with significantly greater RAM than the standard workstation. Consequently, to achieve the ideal level of detail for the documentation of architectural heritage, all buildings captured would need to be rendered with a dense point cloud, a process unlikely to be internally accomplishable by a city or historic community.

Although the majority of the campus's structures are not considered historic, nor

Figure 4.10 *- UMBC Administration Building.*
The image above depicts a rendering of the Administration Building, one of the tallest buildings on campus. Photogrammetry was able to successfully capture its height.
Image produced by Stephen Gienw and the Ecosynth Research Team, used with permission

was the project undertaken as a preservation initiative, the aerial photogrammetric scan was still able to successfully document the architecture of the campus. The objective of the orthophotographic scan was intended towards documenting the overall environment of the campus; however, the generated product successfully recorded the relationship of the structures to one another. Differences between the buildings are distinguishable. The photogrammetric scans effectively captured the massing of the structures, as well as the

[192] *Ibid*.

structures' colors and general styles. The implied height of the buildings as well as their fenestrations can be gathered from the photogrammetric model. However, the model appears cartoonish; many of the structures are blurred and lack sharp edges or defined features. The facades and elevations of the structures are significantly more distorted than the roof and ground elements. Additionally, although color is successfully portrayed, material texture is ineffective. Many areas of the scan are difficult to decipher due to their light color and wash out.

Zidek contends that one of the largest obstacles of the project was an inadequate

Figure 4.11 *- Aerial Perspective from the Final Photogrammetric Model.*
The image above portrays a section of the final textured model created of the UMBC campus. Areas of significant washout are visible in this rendering.
Image produced by Stephen Zidek and the Ecosynth Research Team, used with permission

level of data captured of the sidewalks and areas of the roofs. He explains that plain white roofs resulted in poor reconstructions, as they had few identifiable features. Both the white roofs, as well as the sidewalks were excessively washed out in the photographs and resulted in little data and texture for modeling. Zidek attributes this difficulty to the lighting. The majority of cities undertaking an aerial documentation campaign will encounter this issue.

However, Zidek contends that dialing down the camera's exposure – arguably using manual camera settings – would be a likely method of making the bright roofs appear less washed out.[193]

An additional challenge the Ecosynth team encountered was the large amount of data involved and the resulting file size. Due to the size of the file, Zidek and his team had to crop the campus to smaller areas in order to apply the textured mesh. Zidek asserted that the complexly textured three-dimensional model produced in PhotoScan was too large to open with external programs. To view the project in an outside platform required decimating the model resulting in significant data loss.[194] The developer explained that although the models were decimated or down-sampled within the PhotoScan platform, they were still incredibly large. As a solution, images of the model were captured as "screenshots" to allow interested parties to view the photogrammetric scan.[195] In addition to the screen captures, the decimated model has been uploaded to Sketchfab to allow users to interact with the project.[196] Within the Sketchfab platform, users can navigate through the model, zooming in and out, as well as rotating the image.

In conclusion, this case study provides a unique opportunity to evaluate the direction photogrammetry is directed with regards to its application to architectural heritage. The photogrammetric scan of the University of Maryland Baltimore County campus could visually be comparable to a three-dimensional model produced through a

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193 *Ibid*.
194 Decimating or down-sampling a model in PhotoScan allows the user to reduce the amount of polygons. This typically results in a smaller file that more adequately addresses the client's desired deliverable.
195 "Ecosynth: 3D Tools for Ecology"; Zidek, "Full Campus Scan With Octo"; Zidek, "Aerial Scan."
196 Sketchfab is a website used to share and display three-dimensional graphics. The three-dimensional model viewer, part of the Sketchfab platform, is open-source and employs WebGL JavaScript technology. Sketchfab was used for this case study, as it does not require plug-ins for third party downloads. "Sketchfab - The Place to Be for 3D," *Sketchfab*, accessed January 16, 2016, https://sketchfab.com/; "MAIN UMBC Aerial Ecosynth Scan," *Sketchfab*, accessed January 15, 2016, https://sketchfab.com/models/733719d35b564814a8e3269b268c2637/embed?ui_watermark=0&ui_stop=0&tracking=0&ui_snapshots=0&internal=1&autostart=1&ui_infos=0.

platform such as Google SketchUp or Autodesk Revit. The model's isometric and aerial perspectives are more aligned with the visual deliverable of a three-dimensional model and could prove applicable for city planning. However, the photogrammetric scan is significantly more detailed and complete than a simple massing model. Photogrammetric data would result in more thorough reconstructions of architectural heritage should that avenue be initiated. While he views the project as successful, Zidek does assert that if an organization is trying to accurately capture the texture on the facades of buildings, aerial photogrammetry is disadvantageous. He contends that although the camera has a wide field of view, the sides of buildings are photographed from a steep angle and are likely distorted.[197] Incorporating additional images captured of the sides of structures would provide better-textured renderings. The principal issue confronted by a city employing this documentation technology would be the size of the data and model generated. The sizeable point cloud would likely be an obstacle for organizations trying to export and display the generated deliverable.

Historic Columbia's Map Project

The Historic Columbia Foundation, located in Columbia, South Carolina, is a nonprofit organization dedicated to preserving Columbia and Richland County's cultural heritage. Addressing preservation advocacy and education programs, the Foundation is digitally preserving and promoting the history of the city's neighborhoods and historic properties through a multimedia GIS documentation method. In August of 2008, an Institute for Museum and Library Services, *Museums for America* grant enabled the Historic Columbia Foundation to take steps towards creating a digital platform for the

[197] Zidek, "Full Campus Scan With Octo."

history of six downtown neighborhoods.[198] The result was a web-based virtual tour of the city's historic neighborhoods and architectural heritage titled *Connecting Communities through History.*[199]

The interactive online tour, *Connecting Communities through History,* is a Google map based project undertaken by the Foundation with the objective of enhancing the "collective understanding of [the] community's history."[200] The project was initiated to create stronger bonds with communities outside of the historic properties immediately under the care of Historic Columbia and to strengthen contacts made during historic preservation advocacy outreach. Through the interactive maps project, oral histories relating the architectural heritage of the area were combined with historic images to heighten community pride and enrich the general history on record of Columbia's historic neighborhoods. The recollections, photographs, maps and conversations donated by current and former residents are now being preserved through the multimedia GIS project. The platform has helped the Foundation to promote public education and local heritage tourism, documenting the architectural heritage of Columbia at a citywide scale, while maintaining a more intimate character.[201] The Historic Columbia Foundation expects that the initiative will "invite visitors to retrace these neighborhoods' pasts" and hopes that the approaches taken with this platform to access past neighborhood history might become a prototype for other cities and their historic neighborhoods.[202]

Images and documents included on the website have been compiled from both Historic Columbia Foundation's archives, as well as community donations. All imagery

198 "Historic Columbia," *Historic Columbia*, accessed September 12, 2015, http://www.historiccolumbia.org/.
199 "Six Historic Columbia Neighborhoods Are Being Studied," *The Humanities Council*, May 27, 2010, http://schumanities.org/news/six-historic-columbia-neighborhoods-are-being-studied/.
200 *Ibid*.
201 "Historic Columbia"; "Six Historic Columbia Neighborhoods Are Being Studied"; Waites to Brown, "Historic Columbia's Maps Project."
202 "Six Historic Columbia Neighborhoods Are Being Studied."

within the platform relates the architectural history of the neighborhood, displaying single structures, both commercial and residential, as well streetscapes. The stories include interviews from both current and former residents of the neighborhoods; these interviewees have donated some of the photographs seen through the online project. The initial collection began at "Image Collection Days" where residents were able to bring images to be scanned and archived. "We believe that with each aspect of the initiative that is realized, more and more people will come forward with greater amounts of materials that will help further develop these areas' respective stories – something that will be wonderful and encouraged," adds John Sherrer, Director of Cultural Resources for the Foundation.[203] The endeavor initially focused on six historic Columbia neighborhoods, including Arsenal Hill, Cottontown, Heathwood, Hollywood-Rose Hill Lower Waverly, and Old Shandon. The first interactive neighborhood map tour generated was of the Arsenal Hill neighborhood.[204] The interactive neighborhood tour initiative has continued to expand and now includes

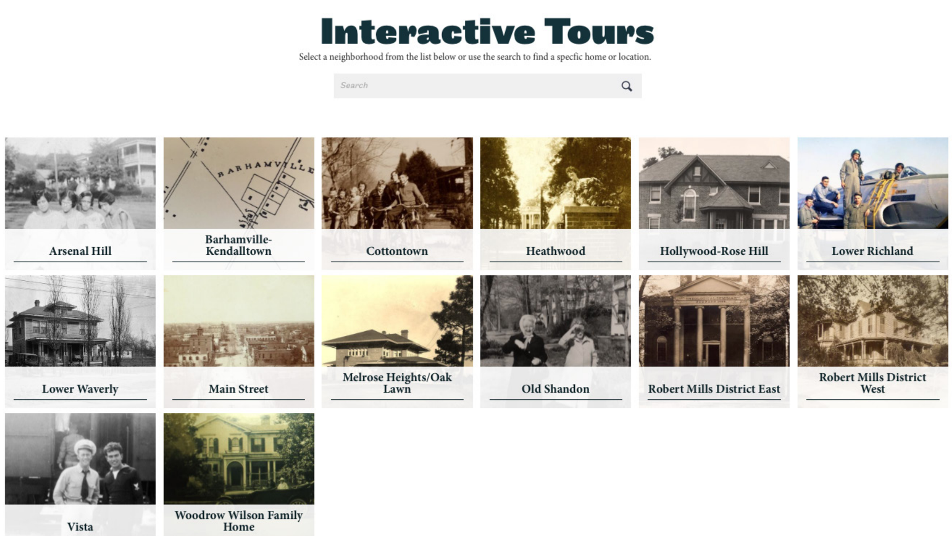

Figure 4.12 *- Base Platform for the Interactive Maps Project.*
The image above depicts the home page for the interactive maps initiative.
Screen-capture of the online maps project published by the Historic Columbia Foundation

[203] "Six Historic Columbia Neighborhoods Are Being Studied."
[204] *Ibid*.

Arsenal Hill, Barhamville-Kendalltown, Cottontown, Heathwood, Hollywood-Rose Hill, Lower Waverly, Main Street, Old Shandon, Robert Mills District East, Robert Mills District West and the Vista.[205]

The project began as a three year endeavor called "Retrace: Connecting Communities through History." However, the oral interviews, recollections, photographs, maps and conversations have since been translated and transferred to the Foundation's interactive neighborhood maps platform, preserving the documents and creating a record of the neighborhood's architectural heritage.[206] Titled "Interactive Tours" and viewable through an Internet platform, the project allows the viewer to choose one of Columbia's historic neighborhoods for further study. Each neighborhood displays between twenty and fifty historic structures and sites. The simplicity of the user interface platform can

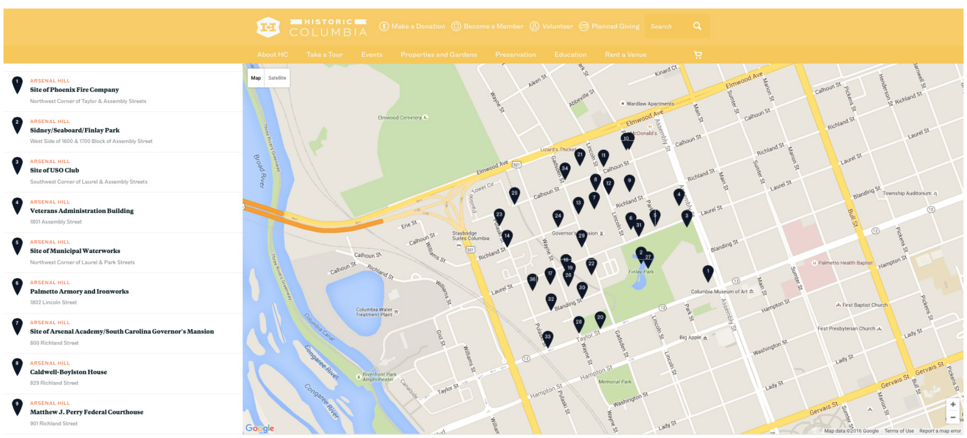

Figure 4.13 *- Map Overview for the Arsenal Hill Historic Neighborhood.*
The image above depicts the initial interactive platform displayed when a user explores the Arsenal Hill neighborhood. The black pinpoints represent the historic structures with viewable data within the neighborhood
Screen-capture of the online maps project published by the Historic Columbia Foundation

be attributed to the program's similarities and ability to interface with Google maps. The historic structures are pinpointed and numbered on the map, as well as listed on a sidebar. When a user selects a location, the selection is expanded to display historic photographs of

[205] "Historic Columbia."
[206] *Ibid*.

the structure, Sanborn Fire Insurance maps, contemporary photographs, historic renderings of the building and historic maps, as well as a short narrative explaining the significance of the structure to the city. Additionally, some structures also include videos of residents describing life in the neighborhood.[207] John Sherrer, Director of Cultural Resources for the Foundation asserts, "Some of the most memorable moments of the work thus far have been conducting oral history interviews; the opportunity to empower folks throughout these six neighborhoods by granting them a voice in relating their stories is so meaningful to them and to us."[208]

Figure 4.14 *- The Smith House in the Old Shandon Neighborhood.*
The image above depicts the narrative and historic images uploaded into the multimedia GIS platform for the historic Smith House in the Old Shandon neighborhood. The map overview for the neighborhood is visible in the background.
Screen-capture of the online maps project published by the Historic Columbia Foundation

The narrative included for each structure gives a brief introduction, with more emphasis placed on describing the historic images present. However, certain structures' pages contain more documents and images than others; some structures are more thoroughly portrayed with a house history, brief chain of title and description of architectural additions to the structure. Still, the majority of the structures and lots included in the multimedia GIS

[207] "Historic Columbia."
[208] "Six Historic Columbia Neighborhoods Are Being Studied."

platform are minimally documented as they contain just single photographs. The lack of data for some of the neighborhoods is due to the relative newness of the project. There is an understanding that the platform will continually increase as historic data is accumulated. Although not as expansive as an archival record, arguably, the web-based virtual tour of the city's historic neighborhoods has proven a successful and effective tool as a digital archive for the Historic Columbia Foundation.

The digital documentation method used to create the interactive maps platform has been a multipronged strategy involving both the Historic Columbia Foundation and external branding firms. The project team consisted of permanent, full-time employees of the Foundation and part-time graduate assistants from the University of South Carolina, who worked with the Historic Columbia Foundation as interns and volunteers. Design of the actual multimedia GIS platform was performed by Cyberwoven, a contractual firm based in Columbia.[209] Cyberwoven is a full-service digital agency that focuses on the design and development of online experiences used to grow businesses. Their site states that they translate companies' brands to the web with intuitive, user-friendly websites that drive real, measurable results.[210] While Cyberwoven designed the interactive maps platform, the Historic Columbia content and executive staff, along with the marketing staff, reviewed the format and graphics. The Foundation's involvement was centered on digital scanning and collection of historic images and oral histories, while the digitization of these records and development of the interactive platform was performed by a contractor.[211]

[209] Waites to Brown, "Historic Columbia's Maps Project."
[210] "Cyberwoven | Web Design, Development & Strategy," *Cyberwoven*, accessed November 19, 2015, http://www.cyberwoven.com/#services.
[211] Waites to Brown, "Historic Columbia's Maps Project."

The interactive maps site was built using the Orchard Content Management System.[212] All content related to the historic neighborhoods and architectural heritage is entered in the body field of the content management system. Photographs and images are uploaded as a .JPEG or .PNG file format. The map itself utilizes Google Maps. The team member enters the longitude and latitude of each structure included in the historic neighborhood map to allow for users to view pinpoint locations. In addition to the web-based interpretative tour platform, the project has allowed the Historic Columbia Foundation to create wayside and print brochures of the historic neighborhoods. Originally marketed for tourists through the Convention and Visitors Bureau, the maps project has reached a wider audience of neighborhood residents and local history enthusiasts.[213]

The interactive maps project began in 2008 with a grass roots grant, associated with the "We Want to Hear Your Story" initiative and funded by the Institute of Museum and Library Services and the Humanities Council.[214] Robin Waites, Executive Director of the Historic Columbia Foundation explains that the original design of the multimedia GIS tool was "quite extensive and expensive" costing about $75,000. She stresses that without the *Museums for America* grant, as a non-profit, they would not have been able to initiate and generate the platform. In 2013, after several iterations, the platform design transitioned allowing for easier internal management, therefore making the interactive site more cost effective.[215] Waites asserts that if an organization were to employ the multimedia GIS technology to "preserve meaningful histories into an online research project", that Historic

[212] The Orchard Content Management System, also recognized as the Orchard Project, is a free, open source, community-focused content management system (CMS). The Project was jointly developed between Microsoft and .NET, and released in the 2000s. This platform is the successor to Microsoft's Oxite content management system. "The Orchard Project," *Orchard*, accessed November 23, 2015, http://www.orchardproject.net; "Orchard - Microsoft's Bid for Open Source CMS Competition," *WebmasterFormat*, January 13, 2012, http://webmasterformat.com/tools/cms/orchard.
[213] Waites to Brown, "Historic Columbia's Maps Project."
[214] *Ibid*.; "Six Historic Columbia Neighborhoods Are Being Studied."
[215] Waites to Brown, "Historic Columbia's Maps Project."

Columbia's approach would be feasible.[216]

The platform is Google-map based, and presumably will remain a viable interpretation tool for the documentation of the city's architectural heritage as long as Google remains a popular GIS display method. Waites contends that the maps project has adequately documented the sites and structures that the Foundation has historic content and images for. The multimedia maps platform has allowed the staff to manage all content internally, as they are able to program additional neighborhoods and load much of the data themselves. In an interview, Waites explained that ease-of-use for the end user was a significant consideration during the initial design.[217] Use of the project from a desktop or a tablet has proven easy to access and navigate. The simplicity of both the digital documentation technique and the platform has ensured that users of all generations, with or without GIS experience can utilize the project. The Foundation has seen positive results with the project, and states that they would employ the platform again; however, they would consider moving to a platform that was more compatible for accessing content using smartphones or for building a system of self-guided tours.[218]

Although highly successful and well received within the city, Waites explains that the organization of the platform "was not without pitfalls."[219] While student interns and archivists working on the project have been able to address many documentation challenges, the Executive Director stresses that there remains organizational work to be completed to

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[216] *Ibid*.; "Six Historic Columbia Neighborhoods Are Being Studied."

[217] Waites to Brown, "Historic Columbia's Maps Project."

[218] The interactive maps project and corresponding content is accessible through a smartphone. However, the display is not as easily navigable compared to what is experienced on a laptop or desktop. The site must be accessed through an internet page; there is not an option to download an application for the phone. When viewing the platform on a phone, the map and pinpointed locations are not displayed. The user is presented only with the list of historic structures within the neighborhood. Users must scroll through the structures one-by-one without the context of viewing the relationships between the buildings and sites. This arrangement would prove frustrating for a user attempting to use this platform on a self-guided walking tour. *Ibid*.

[219] *Ibid*.

ensure uniformity of content on the site. Many of the obstacles experienced have been attributed to staff turnover both from within the Historic Columbia Foundation, as well as with the design firm, Cyberwoven.[220] Additionally, the multimedia GIS format is arguably more effective for a user sitting at a computer for a virtual tour, than for someone attempting to use the content to physically walk the historic neighborhoods. This arrangement may prove a larger challenge as users generally rely more on smartphone use.

Figure 4.15 *- F.A. Tradewell House in the Robert Mills District East.*
The image above depicts the interactive page that appears when a user selects marker No. 33 of the Robert Mills District East neighborhood. This marker represents the former site of the F.A. Tradewell House circa-1840.
Screen-capture of the online maps project published by the Historic Columbia Foundation

The multimedia GIS platform created by the Historic Columbia Foundation as a means for documenting and digitally preserving the architectural heritage of eleven of the city's historic neighborhoods provides a feasible model for other cities. The platform is arguably most successful in its ability to be modified and expanded as needed. The interactive maps project allows the staff at the Foundation to continuously publish data as additional historic documents are discovered and archived. In contrast to other digital documentation technologies, the multimedia GIS platform does not freeze the architectural

[220] *Ibid*.

heritage in time; this method provides the opportunity to add additional neighborhoods and new structures, as well as increase the historic resources available online for the existing documented buildings. The maps-based platform is arguably the most user friendly enterprise as it is familiar to many users and provides an interactive experience more straightforward than a three-dimensional model. This documentation technique does not offer an even distribution of documentation and historic data within each neighborhood, however, and is disputably biased towards certain structures. The multimedia GIS platform begins to relate the evolution of the architectural heritage of the historic neighborhoods, but is more successful narrating the history of the neighborhood and relating the significance of the architecture.

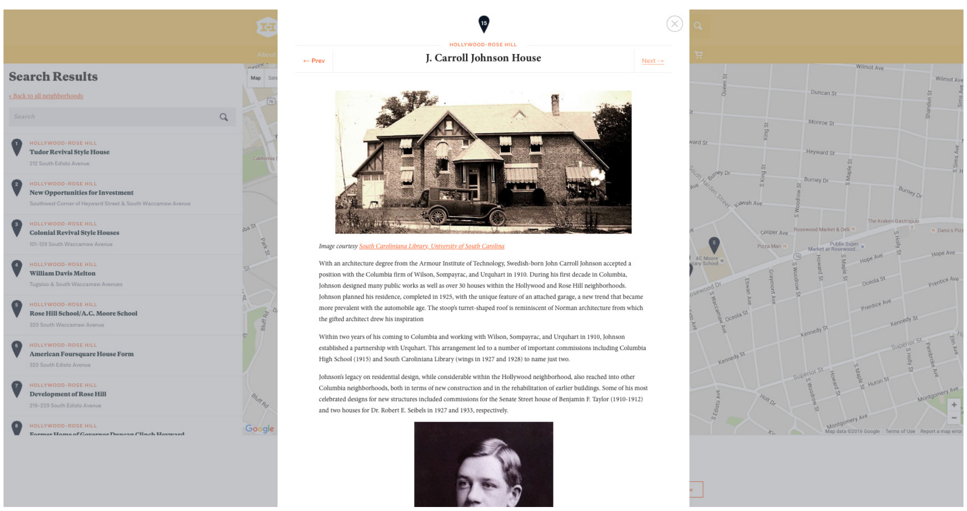

Figure 4.16 *- J. Carroll Johnson House in the Hollywood-Rose Hill Neighborhood.*
The image above represents the typical narrative and historic imagery included for each historic structure or site represented through the Foundation's multimedia GIS project.
Screen-capture of the online maps project published by the Historic Columbia Foundation

Virtual Historic Savannah Project

The Virtual Historic Savannah Project provides a unique case study of early three-dimensional digital documentation efforts at a city scale. Although unfortunately outdated and minimally publicized, the project when initially introduced at the National Trust for

Historic Preservation Conference in Savannah in 1998 generated an enthusiastic response and was described as "cutting edge."[221] Epitomizing the excitement of the project's development, National Endowment for the Humanities Chairman, William Ferriss stated before Congress in April of 2001, "We view this project as a national model and hope to see similar initiatives in other cities around the nation."[222] The Virtual Historic Savannah Project documents the evolution of urban form within the downtown area of Savannah, Georgia, by combining architectural and social history research with three-dimensional database technology. The project displays over 2,200 existing structures, as well information relating to the people, businesses and institutions that occupied them. The project "analyzes urban form by using computer animation to navigate through space and time."[223]

Figure 4.17 *- Virtual Historic Savannah Project Logo.*
Image courtesy of the Savannah College of Art and Design

Incorporating the visualization of a three-dimensional model provides an "enjoyable and interesting" exposure to architectural masses, vastly different from what users typically encounter through a multimedia GIS application.[224] The platform initially displays a computer graphic plan of the city as it currently exists. Various options allow for different types of movement within the city and through the model. The city can be viewed

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221 *Virtual Historic Savannah Project* (Savannah College of Art and Design, 1998), http://vsav.scad.edu.
222 *Ibid*.
223 *Ibid*.
224 *Ibid*.; "Interactive Tours," *Historic Columbia*, accessed September 14, 2015, http://www.historiccolumbia.org/self-guided-tours; Robin Waites to Amanda Brown, "Historic Columbia's Maps Project," November 17, 2015.

from street level, as if flying through the structures, as an aerial perspective or as a plan. The buildings – or individual three-dimensional models – provide a sense of scale within the city. Their massing is supplemented with architectural information for each structure including ward name, contemporary photograph, construction date, architect, building characteristics and occupants.

Figure 4.18 - *Initial Platform View for the Virtual Historic Savannah Project.*
The image above depicts a planar perspective of the Virtual Historic Savannah Project. Images and a short narrative for the Wesley Methodist Church are presented in the lower portion of the screen.
Screen-capture from the interactive 3D model published by the Virtual Historic Savannah Project team

Beginning in 1997, the development of the Virtual Historic Savannah Project stemmed from two motivational factors. The first being the absence of a comprehensive study of the architectural history of Savannah, and the second the belief that the use of three-dimensional digital technology could provide an effective and interactive avenue for studying urban architectural heritage.[225] Publicly accessible, the project was to serve as a real time interface to Savannah's architecture, documenting the vast amount of change that had occurred in the historic city.[226] The initial vision for the documentation project came from Dr. Robin Williams, Chair of Architectural History at the Savannah College of Art

[225] *Ibid*.; Leon Robichaud, Virtual Historic Savannah Project, Email, January 4, 2016.
[226] Greg Johnson, Virtual Historic Savannah Project, Email, October 16, 2015.

and Design. The concept for the project grew out of his desire to create a "comprehensive guide to the city that was not constrained by the limits of a guidebook."[227] Williams believed that printed and structured architectural guidebooks presented the shortcomings of a linear narrative, constrained in their chronological, stylistic or geographic organization. Through the Virtual Historic Savannah Project, Williams looked to create a digital documentation platform where users could investigate Savannah's architectural heritage as they wished, without being "constrained by the editorial preferences of [an] author."[228] Additionally, a strong objective was that the project would be unfettered in its architectural inclusions. The initial ambition was to digitally document and model every building that had stood in downtown Savannah from the present, the late 1990s at the time, back to 1733. This would include both existing and lost structures without the editorial overlay of deeming structures adequately significant or historic, grand enough or large enough in scale for inclusion.[229]

The project is attributed to two key people: Dr. Robin Williams of the Savannah College of Art and Design, who served as the Project Director and Coordinator of Historical Research and Greg Johnson of the Savannah College of Art and Design, who served as the Production Director and Coordinator of Technical Development.[230] Specialists for database design, information archiving and documentation were later brought on, including, Leon Robichaud of the Universite de Sherbrooke, who served as the Database Supervisor.[231] Undergraduate and graduate students at the Savannah College of Art and Design also played a significant role within the project as they gathered raw data, photo-documented the buildings, participated in archival research and built the majority of the three-dimensional models.[232]

[227] Robin Williams, Virtual Historic Savannah Project, Phone, October 30, 2015.
[228] *Ibid*.
[229] *Ibid*.; Johnson, Virtual Historic Savannah Project.
[230] *Virtual Historic Savannah Project*.
[231] Robichaud, Virtual Historic Savannah Project.
[232] Johnson, Virtual Historic Savannah Project.

With this case study, three-dimensional modeling was chosen as the digital documentation technique as the developers sought the characteristics of a visual model that would be infinitely changeable, nimble and navigable. Greg Johnson, Production Director and Coordinator of Technical Development suggested the use of an online language called VRML, or Virtual Reality Modeling Language.[233] Three-dimensional modeling and VRML appeared a valid choice, as the developers assumed that the Internet would become increasingly three-dimensional with future advances.[234] The objective was to produce a city scale digital model of Savannah's architectural heritage that was accessible by the public, for free, through a three-dimensional online interface.[235]

Figure 4.19 *- Aerial Perspective of the Virtual Historic Savannah Project.*
The image above depicts an aerial or "flying" perspective of the 3D model. A model of the Cathedral of St. John the Baptist is visible at the left side of the image and the building's corresponding narrative is seen in the lower portion of the screen.
Screen-capture from the interactive 3D model published by the Virtual Historic Savannah Project team

233 Virtual Reality Modeling Language (VRML) is a standard file format for describing interactive three-dimensional vector graphics. VRML is designed for Internet use and can be employed as a universal format for three-dimensional objects and multimedia. One of the platform's primary uses is for the creation of a virtual world. The first version of VRML was specified in 1994. Since then, it has been superseded by X3D, an XML-based file format used to represent three-dimensional computer graphics. "Virtual Reality Modeling Language (VRML) - ISO/IEC 147772-1:1997 Standard" (SGML/XML: Related Standards, November 14, 2000), http://xml.coverpages.org/related.html#vrml.
234 While the Director of the project admits that the creation of the Virtual Historic Savannah Project looked as if the team was trying to create something from uncharted territory, the Google Street View platform emerged less than ten years after the Savannah project was initiated.
235 Williams, Virtual Historic Savannah Project.

In an interview, Dr. Robin Williams explained that it was an early decision to use off the shelf software, nothing proprietary from a technological stance. This parameter, the use of generic, non-branded software, was established as a means of making the project replicable. To model the massing of the structures, the team planned to use the three-dimensional data layer of the city's GIS and extrude the wire frame footprints of the buildings. However, it was discovered that the GIS data was not precisely drawn and eventually proved useless to the modeling project. Instead, architecture students working on the modeling phase of the project created a base map of downtown Savannah from older maps. With this, as well as photographs and field notes, the students were able to model over 2,000 structures.[236]

Contending with technology restrictions and challenges, three-dimensional modeling obstacles, and a vast area of architecture to be studied, it took the project developers nearly ten years to model the structures of downtown Savannah.[237] Due to the early, restrictive nature of three-dimensional modeling programs paired with limited Internet bandwidth,

Figure 4.20 - *Polygon Budgets for Modeling Efficiency.*
The image above illustrates how the modeling team created polygon budgets for the model. The team elected to depict more distinguished structures - such as churches - with greater detail compared to the surrounding, less prominent buildings.
Screen-capture from the interactive 3D model published by the Virtual Historic Savannah Project team

[236] *Ibid*.
[237] *Ibid*.; Johnson, Virtual Historic Savannah Project; Robichaud, Virtual Historic Savannah Project.

Johnson and the modeling team had to develop strategies for modeling efficiently. The team concluded that the more geometry put into a structure's model – the more it accurately resembled the building – the more polygons were generated in the program. The issue with elaborate geometry or more polygons is significantly longer loading times. To address this tradeoff, polygon budgets were created delineating how many buildings in a Ward (also recognized as an open city square and its eight surrounding blocks) could be modeled as simple cubes and how many required detail.[238]

The three-dimensional modeling of the Virtual Historic Savannah Project visually resembles a city's massing model. Structures are devoid of fenestrations, textures and details, and rely primarily on height, shape and setback to communicate urban character. The three-dimensional models are a series of cubes delineated by various colors. The majority of the roofs are flat, lacking parapets or the impression of a slope. When compared

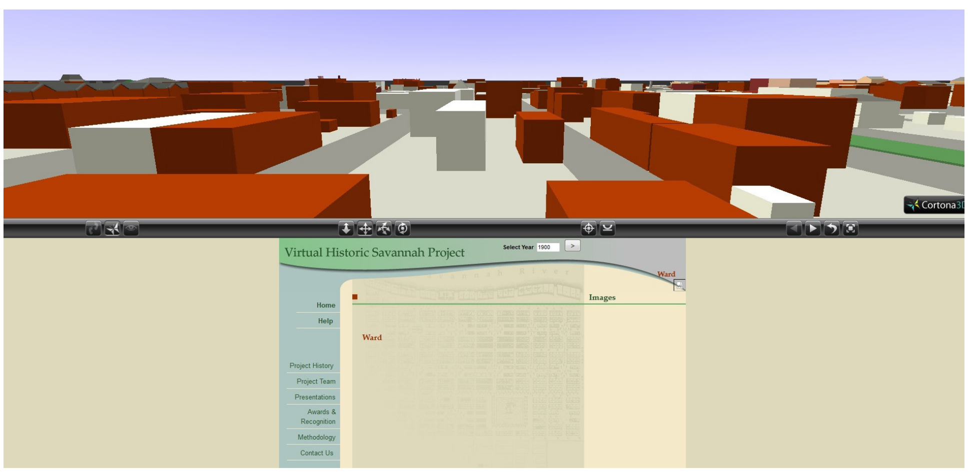

Figure 4.21 *- Aerial Perspective of the Virtual Historic Savannah Project.*
The image above, taken from an aerial perspective within the model illustrates the roof forms modeled within the platform. The roofs of prominent structures are more accurately represented, however, the majority of the roofs are depicted as flat.
Screen-capture from the interactive 3D model published by the Virtual Historic Savannah Project team

[238] Dr. Robin Williams admits that with this methodology, there was some privileging of buildings and landmarks, ultimately contradicting his desire to create the "unfettered anti-guidebook." However, the inclusion of both cubical massing, as well as detail was supported by the theory that to successfully navigate the model, some structures needed to be recognizable. In the model, the structures with more elaborately modeled geometry are typically churches. Arguably, these are the larger and taller buildings of Savannah and successfully serve to orient the user. Williams, Virtual Historic Savannah Project.

to Google Earth, it does not appear that these buildings actually feature flat roofs, but instead many are constructed with hipped roofs. Arguably, this design decision during the modeling phase was selected as means of decreasing the modeled geometry and data size for the project. However, the model does display a selection of gable and hipped roofs as well. It appears that the project developers chose to model only a handful of roof shapes for each of Savannah's wards. The final product resembles a massing model; this characteristic was an intended objective from the initial development phase, but is also partially a result of file size restrictions experienced during the modeling phase. The three-dimensional models included within the project do not serve to document the architectural styles or characteristics of the structures. The models are purely representative of the buildings' mass and relationship to the surrounding environment.

Johnson, Production Director for the project and Chair for the Computer Department at the Savannah College of Art and Design, explained in an interview that ease-of-use was a key determinant during the design of the interface and choice of the three-dimensional modeling technology. However, both Johnson and Williams acknowledge that the three-dimensional modeling of the structures required supplementary technical expertise and a significant learning curve.[239] Williams admits that it was "beyond [his] training as an architectural historian" and therefore undergraduate architecture students completed the majority of the three-dimensional modeling.[240] Regarding the actual use of the platform and site, tools such as fly, walk, plan, pan, turn, roll, go to, straighten and next viewpoint allow the user to interact with the three-dimensional model. It is challenging to "walk the streets" of the model, and proves most effective to "float" above the buildings, viewing the models as an axonometric. Additionally, the perspectival views often become warped. This can be corrected by selecting the "straighten" tool, however it may prove easiest for users to

[239] Johnson, Virtual Historic Savannah Project; Williams, Virtual Historic Savannah Project.
[240] Williams, Virtual Historic Savannah Project.

employ the "next viewport" tool to click through the structures individually. This method is more restrictive, as users are not able to create their own course and experience within the platform. While movement within the platform is initially challenging, by clicking on a model, architectural information about the structure and historic photographs are presented to the viewer.[241] This component of the platform is incredibly effective in rendering the structures' history and evolution, and has demonstrated ease-of-use.

Scale, funding and technology posed the greatest obstacles encountered by the developers of the Virtual Historic Savannah Project. Williams rationalized that the scale of the project and his overly ambitious vision led to many of the project's shortcomings. Analyzing the methodology posted on the project's website, it took the team nearly ten years to develop procedures, research and accumulate data, model the existing structures and combine the three-dimensional graphics with historical data of the structures' occupants.[242] Williams explained that at the pace the team was working, to do the project to his original vision would have taken thirty years. When asked if he would employ the same digital documentation methods again, Williams answered yes, but clarified that he would choose a smaller area of downtown Savannah for modeling.[243] While the project was awarded three separate grants, totaling $210,000, both Williams and Johnson attribute the lapse of activity on the site to funding.[244] The grants were primarily used to sponsor consultants and specialists. Williams and Johnson both continued to work full time at the College, and

[241] Including the architectural narrative and social history for each structure is similar to the multimedia GIS method of documentation. The building's information is displayed on the lower portion of the screen, beneath the model and includes the building name, year of construction, number of stories, roof type, cladding materials and historic photographs.
[242] *Virtual Historic Savannah Project*.
[243] Williams, Virtual Historic Savannah Project.
[244] The Virtual Historic Savannah Project received an initial grant from the State of Georgia for $10,000. Two grants from the National Endowment for the Humanities, one for $50,000 and a third for $150,000, followed this. *Ibid.*; *Virtual Historic Savannah Project*; Robichaud, Virtual Historic Savannah Project.

employed the help of students through course requirements.[245] A quicker deployment of the site could have been possible with greater funding to support a full-time team devoted to the development of the project and creation of the three-dimensional model.[246]

The innovation of the technology being employed, unprecedented before this project, arguably created the greatest obstacle and frustration for the development team. At its production in the early 2000s, the Virtual Historic Savannah Project was larger than the average bandwidth capacity of an internet connection.[247] This resulted in a slow loading process for the architectural models and low resolution of the three-dimensional graphics, presumably adding a level of frustration for the users. Additionally, the VRML technology required a plugin – users had to download a specific software to be able to view the site – this

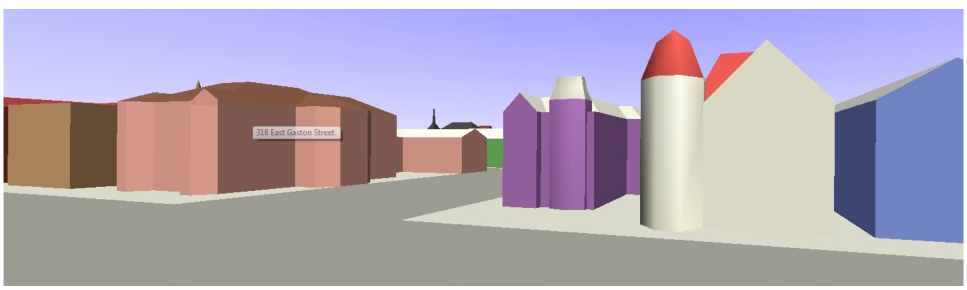

Figure 4.22 *- Street Perspective at East Gaston Street.*
The image above depicts the 3D Savannah model from a street-level perspective at 318 East Gaston Street. This image illustrates the low level of resolution users experience when interacting within the model.
Screen-capture from the interactive 3D model published by the Virtual Historic Savannah Project team

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245 Williams explains that at one point thirteen people were working simultaneously on the model and platform, however, none of these team members were employed full-time. Williams, Virtual Historic Savannah Project.

246 Leon Robichaud, a consultant for the development of the database for the model asserts that without a substantial investment, such that was provided by the National Endowment for the Humanities, a similar project would not be feasible. However, he suggests that to limit costs, a sponsoring organization could choose to utilize successive Sanborn Fire Insurance maps, rather than creating individual building histories as the developers of the Virtual Historic Savannah Project did. Robichaud, Virtual Historic Savannah Project.

247 In an interview, Williams explained that the project team was conceiving a project that would work over an internet connection. However, at the time of the project's inception bandwidth could not handle the size of the project. Williams explained that Johnson suggested they build a project too big for the current (late 1990s and early 2000s) bandwidth, recognizing that at the pace the site was being developed, the bandwidth would catch up. While the bandwidth did eventually advance, the excitement of the project had worn off and other technical challenges had presented themselves.

proved deterrent for many online visitors.[248] As a general statement to the use of technology in the field of preservation, Johnson argues that the "ephemeral nature of electronic data becomes all too apparent after even a couple of years" and must be continuously updated to remain usable and relevant. Speaking to the Virtual Historic Savannah Project, he asserts that technology has "moved on" and believes that if the project were recreated current-day, it would utilize technology more similar to Google Earth or GIS.[249] The original objective of the Virtual Historic Savannah Project was to have the public be the primary users of the platform. However, both primary developers of the project admit that use of the project seemed restricted to serious students of architecture and urban history. The lack of public interest could be attributed to a lack of funding for advertising, the requirement of an internet connection, restricted viewership due to the size of the files and long download times for the models, all significant obstacles encountered during the project.[250]

Regardless of the obstacles presented through technology challenges, the Virtual Historic Savannah Project does successfully provide an interface that allows the public to interactively explore a three-dimensional model representative of Savannah's evolving architectural heritage. The project provides a unique tool and succeeds in attracting users to the platform who might otherwise not have explored the urban evolution of the architecture of the historic city.[251] Although now nearly two decades old, the three-dimensional interface remains functional and is surprisingly detailed. The architectural heritage model created in this case study aids in public outreach and fosters interest in the preservation of Savannah's urban architecture. The developers of the Virtual Historic Savannah Project contend that the three-dimensional model, as well as the launched site, are a low cost and

[248] A plugin is a piece of software that acts as an add-on to a web browser and gives the browser additional functionality. Williams, Virtual Historic Savannah Project; *Virtual Historic Savannah Project*.
[249] Johnson, Virtual Historic Savannah Project.
[250] *Ibid*.; Robichaud, Virtual Historic Savannah Project.
[251] Williams, Virtual Historic Savannah Project; Johnson, Virtual Historic Savannah Project.

flexible method of creating wide distribution of a preservation education initiative.[252]

Johnson asserts that with the resources, any historic city could create a similar city-scaled platform for the documentation of their architectural heritage. However, he states that three-dimensional digital documentation of architecture has a specific application. Johnson elaborates, stating that if the objective is to preserve data for the use of future generations then a digital format could be futile. He reasons "all electronic data is by its very nature, ephemeral." If documentation of architectural heritage for posterity is the overarching objective, he asserts that any means of digital documentation would be unsuccessful and cities would find a greater long-term solution in a printed format.[253]

When asked to explain the success of the Virtual Historic Savannah Project in documenting the city's architectural heritage, Williams stated that the project was "most successful in terms of documenting the city as it stood in the late twentieth century." As an initiative to document the architectural evolution of a city, he did not think the documentation method was successful.[254] The three-dimensional models of the structures provide the user with information about the existing present-day built environment. The interface allows the user to transverse the city digitally decade-by-decade, viewing the structural population of downtown Savannah relative to the late-twentieth century.[255] This methodology of modeling allows visitors of the project to visualize the extent of existing structures, as well as the structures that have survived Savannah's urban development and evolution. Utilizing the decade search tool provides a unique opportunity for users to see the sparse amount of surviving eighteenth century structures, in contrast to the pronounced presence of mid-1800s and late-1800s surviving buildings. Additionally, the archival segment of the platform provides perspective on the architectural occupation history of

[252] Williams, Virtual Historic Savannah Project; *Virtual Historic Savannah Project*.
[253] Johnson, Virtual Historic Savannah Project.
[254] Williams, Virtual Historic Savannah Project.
[255] *Ibid*.; *Virtual Historic Savannah Project*.

Figure 4.23 *- New Franklin Ward circa 1850.*

The image above portrays the 3D Savannah model near the New Franklin Ward when the user selects the year 1850 for viewing. Visually, this perspective helps to illustrate the modest amount of mid-1800s structures that survive present-day. While other buildings may have been present at this time, they are no longer standing. This interactive element helps to illuminate building development and urban evolution within the Historic District of Savannah.

Screen-capture from the interactive 3D model published by the Virtual Historic Savannah Project team

Figure 4.24 *- New Franklin Ward circa 1900.*

This image depicts a perspective similar to the image above, however this view was captured when the user selected the year 1900. In comparison to the 1850s illustration, a significantly larger portion of buildings survive from 1900. The difference in urban density helps to illustrate an increase in urban development and preservation efforts. The Wesley Methodist Church can be observed in both images.

Screen-capture from the interactive 3D model published by the Virtual Historic Savannah Project team each of the existing buildings. However, regarding the evolution of the city's architectural heritage, the project does not document or portray the progression of architectural styles throughout the city, or the details, features and additional construction endeavors of the individual structures.[256] Addressing posterity, Williams states that the project team was able to document buildings that have disappeared since the project was started; the website has some of the only photographs of downtown structures that have been lost to urban development.[257]

As a testament to its success, the Virtual Historic Savannah Project is still functioning after eighteen years. While the documentation project is not regularly used, presumably attributed to the deterrent of the plugin, the site does still receive visitors. Ultimately, the scale and ambition of the project, paired with inadequate funding and time posed the greatest impediment through the development phase of the platform. The development team expressed that if the project were to be revamped, due to technology advances, a three-dimensional GIS model would likely be employed. As an early initiative in city scale digital documentation, the Virtual Historic Savannah Project was an effective platform in recording the city's urban form.

In conclusion, the Virtual Historic Savannah Project represents a citywide massing model paired with historic documents. The platform and digital documentation technique would be advantageous and effective for interpreting height, scale and mass at the level of city planning for a Board of Architectural Review. Due to the lack of detail, the Virtual Historic Savannah Project could not be utilized during reconstruction or restoration undertakings. The project illustrates where the downtown structures of Savannah currently exist, and the extent to which they have occupied that space. However, the case study is unsuccessful in portraying evolution of the individual buildings and evolution of the

[256] *Virtual Historic Savannah Project*.
[257] Williams, Virtual Historic Savannah Project.

architectural styles within historic areas of the city. Additionally, it is difficult to distinguish residential, civic and commercial structures. Structures with greater detail, primarily churches, considerably standout, or emerge among the other more simply modeled buildings. While the Virtual Historic Savannah Project does not effectively display the architectural heritage of Savannah, the digital documentation method employed records the urban form of Savannah, allowing visitors to see the extended presence of the existing structures within the historic downtown area.

Synthesis

The four case studies presented – New Orleans laser scanning, University of Maryland photogrammetry, Historic Columbia Foundation multimedia GIS and the Virtual Historic Savannah three-dimensional model – all achieve successful architectural heritage documentation. However, the case studies utilize four distinctive methods of digital documentation, arguably developing different preservation applications and deliverables. The objective of each of the case studies, as well as the successes and failures generated from their digital heritage endeavors can educate cities evaluating potential documentation technologies for future recordation campaigns. In addition to achievements and challenges, the case studies were evaluated in terms of application, audience, ease of use, manageability, labor and economics.

The case studies foster a comprehensive understanding of the requirements of a digital model for a city or historic community, as well as the successes and failures of each technology. Additionally, the case studies demonstrate potential applications for each method of documentation. The applications presented are not strictly preservation inclined; several case studies would arguably be more efficaciously implemented for planning purposes. The intended or actual audience for each of the case studies closely relates to the objective and characteristics of the digital documentation product. Any of the four case studies could be utilized for educational objectives. However, the technologies that render data at a greater level of detail may foster superior applications such as three-dimensional replication, reconstruction, heritage tourism and the documentation of architectural evolution. The laser scanning campaign of the New Orleans streetscapes undertaken by CyArk presented the most graphic and realistic documentation rendering. In contrast, the Virtual Historic Savannah Project generated the least realistic representation and would not be likely to advance a reconstruction initiative. The orthophotographic model created of the University of Maryland Baltimore County campus is a median between the detailed, photorealistic documentation of New Orleans and the massing model created of Savannah. The multimedia GIS platform created for the Historic Columbia Foundation includes realistic representations of the architecture through photographs, however it does not document the architectural relationship visible in the other case studies.

CyArk's motivation to laser scan the streetscapes of New Orleans was due to the historic districts' vulnerability to natural disasters and the risk of the destruction of historic architecture. The documentation project digitally recorded the streetscape heritage creating a virtual three-dimensional replica of the city. Although CyArk initially created the project for educational initiatives, the recordation's incredibly realistic appearance and level of accuracy lends itself to successful applications with reconstruction, restoration and conservation projects. The developers at CyArk assert that the street views and aerial perspectives generated from the point cloud could serve as a digital blueprint for reconstruction should it become necessary. Although this documentation product serves as a photorealistic interpretation of the city circa 2014, it is unlikely that the laser scanning procedure captured a level of accuracy and detail great enough to foster a accurate reconstruction. The environmental orthophotographic model created of the University of Maryland Baltimore County campus is closely aligned to the New Orleans laser scan in terms of its photographic appearance. In contrast to the orthorectified visual created from the

New Orleans scan, the University of Maryland photogrammetry project was undertaken for aerial mapping and analytical purposes; the documentation enables the Ecosynth Research Team to quantify the green space on the campus, as well as assess building conditions. Despite its photographic characteristics, the generated data is arguably more successful in portraying massing and would be less applicable to architectural heritage preservation, but relevant to urban design and city planning.

The multimedia GIS platform created for the Historic Columbia Foundation has a considerably different application and audience when compared to the New Orleans and University of Maryland Baltimore County case studies. The interactive maps project was created by the Historic Columbia Foundation to promote the architectural history of Columbia's neighborhoods through digitized archival documents. The project serves to enrich local heritage tourism and acts as an interpretation tool for visitors. Functionally, this case study is limited to educational and interpretative applications; the multimedia GIS project does not portray the relationship between the structures as experienced through the laser scanning and photogrammetry case studies, and would be ineffectual for urban planning objectives. The Virtual Historic Savannah Project exhibits similarities in application to both the Historic Columbia Foundation multimedia GIS project and the University of Maryland Baltimore County photogrammetry model. The Savannah case study documents the evolution of urban form within the historic downtown of the city; the project combines three-dimensional modeling with social history multimedia. Arguably, the project's most successful application is as a citywide massing model. The lack of detail – fenestrations, texture, and architectural features – prohibits this case study from being used for restoration or conservation purposes. The case study does incorporate historic photographs cultivating resemblances to the Historic Columbia Foundation maps project and its application as an interactive tool for studying urban architectural heritage.

Each of the four case studies highlights specific characteristics that made it an effective product of architectural heritage documentation. These characteristics determined the most effective application for each case study. The New Orleans case study utilized terrestrial scanning to capture rectified visualizations of the city, a disparity to the aerial scanning completed of the University of Maryland Baltimore County campus. The use of cars for laser scanning data capture, in contrast to the UAV used to capture the data for the photogrammetry case study resulted in visually distinct products. Both case studies captured 360-degree views of the architecture. However, the New Orleans case study more effectively rendered the street facades and architectural details of the structures. The University of Maryland Baltimore County case study demonstrated that UAV documentation is less valuable for architectural heritage and is better adapted for spatial and massing analysis. Additionally, the orthorectified rendering in the New Orleans case study lends a high degree of accuracy when compared to the visibly distorted representation of the architecture in the photogrammetry case study. Although lacking in accuracy compared to the laser scan of New Orleans, the University of Maryland Baltimore County photogrammetry case study was arguably more successful as a massing model than the Virtual Historic Savannah Project. The photogrammetric model captured the massing and general colors of the structures, as well as the location of fenestrations. Although the three-dimensional model of Savannah lacked fenestrations, textures and details, relying primarily on height, shape and setback for interpretation, the interactive element of the case study rendered the project more applicable for educational purposes. The Historic Columbia Foundation maps project also successfully implemented an interactive element. The simplicity of this case study's platform and cohesiveness with Google Maps arguably made the project more user-friendly than the Savannah model.

The level of technical expertise required by both the developer and the end user arguably affected the benefits and deficiencies of the case studies. A higher level of experience required for the creation of the documentation project can be linked to the relative economics of the technique employed for the case study. Additionally, the characteristic of user-friendliness and the level of technical experience required of the audience influenced if the project became useful after production. The New Orleans laser scanning campaign was a highly specialized project that required the partnership of CyArk and HERE. This case study employed advanced technology. The CyArk team asserted that unlike photogrammetry, users needed to be educated on the equipment and software and the service of a full time specialist was necessary. In contrast to the high level of technical expertise required for the New Orleans case study, a team of research students only marginally familiar with the processing platform completed the University of Maryland Baltimore County photogrammetric model. The lead developer of the project explained that the photogrammetry software used, Agisoft PhotoScan, is a simple task for first time users with the help of the published manual. Despite the contrast in the level of experience required for capturing and processing the data, both case studies produced photographic images easily accessible for their audiences.

A specialized external firm created the base platform for the Historic Columbia Foundation's maps project; the team believed its design would be overwhelming without the support of an information technology (IT) employee. However, the project has since returned to internal management. The staff at the nonprofit explained that management of the platform is an unsophisticated task of scanning and loading archival documents. From the audience's perspective, despite the interactive element, the multimedia GIS project created by the Historic Columbia Foundation was arguably the simplest to navigate. The case study's navigability tools, a graphic similarity to Google Maps, fosters familiarity for users. The initial conception of the Virtual Historic Savannah Project was treated similarly to the Historic Columbia Foundation case study; the development team was out sourced and highly specialized. Supplemental technical expertise was necessary for the database creation and the majority of the modeling was undertaken by personnel with backgrounds in architecture. For users, the interactive component of this case study is less candid than that of the multimedia GIS case study. Movement within the three-dimensional model is initially challenging and could prove frustrating to inexperienced users.

Manageability, or the ability to later update and expand the digital documentation production, falls to three tiers of difficulty within the case studies. Both the New Orleans laser scan and the University of Maryland photogrammetry project have the least ability to be revised. Both case studies portray architecture captured and froze at a specific point in time. Tracking changes over time of the case studies' architectural heritage is impossible. A comparison of the architectural evolution would only be plausible if the sponsoring organizations documented the city in yearly – or any period of time – increments. In contrast, the interactive maps project sponsored by the Historic Columbia Foundation is infinitely expandable and changeable. The multimedia GIS platform, in conjunction with the opportunity for internal management allows the organization's staff to accumulate and convert data, uploading new archival information as necessary. The interactive maps project was most successful in its ability to be modified and expanded as needed. The Virtual Historic Savannah Project represents the middle level of manageability. Certainly, the three-dimensional model could be changed, added to or updated. However, the managing process would conceivably be significantly more difficult than the Historic Columbia Foundation multimedia GIS project. Arguably, the Virtual Historic Savannah three-dimensional model was not created to be later managed and revised.

The intensity of labor required, as well as the time elapsed to produce the four digital documentation cases studies varied significantly. This difference is attributed to the scale of the project, the area to be documented, the amount of data input required, the deliverable desired, and the technology utilized. The New Orleans laser scan campaign accumulated data from four historic districts: the Garden District, 0.39 square miles; Faubourg Marigny, 0.40 square miles; the French Quarter, 0.66 square miles; and Esplanade Ridge, 1.42 square miles. This resulted in 277 miles of the city's streets being laser scanned, representing 5.71 square miles of New Orleans's approximately 350 square miles. The laser scanning capture process took three days. It took 150 man-hours, or approximately twenty workdays to digest and analyze the 15 billion data points. Similar to the laser scanning case study in New Orleans, the data accumulation phase of the University of Maryland Baltimore County campus was time consuming, but not labor intensive. With the campus photogrammetry project, the use of the Arducopter platform enabled the flights to be preprogrammed and automatically flown. In comparison to CyArk's scanning of New Orleans, the Ecosynth team only captured data for 0.78 square miles, the entirety of the University of Maryland Baltimore County campus. This resulted in three and one-half miles of UAV documentation and a total of 5443 photographs.

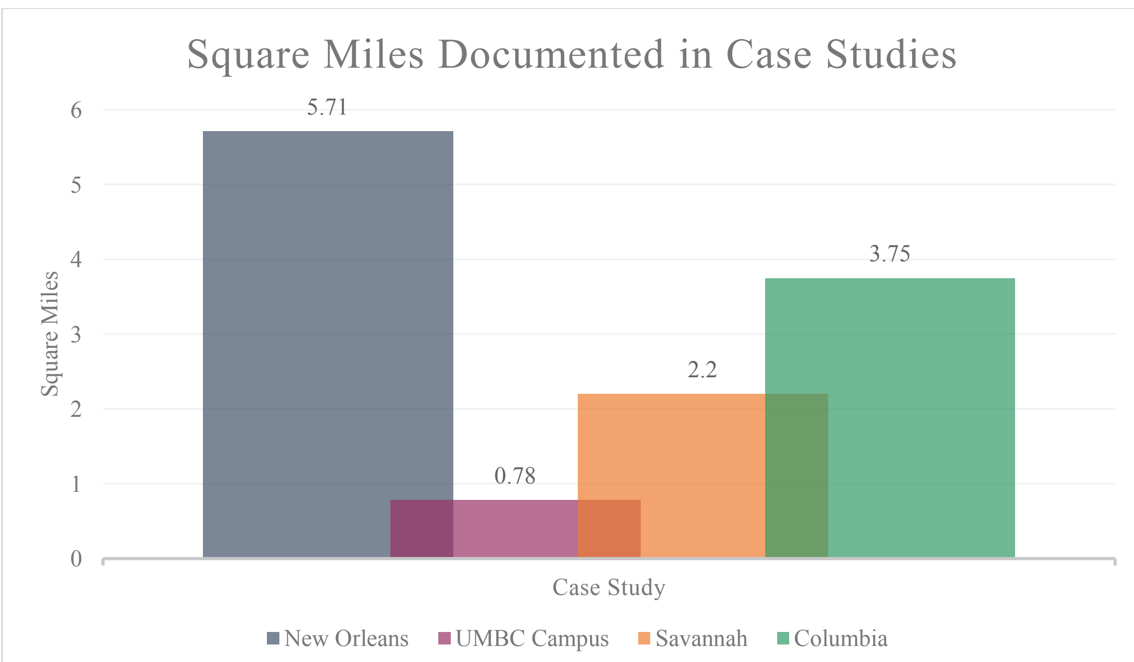

Table 4.0 *- Area Documented by Each Case Study.*
The table above communicates the area, in square miles, documented by each of the four case studies - the New Orleans laser scan, the University of Maryland Baltimore County campus photogrammetry project, the Virtual Historic Savannah Project and the Historic Columbia Foundation interactive maps project. This chart graphically illustrates the size of undertaking experienced by each organization.

Both the Historic Columbia Foundation multimedia GIS platform and the Virtual Historic Savannah Project were completed over a more elongated expanse of time compared to the New Orleans laser scan and the University of Maryland Baltimore County photogrammetric campaign. The Historic Columbia Foundation case study is an ongoing project without a solid completion date. This case study does not have a set amount of data required to function as an interpretation tool; a conclusion to the project depends on the organization's desire to expand the platform. The ability to spread data accumulation and processing phases over longer periods is directly linked to the manageability characteristic of the case study. The construction of the Virtual Historic Savannah Project spanned a period of approximately ten years. The developers of the project modeled approximately 2,200 existing structures. Additionally, the case study incorporates archival documents relating to the people, businesses and institutions that occupied the modeled buildings. The developers explained that modeling the structures was an incredibly time consuming process; however, arguably, the labor intensity of this digital documentation technique is contingent on the number of structures to be modeled and the level of detail to be incorporated.

The sponsoring organizations of each of the four case studies related that the cost of the documentation endeavors was a significant consideration during initial designs and would likely be a decisive concern for cities. Although the infrastructure costs for the data accumulation and processing phases was significantly distinctive between the case studies, the results of the projects were all made viewable on free, web-based open-source platforms. The laser scanning campaign of New Orleans was an expensive documentation endeavor, a factor attributed to the high cost of both the scanning equipment and rendering software. The CyArk team expressed that cities would likely need to partner with larger institutions to replicate the case study. In contrast to the New Orleans laser scan, the photogrammetry case study at the University of Maryland Baltimore County employed hobby-grade equipment and software resulting in a more economically feasible project for the small research team. The team utilized standard, compact digital cameras and open-source software to generate three-dimensional environmental scans. Agisoft PhotoScan, the photogrammetry platform used to process that data, is proprietary software, costing less than $500.

Both the Historic Columbia Foundation multimedia GIS platform and the Virtual Historic Savannah Project were relatively high cost; however, the presence of grants, as well as off-the-shelf software rendered these case studies more economically feasible. According to the Historic Columbia Foundation, the creation of the interactive maps project was only feasible through the help of a grass roots grant. Without the grant, the project would have been an extensive and expensive undertaking, costing the nonprofit approximately $75,000. However, the ability to now manage the project internally has arguably offset the overall costs of the project significantly. The Virtual Historic Savannah Project utilized grants similar to the Historic Columbia Foundation case study to generate the three-dimensional model platform. Through three grants, the developers were able to amass $210,000 to fund the endeavor. This money was utilized principally to sponsor consultants and specialists. Although this case study was more expensive, the economics are attributed to the labor required for the modeling phase, not the equipment and software employed.

Aside from potential impediments presented in terms of economics and technical expertise, there were challenges and deficiencies both experienced in the case studies' platforms and disclosed by the project developers. Arguably these obstacles affected the success of the case studies and their effectiveness in documenting and displaying architectural heritage. The difficulties encountered in the case studies were present during the development of the documentation platform, as well as post-rendering as experienced by the user. The New Orleans laser scan case study and the University of Maryland

Baltimore County photogrammetry project both freeze the documented architecture at a specific point in time. These case studies provide what was referred to as a time capsule, and lack methodology for documenting change over time. In contrast, the multimedia GIS case study sponsored by the Historic Columbia Foundation portrays the historic neighborhoods through several decades. However, the developers of the platform did not include a contemporary comparison to the historic images presented. The concept of depicting the architectural evolution of the historic neighborhoods is made possible through the interactive component of the site for this case study.

While the use of terrestrial scanning for the New Orleans case study effectively documented the detail of the street facing facades, the developers expressed difficulty accurately documenting the upper planes of the structures. This data hindrance was opposite the issue of the photogrammetry case study. With the University of Maryland Baltimore County case study, the facades of the structures possessed less data points and were visibly distorted compared to the roofs and planes parallel to the UAV. The images captured for the photogrammetry case study were slightly muddled, an error attributed to motion blur and overcast lighting. Additionally, the case study presented significant washout in areas and the material texture was ineffective. The issues of clarity and sufficient documentation of architectural details seen between the New Orleans and University of Maryland Baltimore County case studies may spur cities to ponder the argument of close-range or terrestrial documentation versus aerial scanning.

Similarly to the University of Maryland Baltimore County case study, the Virtual Historic Savannah Project presented obstacles in regards to adequately captured details. Due to the size of the data set, the developers of the Virtual Historic Savannah Project restricted the number of structures to be included in the model, as well as the level of detail for the modeling. This resulted in the privileging of some buildings compared to others. Additionally, the decision not to model architectural characteristics rendered it difficult to distinguish residential, commercial and civic buildings. Although there was a varying level of detail throughout the model, the Virtual Historic Savannah Project, as well as the New Orleans and University of Maryland Baltimore County case studies provided a cohesive and undeviating rendering of each area's architecture. These case studies display a uniform assemblage of data. Adversely, the Historic Columbia Foundation multimedia GIS platform gives privilege to certain buildings and areas. Many of the structures digitally documented lack data, containing only a single photograph and no narrative, while other structures feature multiple historic images, as well as interviews, narratives and maps.

The synthesis of the four case studies analyzed – New Orleans laser scanning, University of Maryland photogrammetry, Historic Columbia Foundation multimedia GIS and the Virtual Historic Savannah three-dimensional model – should be a resource for cities considering a digital documentation campaign of architectural heritage. Each of the case studies is effective in terms of its successful application for architectural heritage and the sponsoring organization's preservation objective, though in different ways. The case studies depict varied successes and challenges, arguably aligned with the concluding analysis presented later in this thesis.

CHAPTER FIVE

INVESTIGATIVE TRIALS

A significant amount of the primary data necessary for the thesis stems from an investigative trial of each of the four digital documentation techniques being evaluated – laser scanning, photogrammetry, three-dimensional modeling and multimedia GIS. The objective of the trial is to generate a digital deliverable produced from the same number of man-hours from each of the four documentation methods being studied. The intention of the trial is not to create a finished product, but rather to create a model portraying a limited selection of the city's architecture – one block – completed as thoroughly as possible in a specific time allocation of ten hours. The documentation trials are analyzed according to the parameters presented in the methodology. The trials provide a parallel comparison of the technologies' and thus inform the selection process when a city commissions an architectural heritage documentation campaign.

Establishment of the Unit of Analysis

As the purpose of the trial is to inform the selection of a technique for the documentation of architectural heritage, potentially at a citywide scale, a block of architecture, rather than a singular structure was chosen as the unit of analysis for the trials. Documenting a large area of architecture involves multiple building types and sizes, presenting different challenges than encountered when digitally documenting a solitary building. The city block elected represents the evolving architectural heritage of Charleston. The trial block is located on Church Street between Queen Street and Chalmers Street within the Old and Historic District of Charleston. The structures located on the block, the "unit of analysis" include: 127 Church Street, the Charles Mouzon House; 128 Church

Street, the Keenan-O'Reilly House; 129 Church Street; 130 Church Street; 131 Church Street, the James Huston House; 132 Church Street, the Douxsaint-Macaulay House; 134 Church Street, the French Huguenot Rectory; 135 Church Street well-known as the Dock Street Theatre and historic Planter's Hotel; and 136 Church Street, the French Huguenot Church.[258]

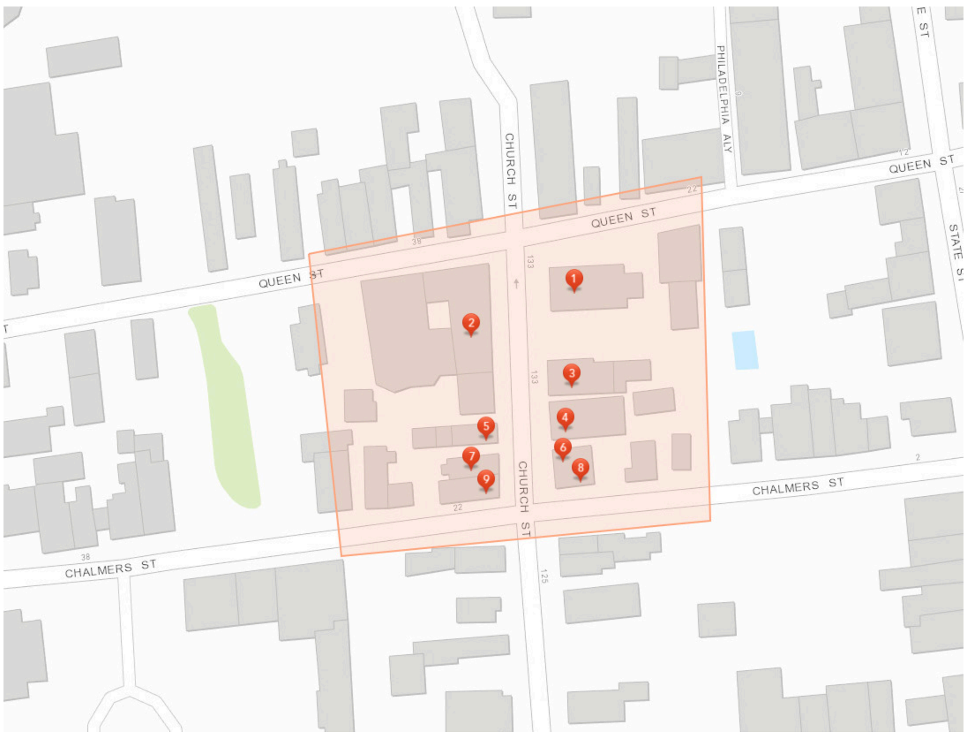

Figure 5.1 - *Map Depicting Unit of Analysis for Investigative Trials.*
The image above depicts the unit of analysis for the investigative trials. The shaded area encompasses the trial block between Queen Street and Chalmers Street in Charleston, South Carolina. The numbered markers indicate the nine structures documented during the trials.
Image created by author through ESRI ArcGIS

This block of structures was selected for its representation of a range of Charleston's historic architecture. In addition to being located within the Old and Historic District, the

[258] S.C. Dept. of Archives and History, "National Register of Historic Places Inventory - Nomination Form, Charleston's French Quarter District" (United States Department of the Interior, National Park Service, September 14, 1973), South Carolina Department of Archives and History.

trial block on Church Street has established significance and integrity as it contributes to the Charleston French Quarter District recognized by the National Register of Historic Places. The French Quarter District was designated in 1973 and is bound by Lodge Alley, Cumberland Street, East Bay and State Street. The neighborhood surrounding the trial block was settled as part of the original Grand Modell of Charles Towne in the 1680s and is part of the old walled city of Charleston. The name, the French Quarter, recognizes the prominence of French merchants in the area's history. The district is recognized for its importance in architecture, commerce and social history, with a period of significance ranging from 1700 to 1849. The structures located at 127 – 134 Church Street are contributing properties to this designation.[259]

Figure 5.2 - *The Church Street Trial Block, Charleston.*
The image above portrays the present-day streetscape of the trial block looking south down Church Street. The unit of analysis is located within the Charleston Old and Historic District. Additionally, seven of the structures within the unit of analysis are contributing properties to the French Quarter District. The Dock Street Theatre and the French Huguenot Church are separately listed on the National Register of Historic Places.
Photograph by author

[259] *Ibid*.

The Dock Street Theatre and the French Huguenot Church are also present on the trial block and located within the historic district. These structures were individually listed on the National Register of Historic Places in 1973.[260] The Dock Street Theatre was once known as the Planter's Hotel and is an example of a historic building being usefully adapted to meet present-day needs while preserving visual evidence of the past. The National Register nomination states that the Dock Street Theatre is the site of the first theatrical productions in the United States and the complex is the last surviving antebellum hotel building in Charleston. The three-story building has undergone several expansions, with the oldest area dating to 1809.[261] The building contains a recessed porch with six brownstone columns and five round arches. A wrought iron openwork balcony projects outward above the recessed porch. The Dock Street Theatre is significant for both architectural and social history dating to the mid-nineteenth century.

Noted architect Edward Brickell White designed the French Huguenot Church in 1845. The Church was the first Gothic Revival style building to be constructed in Charleston and was built of brick covered with a rose-tinted stucco. The building features six bays along the sides with pinnacle-topped buttresses, a battlement parapet and dripstones. The French Huguenot Church is recognized for its architectural significance, with a period of significance attributed from 1825 to 1849.[262] These designations convey that the area surrounding the trial block reflects not only South Carolina history, but also centuries important to the course of American history.

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260 S.C. Dept. of Archives and History, "National Register of Historic Places Inventory - Nomination Form, The Huguenot Church" (United States Department of the Interior, National Park Service, November 7, 1973), South Carolina Department of Archives and History; Elias B. Bull, "National Register of Historic Places Inventory - Nomination Form, Dock Street Theatre" (United States Department of the Interior, National Park Service, March 13, 1973), South Carolina Department of Archives and History.
261 Bull, "National Register of Historic Places Inventory - Nomination Form, Dock Street Theatre."
262 S.C. Dept. of Archives and History, "National Register of Historic Places Inventory - Nomination Form, The Huguenot Church."

Figure 5.3 - *Dock Street Theatre, Church Street, Charleston.*
The image above portrays the present-day streetscape of the trial block looking south down Church Street. The unit of analysis is located within the Charleston Old and Historic District, as well as the French Quarter District.
Photograph by author

Figure 5.4 - *French Huguenot Church, Church Street, Charleston.*
The image above portrays the present-day streetscape of the trial block looking south down Church Street. The unit of analysis is located within the Charleston Old and Historic District, as well as the French Quarter District.
Photograph by author

Trial One: Laser Scanning

Data Accumulation

Amy Elizabeth Uebel, an Architectural Conservator at the Warren Lasch Conservation Center in Charleston, South Carolina, helped capture the raw data for the terrestrial laser scanning trial. Weather was a determining factor in both the date chosen, as well as the time of the day for documentation; a day where the forecast did not predict rain, but overcast skies were present was the ideal situation. The trial began in the early afternoon, as that was the most overcast time of the day. Overcast skies provided an ideal environment for the laser scan, minimizing the potential for washout (appearing faded, or lacking in color and intensity). Additionally, the scans were taken during the winter months, when the trees are mostly barren, allowing more of the structures' façades to be visible.

Data accumulation began by systematically placing reference spheres along both the east and west sides of the trial block. The reference spheres are approximately 5.7 inches in diameter and serve as laser scanning targets.[263] The reference spheres were placed so that at least three reference globes would fall within the "line of sight" of the scanner at each position along the block. The spheres serve to tie together the separate scans that the laser captures at each strategic position as the operators move it down the block. In order for the sphere to be useful, it had to be visible in more than one scan.[264] With the reference spheres in position, the fieldwork team placed the laser scanner on a tripod and initial preparation for the scan began.

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[263] The reference spheres are a hollow plastic form with a distinct white surface to achieve reflective properties necessary for accurate referencing. The spherical shape allows for the highest possible scanning efficiency from various directions.

[264] The reference spheres are employed as targets for the laser scanner and serve as markers when stitching the scans together. Use of the reference spheres is not necessary to the laser scanning technique; however, their inclusion does allow the processing phase to be simpler. The more scans a target is in, the tighter the tolerance is when the scan are stitched together.

The FARO Focus^{3D} X 330 laser scanner is a large volume laser scanner that captures laser points. The machine sends out laser beams that travel from the equipment sensor and return to the receiver after bouncing off of the nearest surface in their path. The platform analyzes the time required for the laser to bounce off a surface and return to the device, and the distances measured are overlaid on global positioning system (GPS) coordinates and captured color data to generate a mesh product.[265] To get a scan that is an accurate representative of the objects – in this case, the streetscape – the machine must be leveled. After leveling the scanner to an acceptable position – an accurate scan can be produced to a five-degree margin of levelness – identifiers and parameters within the FARO equipment were established. Identifiers included the project name and file base name for the trial; latitude and longitude for the trial block were not included. Next, the parameters for the scans were adjusted within the scanner. The fieldwork team set the profile of the scans to "Outdoor 20m…" indicating that the scanner would collect data at a distance greater than thirty feet.[266] Additionally, the option to scan with color was selected, prompting the scanner to capture photographs after each scan. Although this inclusion adds additional time to the scanning procedure, the process increases the detail of the final scan deliverable by capturing surface color as well as surface position.

The fieldwork team programmed the quality of the scans to a 4x megapixel color resolution. This resulted in an eleven minute and thirty-three second scan. In total, to adequately capture the streetscape of both sides of the trial block, seven scans were taken with the FARO scanner in seven different positions. Seven scans in seven positions were necessary to capture the entire block in the line of sight of the scanner, while providing

[265] The FARO Focus utilized for the data accumulation of this trial was provided by the Clemson University Warren Lasch Conservation Center.

[266] There is an option within the scanner, "Outdoor…20m" where the capture of data is restricted to thirty feet from the scanner. However, this option would not have adequately captured the data on the trial block.

ample overlap between scans so that the discrete scans could be "stitched together".[267] To achieve ample overlap the laser scanner position alternated between the west side and the east side of the trial block. Alternating sides of the street, the fieldwork team positioned the scanner at seven positions, moving from the north end of the block to the south end

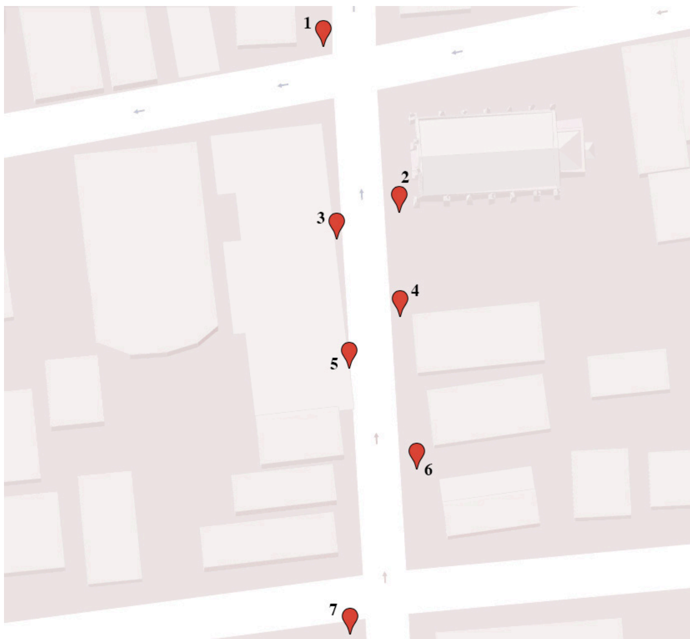

Figure 5.5 - *Laser Scanner Positions.*
The map above illustrates the seven positions of the laser scanner during the data accumulation phase. Data capture began at Marker No. 1 at the northwest corner of the intersection of Queen and Church streets and ended at Marker No. 7 at the southwest corner of the intersection of Chalmers and Church streets.
Image created by author through Google Maps

of the block. For the first scan, the fieldwork team positioned the FARO Focus^{3D} X 330 laser scanner at the northwest corner of the intersection of Church and Queen streets. For the second scan, the team repositioned the FARO scanner to the right corner of the French Huguenot Church on the east side of the block. The team moved the scanner beneath the far right side of the Dock Street Theatre balcony for the third scan. For the fourth scan, the fieldwork team relocated the scanner to the left corner of the structure located at 134

[267] It is important to note that the FARO laser scanner captures 360-degrees of data.

Church Street. The team repositioned the equipment in front of the door to the Dock Street Theatre office to capture data for the fifth scan. The fieldwork group moved the scanner to the right corner of the gate belonging to 132 Church Street for the sixth scan. For the seventh and final scan, the team relocated the scanner to the southwest corner of the intersection of Church and Chalmers streets.[268]

The site process of capturing raw data with the laser scanner required a total of two hours. The laser scanning procedure was generally uncomplicated and undemanding, although several impediments proved slight challenges during the later data processing phase. Although not a main street of Charleston, the Church Street trial block was moderately heavy in pedestrian and vehicular traffic during the scanning time frame. The foot traffic posed less of an obstacle than the vehicles. Pedestrians were intrigued by the equipment and scanning process, and often stopped to examine the scanner. This resulted in them falling in the line of sight of the scanner and blocking surfaces past them during data capture.[269] Correcting for pedestrians captured in the scans is addressed later in the data processing section. In addition to foot traffic, many vehicles were captured in the scans. Moving vehicles posed less of a hindrance than the delivery vans and trucks arriving and parking on the block once the scans were underway. Neither the vehicular nor pedestrian traffic proved detrimental to the raw data accumulation; these obstructions were compensated for during data processing.

Due to the volume of vehicles arriving and parking on the block, the reference spheres were removed following the third scan. The cars blocked line of sight to many of the targets, rendering the references useless in many cases.[270] The trees located along the

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[268] The data from the scans was captured on a Secure Digital (SD) memory card.
[269] The FARO Focus^{3D} X 330 laser scanner features a Class 1 "eye safe" laser.
[270] The spheres were available to stitch the first three Church Street scans together. The fourth, fifth, sixth and seventh scans were stitched and referenced by choosing arbitrary, known points within the scan that overlapped.

sidewalk, primarily the Crape Myrtles located in front of the French Huguenot Church, posed an additional obstacle during the scanning procedure. The trees were not a direct obstacle during the data accumulation phase, but became a greater challenge, creating "noise" when rendering the scans during the processing phase. Additionally, on the west side of the block, a large tree prohibited the scanner from adequately documenting the roof pitch of 129 Church Street. This void could have been remedied by taking an additional scan from a different location; however, the fieldwork team determined that the original methodical system of "leap-frogging" down the trial block should be continued and not altered. The shortcomings encountered during the scanning phase are further addressed in the data processing phase and the concluding analysis.

Figure 5.6 - *Laser Scanning Data Accumulation on Trial Block.*
The image above portrays the FARO Focus^{3D} X 300 scanner as it captured data points in front of the Dock Street Theatre on the Church Street trial block.
Photograph by author

Following initial setup, labor was only required to systematically reposition the laser scanner along the trial block between scans and push the start button. With sufficient familiarity with the equipment and process, a single person could undertake the laser scanning technique. A team of two, however, allowed for monitoring traffic, pedestrians and the reference spheres, affording a more efficient documentation activity. Data accumulation during the laser scanning trial alternated between active and passive time spent on site and resulted in an .FLS (FARO Laser Scan) file to be analyzed in the processing platform.

Figure 5.7 *- Scanning at the French Huguenot Church.*
The image above shows the FARO Focus laser scanner as it captured data in front of the French Huguenot Church.
Photograph by author

Data Processing

The objective of the data processing phase was to stitch together the multiple scans to create a large singular point cloud.[271] To process the seven scans taken during the data accumulation phase, SCENE, a point-cloud software for laser scanners, was utilized. SCENE is specifically designed for the FARO Focus3D scanner. The software

271 A point cloud is a vast number of individual scan points with corresponding X, Y and Z coordinates.

uses object recognition as well as scan registration and positioning to process the scans.[272] The SCENE platform also supports automatic coloring of the scans with high-resolution color photographs overlaid from the FARO Focus scanner. Analytical tools within the software platform enable distance measurements and the analysis of surface evenness. The operators chose SCENE as it is the proprietary software of FARO, and for its advertised user-friendliness.[273]

To begin the processing phase, the operators created a new project for the trial documentation within the SCENE platform. They then imported the raw scan data, an .FLS format file, from the Secure Digital (SD) card in the scanner by moving the SD card to a reader in the port of the computer. Running the SCENE software, the .FLS files were dragged and dropped into the SCENE workspace. Once imported, the scans were displayed in the project structure on the right side of the screen. Importing the scan files required less than five minutes. Data processing continued with the preprocessing phase.[274] With

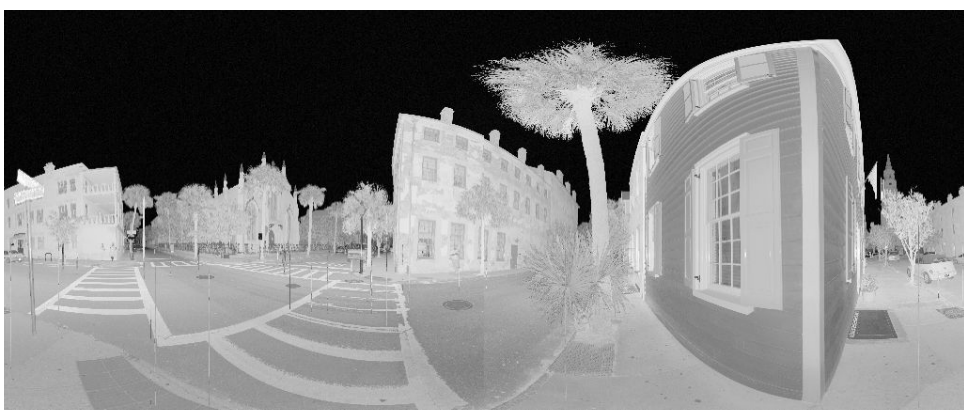

Figure 5.8 - *Preprocessing the Scan Data.*
The image above was captured within the FARO SCENE processing software as the platform preprocessed the data prior to creating correspondences.
Screen-capture in the FARO SCENE software by Amy Elizabeth Uebel

[272] "SCENE, FARO's 3D Documentation Software," *FARO*, accessed October 20, 2015, http://www.faro.com/en-us/products/faro-software/scene/overview.
[273] *Ibid*.
[274] To initiate the preprocessing of the scans, dialog parameters were selected to manage how SCENE preprocessed and aligned the scan data. The parameters selected for this trial process included: artificial spherical references and natural references, including corner points and planes. This created a scan point cloud for each of the scans.

this step, external GPS information from the initial scanning phase was synced as a means of arranging the scans and determining relationships. Through this step, the scans were closely aligned; however, the relationship between the seven scans was not fully accurate and required further registration.[275] The scans took forty-five minutes to preprocess. This step was primarily passive for the operator since the software processed without ongoing inputs once the files were uploaded.

After the preprocessing of the scans, the creation of correspondences or matching points between the scans in the SCENE platform helped to achieve further alignment.[276] SCENE presents a processing stage for automatic registration of the reference targets, however, since neither checkerboards nor spheres were used consistently through the trial, the operators elected the option of manually matching correspondences.[277] For this trial, the plane and scan point reference targets were utilized. The process began with scans one and two at the north end of the trial block. Two planes on the front façade of the French Huguenot Church and one point on the painted text of the street were selected as the correspondences. Next, correspondences were selected between scans two and three. Reference points were established at the corner of a brick, a plane on the face of the French Huguenot Church and a corner point on the balcony of the Dock Street

[275] Registration is the process of stitching multiple scans together to create a single scan point cloud.

[276] The process of creating correspondences employs the concept of triangulation to register the data. The software platform requires that at least three correspondences be accurately matched between each scan to foster correct alignment of the scans.

[277] Automatic registration through targets allows the computer to attempt to stitch the scans together by determining similar patterns between the target locations. This method often saves processing time, however, if targets were not used then manual registration is necessary. Limiting the use of target objects is often due to small time frames for data acquisition or a lack of suitable locations for the targets. The manual creation of scan reference objects prompts the user to identify and mark the area in the scan containing the selected object type. This tells the software what reference object to create at that point. Reference objects are created with the *Object Marker Toolbar*, and include a checkerboard target, a sphere, a plane, a slab or a scan point. Spheres and checkerboards are referenced as artificial targets, while planes, slabs and scan points are indicated as natural targets. Natural targets are points that are part of the environment of the scan. Registration with natural targets is often more time consuming and less accurate than using artificial targets.

Theatre. The registration process methodologically continued between each scan, ending after correspondences were located between scans six and seven.

After the operators selected each target object, the scan manager dialog box appeared relaying statistics regarding the quality of the object recognitions and correspondences. The quality of the correspondences is symbolized through green, yellow and red traffic lights.[278] Ideally, all correspondences would be classified as green. However, for this trial, the scans were generated in a "leap-frogging" pattern, alternating sides of the block. This resulted in difficulty finding successful correspondences between the scans due to the difference in the observed angle; many of the matches were "forced" rather than natural correspondences.[279] Additionally, the dialog box conveyed a standard deviation of the scans and targets; with this information, the operators detected tension present between the reference objects of scans six and seven.[280] With target based manual registration, these issues were present; however, when the operators altered registration to a cloud-to-cloud methodology, all traffic lights registered as green.[281] The correspondences were then locked and the software pushed the data to the main file. The data took approximately three hours to register and align.

After registration, the next step colorized the data point cloud. This was a passive process for the operator that took approximately five minutes as the photographic data

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[278] A green light indicates that the scans have been successfully and accurately matched without anomalies in the data. A yellow light suggests that the reference targets should be matched again. A red light signals a major inconsistency with the scans and targets.

[279] Forcing correspondences is done when SCENE registers a yellow light, rather than a green light between matched points. By forcing the registration between the points, the correspondence is manually created by the user and the platform is told to accept the alignment although it may not be unconditionally accurate. Forced correspondences are initiated when SCENE cannot find matched point between scans.

[280] A minimum overlap of 30% is ideal between scans. At this point in the registration process, the overlap between scans six and seven was 29.6%. All other scans were acceptable.

[281] Registration can be calculated as target-based, top view based or cloud-to-cloud based. For this trial, registration began as target-based. However, due to the lower overlap percentage between scans, after correspondences were selected, the registration calculation option was changed to cloud-to-cloud based and the scans were updated. With this change, the tension level between reference objects was reduced and the overlap percentage was increased. This process changed how SCENE calculated point alignment.

captured during scanning fieldwork merged with the point cloud. Colorizing the model transformed the black and white point cloud, adding detail to the documentation, but arguably obscuring the image as well. By colorizing the scan, visual issues embedded in the photographic data were more pronounced. Pedestrians as well as vehicular movement that were significantly less visible in the monochromatic point cloud became prominent with the superimposed photographs. The pedestrians and vehicles were captured when the scanner took the overlaid photographic data; this resulted in images of pedestrians and vehicles stretched across the street in several instances.[282] Additionally, the light hue of the rose-tinted French Huguenot Church was achromatized after the colorizing process.

Figure 5.9 - *Colorized Point Cloud.*
The image above was captured after the point cloud was colorized by overlaying photographs captured by the FARO scanner. Pedestrian and vehicular traffic is more pronounced than the initial black and white images. The image of a pedestrian can be seen stretched across Church Street - her figure was captured when the scanner took photographic data after scanning. Remedying this obstacle is addressed later in the chapter.
Screen-capture in the FARO SCENE software by Amy Elizabeth Uebel

[282] This issue was resolved when the scans were cropped and refined.

Figure 5.10 - *French Huguenot Church After Color Overlay.*
The image above was captured within the FARO SCENE processing software after the data was colorized. The light hue of the French Huguenot Church was not successfully rendered and the structure appears achromatized rather than rose-tinted.
Screen-capture in the FARO SCENE software by author

Once the scans were colorized, the operators created a "project point cloud". The project point cloud is a comprehensive cloud compiled of the points from all seven scans within the project.[283] The project point cloud is optimized for fast visualization of an enormous number of scan points in a three-dimensional view. Though optimized, the point cloud file is typically large, and sources recommend this step be initiated near the concluding stages of the processing phase if possible.[284] When creating the project point cloud, SCENE presented several automatic point filter options. These filters can help to eliminate unwanted or duplicate data; however, for the trial the operators chose not to

[283] Until this point, the scans were individual clouds that were individually loaded and viewed within the workspace. Utilizing this methodology required less RAM of the processing platform and computer, and arguably made the processing of the data quicker. With the project point cloud, manual scan file loading was not necessary; the automated loading of the project point cloud allowed all scans to be seen at once, not hindering computer memory.

[284] A project point is often two to four times the size of the scan files. However, in this instance, the project point cloud was created prior to cropping and refinement. This step was initiated as it generated a global point cloud, combining all the scans within the project. This ensured all areas of the scans were visible for the cropping stage and that the accidental removal of unloaded (and invisible) scans would not occur. "SCENE 5.1 - User Manual" (FARO Technologies, Inc., October 2012), https://doarch332.files.wordpress.com/2013/11/e1020_scene_5-1_manual_en.pdf.

utilize these filters and undertook data refinement through manual cropping.[285] The project point cloud took thirty minutes to create; this was passive processing time for the operator as the SCENE platform undertook production. The point cloud was still editable after its creation, however, changes, such as cropping or deleting points, were not applied until the operator had updated or recreated the project point cloud. Therefore, the point cloud had to be deleted after the scans were cropped and refined in the next step. Recreating the project point cloud took an additional fifteen minutes.

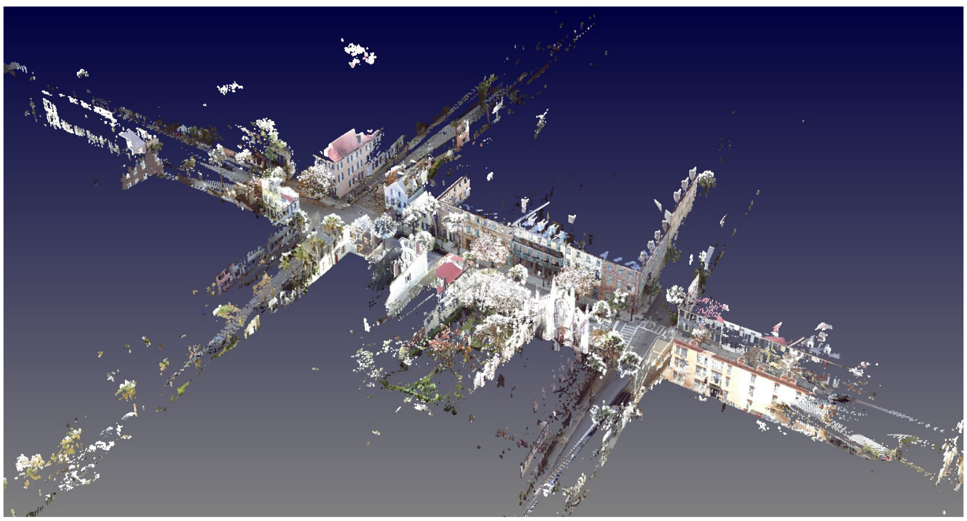

Figure 5.11 - *Isometric View of the Project Point Cloud.*
The image above shows an aerial perspective of the registered and colorized project point cloud prior to cropping data. This perspective illustrates the distance at which the scanner captured and registered data.
Screen-capture in the FARO SCENE software by author

At this point in the processing phase, the scans could be considered complete. The scan with photographic overlay is a viable deliverable. The trial scans captured the streetscapes accurately. However, the data was cropped to further refine the point cloud and initiate noise reduction. For example, a significant amount of the captured data extended well beyond the trial block. Editing began by deleting this data from the point

[285] The three-dimensional stray point filter removes stray points from the project point cloud, creating a cleaner look. Additionally, a filter can be applied that eliminates duplicate points. This aids in optimizing areas of overlap.

cloud. Removing unnecessary data increased the speed of SCENE. Next, vehicles and blur motions present on Church Street were removed. The operator created a clipping box to limit the area of study. Scans were then individually loaded and the operator selected the data to be deleted – primarily vehicles utilizing the lasso tool. Motion blurs attributed to the movement of pedestrians and vehicles were also cropped using this methodology. The scans captured some data of the interiors of the structures by seeing through windows; the operator removed this data to decrease the file size. Refining the scans by removing unwanted data, arguably creating a cleaner visual appearance, took approximately two hours.

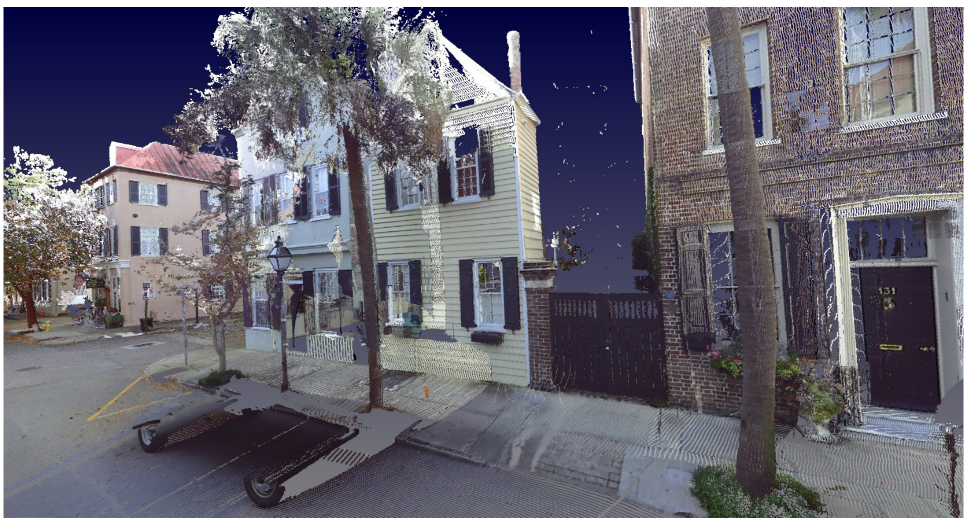

Figure 5.12 - *Visible "Noise" from Vehicular Traffic.*
The image above depicts the structures at 127 and 129 Church Street. A parked vehicle was cropped from in front of the buildings. "Noise" from the traffic is visible against the building facades and remnants of the cropped vehicle remain on the street plane.
Screen-capture in the FARO SCENE software by author

The data processing phase of the laser scanning trial included: loading the scans; preprocessing the data; registering and aligning the scans; colorizing the model; cropping and refining the scans; and creating the project point cloud. The procedure of deleting the project point cloud and then recreating it, in order for the platform to remove the points that had been removed during the cropping stage was the largest obstacle encountered during processing. Amy Elizabeth Uebel of the Warren Lasch Conservation Center assumed the majority of the processing work since familiarity with the SCENE platform was necessary. In total, data processing for the laser scanning documentation trial procured six hours and forty minutes of the allocated ten hours

<u>Data Post-Processing and Rendering</u>

Data post-processing was a two-part phase. Post-processing began with the rendering of individual images from the laser scan point cloud. The operator manipulated the workspace of the scan to various viewpoints and then initiated the *Save 3D View Screenshot* tool. Utilizing this tool saved an image of the current three-dimensional view content as a high-resolution .JPEG file.[286] This step created smaller file sizes with a standard format that could be more easily viewed by a wider audience, than the exported SCENE model file. By manipulating the viewer's position in the model, the operator was able to capture rendered images of the scans from different positions. The rendered

Figure 5.13 - *Laser Scan of 130 Church Street.*
The image above displays the level of detail and accuracy obtained through the laser scanning technology. With this documentation technique the facade of the structure was successfully rendered to a high level of detail with photorealistic quality.
Screen-capture in the FARO SCENE software by author

[286] The images were directly saved to the project data file.

images included rectified street perspectives, planar perspectives, isometric or aerial views, perspectives taken from the street-level and images depicting greater detail of building material and architectural features.

Figure 5.14 **-** *Rectified Image from Laser Scan Data.*
The image above is a rectified portrayal of the west side of the trial block captured within the FARO SCENE processing software. This perspective depicts the Dock Street Theatre, as well as 131, 129 and 127 Church Street.
Screen-capture in the FARO SCENE software by Amy Elizabeth Uebel

After images of the project point cloud were captured and saved, the operator transferred the model and supporting data through a shared Dropbox file. The shared file included the default project file produced by SCENE, as well as the log files, workspace data, raw scans, revisions, rendered images and the scan project. Exporting the scan files in an altered file form was unnecessary for this thesis trial. However, if chosen, the scan points could be exported from SCENE in several file format types.[287] It took one hour and fifteen minutes to post-process or render the data. This phase involved capturing .JPEG images of the point cloud and transferring the model data. In total, nine hours and fifty-five minutes were consumed documenting the structures on the trial block through the laser

[287] The E57 file is the most popular open-source format and is recommended by the FARO User Manual. The scan can either be exported in full, or exported as a selection of the individual scans. "SCENE 5.1 - User Manual"; Alan Sanoja, "Scene 5.2 Laser Scanning Manual" (FARO SCENE, n.d.).

scanning technique.

Figure 5.15 *- Laser Scan of the Dock Street Theatre.*
The image above was captured at street-level and portrays the Dock Street Theatre. The structures at 131, 129 and 127 Church Street are visible at the far left of the image.
Screen-capture in the FARO SCENE software by author

Trial Two: Photogrammetry

Data Accumulation

The fieldwork team accumulated data for the close-range photogrammetry trial of this thesis in the form of digital photographs. The images were captured with the Nikon D7000 digital SLR camera belonging to the Clemson University – College of Charleston Graduate Program in Historic Preservation, and were initially taken and saved as RAW data, or a .NEF file format.[288] The fieldwork team used an 18-200 mm Nikon DX focal length lens to capture the photographs. The focal length for all images captured with the zoom lens was set to the minimal value at 18mm. The fieldwork team chose this lens because it minimizes distortion as is seen with ultra-wide angle or fisheye lenses.

[288] The images were initially captured as RAW data, rather than .JPEG file formats. This is a recommendation seen in photogrammetry literature, in which authors argue that a .JPEG file compresses the captured data and induces unwanted noise to the images, arguably making the processing phase longer and more difficult.

To avoid washout and harsh shadows, the photographs were taken during overcast weather in the late morning. Prior to beginning the photographical documentation, the camera settings were adjusted based on the soft light conditions. The fieldwork team established the ISO at 400, a fairly low ISO value within the 100 to 6400 scale. The aperture value was set at f10 and the shutter speed of the camera was programmed to 1/100. These settings were chosen as they provided a uniform level of exposure and brightness for the images. Manual settings also afforded consistency compared to allowing the camera to employ automatic settings.[289] The ISO, aperture and shutter speed settings were maintained throughout the documentation for both the east and west façades of the trial block. The field team spent twenty minutes establishing appropriate camera settings. To capture the acceptable lighting level settings, the field team took several experimental photographs at different locations along the trial block.

After establishing the camera settings, the fieldwork team collected the data in the form of RAW photographs for each side of the block of Church Street. Data collection began by documenting the west side of the trial block, starting at the intersection of Queen and Church streets, progressing southward down the block and ending at the intersection of Chalmers and Church streets. The fieldwork team took the initial photograph opposite the façade, standing at the northeast corner of the Queen and Church Street intersection, ensuring that the north side of the Dock Street Theatre would be captured. The process systematically moved down the sidewalk of the east side of the trial block towards Chalmers Street, capturing a photograph at three stride, or approximately four-foot intervals. Taking photographs with this regularity ensured sufficient overlap; overlap is defined as the percent

[289] The ISO was programmed to a lower value to avoid inducing additional noise into the images. Additionally, the aperture was maintained at a median value resulting in sufficient focal depth; this allowed for the capture of sharp photographs, as well as a consistent level of focus throughout the images. The shutter speed was set at a higher value to reduce the possibility of blur due to the movements of pedestrians and traffic.

of subject matter that is captured in sequential photographs. Approximately between sixty and seventy-five percent overlap was captured on site.[290]

The photographs were taken from a position perpendicular to the structure's Church Street facing facade. The photographs were captured from the sidewalk, rather than the center of the street due to both the height of the structures and busyness of the street.[291] Additionally, the images were captured in a portrait orientation rather than a landscape orientation, a constraint posed by the relatively narrow width of the street and the height of the structures.[292] The fieldwork team took a single photograph at each vantage point; angled views were never captured. A tripod was not utilized during the trial. The fieldwork team determined that sufficient light was present to allow an adequately fast shutter speed for clear photographs without a tripod for stability. Because the street was not closed down and photographs were taken straight-on to reduce distortion, vehicles parked along the curb of the street were captured during the documentation. In some instances, the tops of the vehicles parked along the same side of the street as the camera position were captured in the photographs as well.[293] The fieldwork team employed the same systematic process to capture photographs of the east façades of the trial block. Documentation for this side of

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[290] Literature recommends that at least fifty percent overlap is included between photographs to ensure that the processing platform can successfully align and register the images to build the model.

[291] The structures on the trial block were too tall to allow for data capture from the center of the street. Instead, the photographs were taken from the opposite sidewalk looking across the street to the structures' facades. This ensured that the entire height of the buildings would be documented. Additionally, traffic was too heavy for the fieldwork team to have stood in the middle of the road to capture the photographs.

[292] Since the images were captured in a portrait orientation, only a singular photograph was taken at each interval. The entire height of the structures was captured at each interval with one photograph; therefore it was not necessary to "stack" images or capture multiple vertical angles at one location of the same viewpoint.

[293] The tops of the vehicles captured on the data accumulation side of the street when photographing the opposing façade of the trial block were edited and removed through the photogrammetry processing platform; this will be discussed with further explanation later in the methodology. For photogrammetry documentation occurring within an urban center, vehicles will likely be present during the data accumulation phase and in the rendered model. Arguably, documenting the vehicles provides an element of social history and representation of the status of society, allowing future users to date the digital documentation deliverable.

the trial block began at the northwest corner of the Queen and Church Street intersection, and moved down the west sidewalk, ending at the intersection of Chalmers and Church streets.

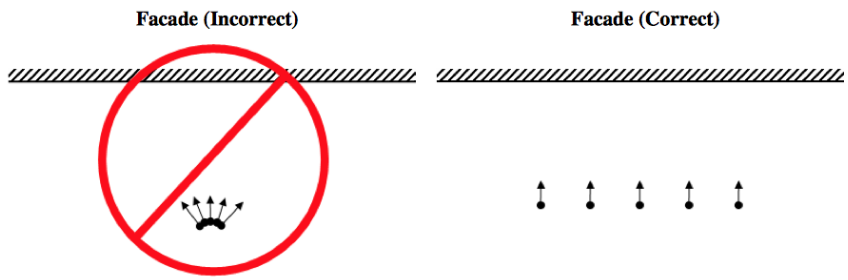

Figure 5.16 - *How to Photograph a Facade.*
The image above demonstrates the correct methodology for capturing photographs for an architectural heritage photogrammetry project.
Image courtesy of the Agisoft PhotoScan user manual

The structures captured on the west side of the trial block were: 135, 131, 129 and 127 Church Street. Photographically documenting the west side of the trial block took approximately twenty minutes and forty-seven photographs were taken. The structures photographed on the east side of the block included: 136, 134, 132, 130 and 128 Church Street. Documenting the east side of the trial block procured approximately fifteen minutes and forty-five photographs were captured. The presence of pedestrian and vehicular traffic elongated the time required to digitally document the façades of the trial block.

The tour groups pausing in front of the structures on the trial block for extended lengths of time proved the most challenging and frustrating obstacle of the data accumulation phase. It was necessary to wait between images for traffic and people to pass before continuing the documentation procedure. Moving vehicular traffic did not generate major complications; parked vehicles were comparatively uncomplicated to photograph around. There were only five parked vehicles on the trial block – all low sedans – a characteristic that allowed for images to be captured above them. To maneuver around the obstacle of low-hanging tree branches on the data accumulation side of the block, several images were taken standing at the edge of the curb, rather than positioned further back. Following the completion of data accumulation on site, the photographs were transferred from the camera's SD memory card to a desktop computer as .NEF RAW data files. Downloading the data took approximately five minutes.

Figure 5.17 *- Single Photograph from Data Accumulation Phase.*
The image above is one of the ninety-two photographs taken to document the facades of the trial block. This image was stitched together with its counterparts to create a photogrammetric model
Photograph by author

The east and west sides of the trial block were documented separately to allow for a model of each of the façades to be generated. The fieldwork team undertook this methodology to ensure that a photographic model would be successfully created for each street-fronting façade of the block, and that the photogrammetry platform would not attempt to register and align the structures as one continuous block, rather than opposing façades. In total, data accumulation for the terrestrial photogrammetry digital documentation trial of this thesis took one hour of the allocated ten hours. Data accumulation during the photogrammetry trial was an active process for the fieldwork team with the majority of the time spent on site at the trial block.

Data Processing

Data processing for the architectural photogrammetry trial was completed through multiple processing phases within the photogrammetry software platform; the data processing phase can be subdivided into various processing steps required to generate the three-dimensional photographic model. Agisoft PhotoScan 1.2.1 is the software product utilized to perform the photogrammetric processing of the digital images.[294] PhotoScan is a stand-alone, advanced image-based product that generates three-dimensional spatial data from still digital photographs to be used in GIS applications, as well as cultural heritage documentation. The platform utilizes three-dimensional reconstruction technology; by processing at least two photographs in which the object is visible, a three-dimensional model can be produced. For the purpose of this thesis, the operator downloaded a thirty-day trial license for the Professional Edition of the software at no cost as part of the manufacturer's promotional offer.[295]

The objective of employing PhotoScan to process the digital images was to build a photographically textured three-dimensional model. The processing procedure of PhotoScan can generally be divided into four main stages: photograph alignment; building the dense cloud; building the mesh; and building the texture. For the majority of the processing and post-processing phases, the operator followed the "Agisoft PhotoScan User

[294] Agisoft PhotoScan is available in both a Standard and Professional Edition. The standard version is sufficient for interactive media tasks. The professional version is designed for generating GIS content. PhotoScan is an off-the-shelf photogrammetric tool used for both aerial and close-range photogrammetry. For this trial, it was used for close-range or terrestrial photogrammetry purposes. The software platform is capable of processing up to tens of thousands of photographs, and produces deliverables with a high degree of accuracy; both horizontal and vertical dimensions can be gathered from the processed data. "Agisoft PhotoScan," *Agisoft*, accessed November 30, 2015, http://www.agisoft.com.
[295] Additional information regarding system requirements for the processing platform can be found on pages 1 and 2 of the User Manual. "Agisoft PhotoScan User Manual, Professional Edition, Version 1.2" (Agisoft LLC, 2015), http://www.agisoft.com/pdf/photoscan-pro_1_2_en.pdf.

Manual, Professional Edition, Version 1.2" verbatim.[296] Additionally, approximately two hours were spent prior to the start of the trial becoming familiar with the process of taking and processing images for photogrammetry, as well as the methodology required for the PhotoScan platform specifically. Because, PhotoScan does not accept .NEF or RAW file formats, after capture the photographs had be reformatted to interface with the software. Using the image processor in Adobe Photoshop CC 2015, all ninety-two files were batch converted to .TIFF file formats. It took approximately ten minutes to convert the digital images to an appropriate file format.[297]

After the images were converted, the photographs of the west façade of the trial block were loaded into PhotoScan through the *Add Photos* command from the *Workflow* menu.[298] Through this step, the operator located the folder containing the photographs and the images to be processed were selected.[299] Once the photographs were loaded into PhotoScan, they were aligned; from the *Workflow* menu, the operator selected the *Align Photos* command. This was a fully automated process during which PhotoScan refined the camera position and orientation for each image, searching for common points on the photographs. Additional settings were adjusted within the software before aligning the photographs. These setting changes were: a high accuracy level was established; pair preselection was disabled; the key point limit was set at 40,000; and the tie point limit was set at 4,000. The automated process of loading and aligning the images, and matching data

[296] *Ibid*.

[297] PhotoScan accepts the following image formats: JPEG, TIFF, PNG, BMP, PPM, OpenEXR and JPEG Multi-Picture Format (MPO).

[298] Only the images taken of the west side of the trial block were loaded into PhotoScan. All of the steps necessary to construct the photogrammetric model of the west side of the block were completed at once. After the west façade model was generated and exported, the photographs taken during the data accumulation phase of the east façade of the block were loaded into the software platform. The same process was then repeated to produce a similar model of the east façade of the trial block.

[299] A photograph naming method is unnecessary for this software platform. PhotoScan does not read or interpret image names, but instead uses pixel data to position and align the photographs. For this trial the camera automatically named the images during the data accumulation phase.

points took fifteen minutes and generated both a sparse point cloud, as well as the camera positions.[300] Once the images were aligned and the platform generated the sparse point cloud, the model resembled a cluster of colorized pixels. The outline of the structures was not visible unless the model was enlarged significantly; the model generally lacked distinguishable geometry.

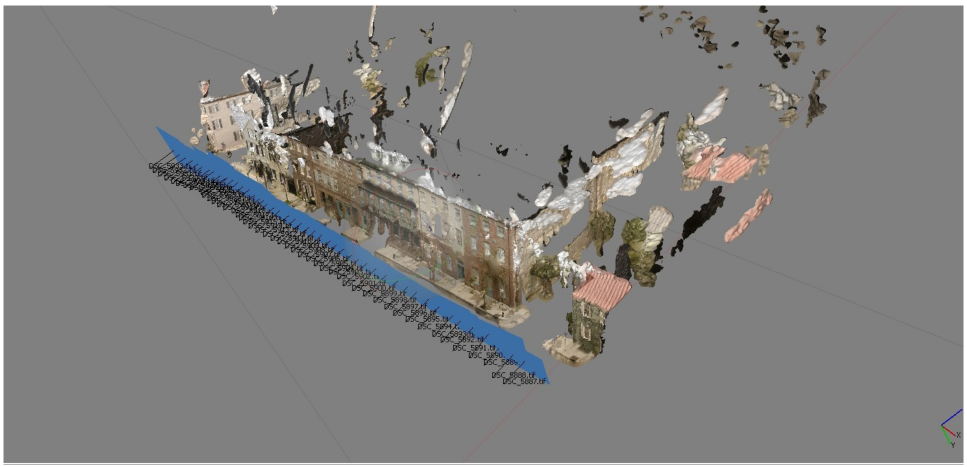

Figure 5.18 - *Camera Alignment.*
The image above depicts the camera positions and alignment of the individual images for the west side of the trial block.
Screen-capture in the Agisoft PhotoScan software by author

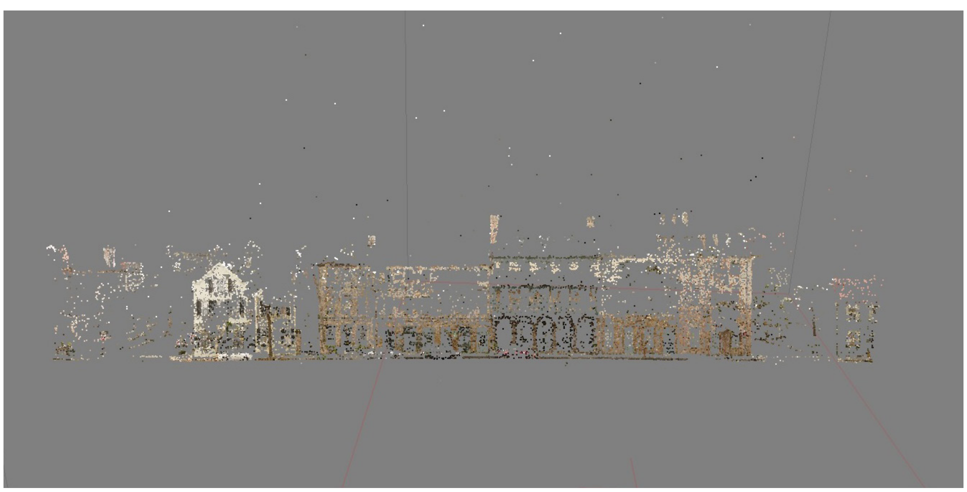

Figure 5.19 - *Sparse Point Cloud.*
The image above shows the sparse point cloud for the west side of the trial block. The sparse point cloud was automatically created by the software after camera alignment.
Screen-capture in the Agisoft PhotoScan software by author

300 The sparse point cloud represents the results of the aligned photographs. The cloud is not directly used in the three-dimensional model construction. The sparse point cloud is generated so users can verify that the portrayed geometry is correct and cameras are accurately aligned.

After alignment, PhotoScan automatically produces a reconstruction volume bounding box based on the sparse point cloud. This means that the software establishes the extent of the point cloud that has the best accuracy and suggests that peripheral data with lower accuracy – fewer overlaps – be excluded. Reconstruction of the images only accounts for the points located within the bounding box volume. In some cases, the automatic process of establishing the reconstruction volume bounding box can produce undesirable selections causing cut geometry or missing parts. To ensure minimal data loss, the operator enlarged the box using the resize region tools to capture several solitary points located outside the principal cluster. The bounding box was also reoriented to correctly position the reconstruction plane as the base of the model. By transforming the position of the red face of the bounding box – the face representative of the ground plane – the reconstruction axis was redefined. This was a simple task that required only five minutes of time. Next, the operator produced a dense point cloud.[301] To generate the point cloud, the operator selected the *Build Dense Cloud* command from the *Workflow* menu. The reconstruction parameters were edited, establishing the quality as medium and the depth filtering as aggressive.[302] After selecting the parameters, PhotoScan automatically processed the data, reconstructing the depth of the photographs to create the dense point cloud; this process derived approximately ten minutes of the trial time. At this step in the processing phase, the appearance of the model changed very little. The model was still primarily constructed from colorized pixels and lacked geometry. The bases of the buildings were more discernable than the roofs of the structures.

The next step of the data processing phase required building a polygonal mesh

[301] Based on the camera positions, PhotoScan calculates depth information for each camera to create a single dense point cloud.

[302] The default quality setting is medium; for this trial, the default setting was sufficient. The default setting for depth filtering is aggressive. This reconstruction parameter calculates depth maps for each image. The parameter level should be determined by the complexity and amount of details within the geometry to be reconstructed. "Agisoft PhotoScan User Manual, Professional Edition, Version 1.2."

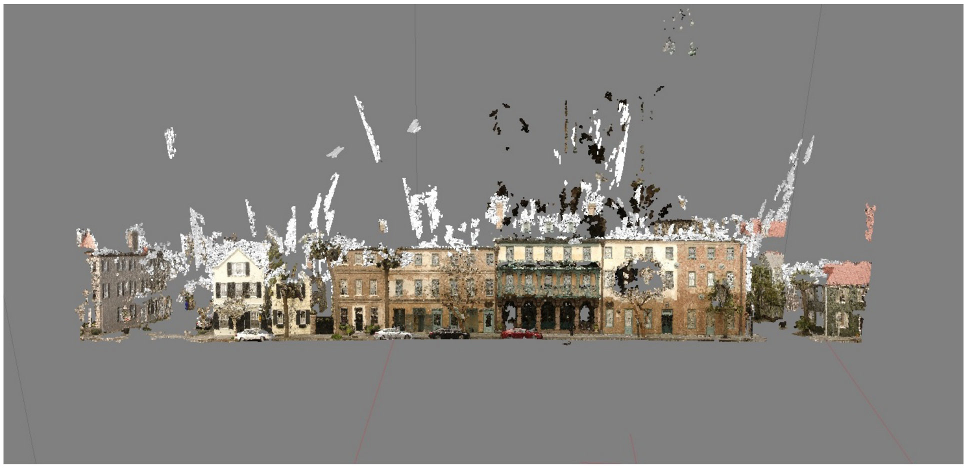

Figure 5.20 - *Dense Point Cloud.*
The image above shows the dense point cloud for the west side of the trial block.
Screen-capture in the Agisoft PhotoScan software by author

model based on the point cloud data. To initiate this step, the operator selected the *Build Mesh* command from the *Workflow* menu. The default parameters for this segment were retained – the surface type was established as arbitrary; the source data was selected as the dense cloud; and the face count was designated as high. After selecting these parameters, it took approximately ten minutes for the platform to produce the mesh. At this stage in the process the mass of the structures, as well as their details were visible. However, extra data accumulated within the photographs altered the model appearance, rendering the scene muddled.

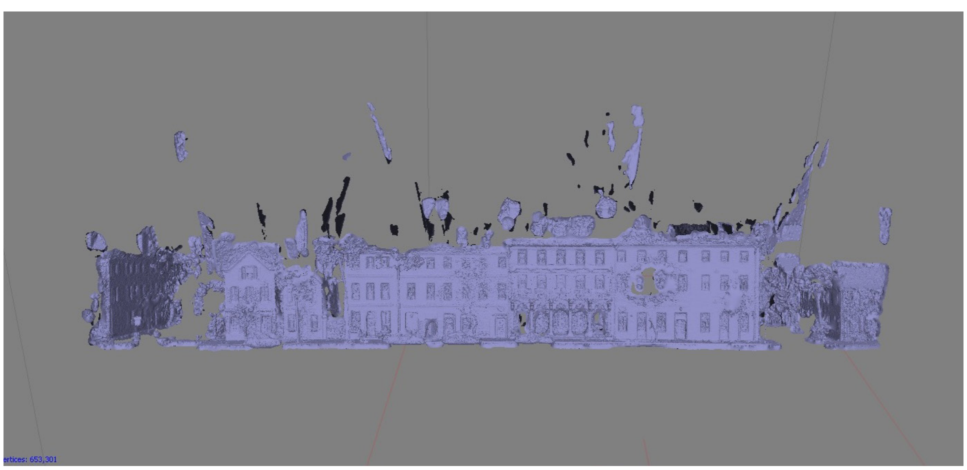

Figure 5.21 - *Polygonal Mesh.*
The image above shows the constructed solid mesh for the west side of the trial block.
Screen-capture in the Agisoft PhotoScan software by author

After the operator generated the mesh, the likeness of the model was significantly more perceptible and the geometry could be edited. Prior to the creation of the mesh, the sparse data point cloud lacked palpable geometry rendering the model problematic to crop. During the editing phase, unwanted faces and data clusters were removed from the model. The majority of the faces and data deleted were concentrated around the upper edge of the model, as well as the left and right edges where the camera had been angled down Queen and Chalmers streets. Additionally, the photogrammetry platform registered data behind the plane of the structures' facades. This data was disconnected from the core geometry and was edited out of the model. Much of the roof features on the structures had to be deleted due to lack of detail; these features' presence would have presented confusion to users observing the model. The dormers on the top of the Dock Street Theatre, as well as several chimneys on the other structures were removed as they appeared to be floating and lacked geometry linking them to the façade image. This shortcoming is a result of the narrow width of the street, height of the structures and angle of the camera compared to that of the roof form. However, if a camera position perpendicular to the roof were achievable – perhaps with aerial UAV – then the roofs of the structures could be rendered with as great of realism as the facades.

In addition to the roof features requiring editing, there was a significant amount of unregistered data on the eastern façade of the street and around the gable roof of 127 Church Street. These areas of unregistered data resembled white clouds and were primarily located around the tops of the structures. This "blind spot" in the model is presumed to be due to "washout" and the condition of the lighting.[303] It is also surmised that the reflective surfaces of the roofs contributed to this data rendering error. The trees directly in front of the structures at 129, 130, 132 and 134 Church Street blocked parts of the surface from view

[303] Washout is when areas of the data or image appear faded, or lacking in color and intensity.

and contributed to issue of unregistered data on the façade of the structures. The faces to be deleted were indicated using the selection tool. When selected, the areas were highlighted in red and then deleted. During the editing phase, the workspace interchanged between the selection tool and the navigation tool to ensure that the operator located all unnecessary geometry by rotating the model. Alternatively, the crop tool could have been used to limit areas of the model visible. Editing the geometry of the model took approximately forty-five minutes.

Figure 5.22 - *Photogrammetric Data Loss.*
The image above illustrates typical areas of data loss in the photogrammetric model. The presence of trees in front of the facades of the structures resulted in unregistered data.
Screen-capture in the Agisoft PhotoScan software by author

Continuing the editing process, there were several holes on the model surface that required adjustment. Holes were characteristically present in two areas: beneath porches and piazzas, and on building facades were a tree was present in the foreground. These regions lacked data and therefore a point cloud and mesh had not adequately been rendered in the area. The operator used the *Close Holes* command from the *Tools* menu at this stage of the processing phase. This was an automated process within the PhotoScan platform that presented a dialog box to adjust the size of the largest hole to be closed. PhotoScan used an automatic procedure to fill the existing holes in the mesh surface by copying surrounding data. Closing the holes in the model took less than one minute. Next, the operator generated the three-dimensional model texture; this again was an automated process in the PhotoScan platform.[304] The operator selected the *Build Texture* command from the *Workflow* menu, and the texture generation parameters were established as follows: the mapping mode was set to generic, this is the default mode and creates a uniform as possible texture; and the blending mode was set to mosaic, also the default parameter, which employs a two-step approach to blend overlapping images avoiding an observable seam line. All other default settings were unchanged. The PhotoScan platform processed and generated the texture in ten minutes.

Generating the texture for the model was the final step undertaken during the processing phase of the trial. The model was adequately cropped during this stage for the purposes of this thesis; however, the opportunity for further editing is possible through both the PhotoScan platform and Adobe Photoshop.[305] Although further refinement is feasible through cropping, adding additional photographs after the mesh and texture have been generated is futile. Ideally, the fieldwork team would have returned to the site to capture supplementary photographs, at different angles, of the surfaces of the structures blocked by trees. These would have been used to patch the data holes seen in the model. However, additional images cannot be easily and quickly added to the built model. When new photographs are uploaded to the textured model, the alignment process has to be initiated again. During this process, PhotoScan automatically "breaks down" the model returning the data to the sparse point cloud stage. The steps of rebuilding the dense point cloud, mesh and texture have to be restarted. Therefore, this was not a feasible undertaking for the time restrictions of this trial.

[304] This is an optional step if the un-textured model is sufficient as the final deliverable. However, for this trial a texture atlas was created for the model arguably resulting in better visual quality.
[305] By cropping within the Agisoft PhotoScan platform, editing is done directly on the photogrammetric model. However, it is also possible to crop and edit the exported model, likely an Adobe .PDF file, though Adobe's Photoshop. PhotoScan has basic cropping abilities, however, the platform was not created as a graphics editing tool and is arguably not as simple or concise to edit with. Post-processing with Photoshop may prove more successful.

Figure 5.23 - *Textured Model.*
The image above displays a section of the final textured rectified photograph of the west side of the trial block.
Screen-capture in the Agisoft PhotoScan software by author

The operator processed RAW photographic data for the photogrammetry trial to develop an image-based model of the trial block. In total, the processing phase for the west façade of the trial block consumed a total of one hour and forty-five minutes. After the operator processed the data for the west façade, the same methodology and process was employed to generate a model of the east façade of the trial block. Creating a photogrammetric model of the east façade entailed: uploading and aligning the photographs (ten minutes); resizing and reorienting the bounding box volume (five minutes); building the dense point cloud and mesh (ten minutes each). However, at this point in the process

Figure 5.24 - *Misaligned Rendering.*
The image above depicts the incorrect rendering of the east side of the trial block. The French Huguenot Church is positioned above the remainder of the block.
Screen-capture in the Agisoft PhotoScan software by author

with a mesh clearly formed, the operator realized that the French Huguenot Church and the property at 136 Church Street were not aligned with the majority of the east side of the block. 136 Church Street was floating above the remainder of the block and was not on the correct reconstruction plane.

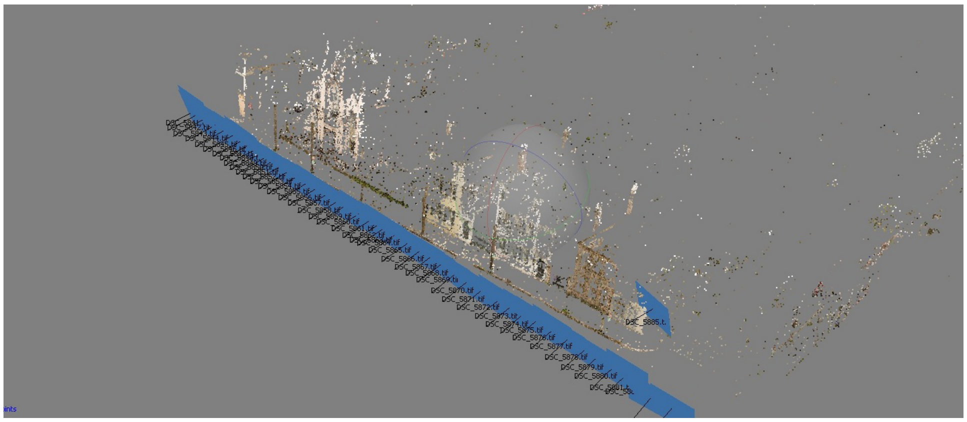

Figure 5.25 - *Misaligned Camera Position.*
The image above shows the misaligned camera position, which resulted in the faulty rendering. The incorrectly aligned photographs can be seen at the right end of the model.
Screen-capture in the Agisoft PhotoScan software by author

The final image captured on the east façade of the trial block was misaligned resulting in an incorrect point cloud. Misaligned images are not uncommon with the processing platform. Photographs fail to align properly as a result of poor overlap or an insufficient amount of texture details on the object's surface. The misaligned image was adjacent the churchyard of the French Huguenot Church; presumably the vast amount of trees in this area and lack of architectural geometry resulted in the misalignment. The operator realigned the photographs and the process of generating the model restarted. Realigning the images and rebuilding the mesh took one hour and fifteen minutes. Once the model was correctly aligned, thirty minutes were spent editing the geometry of the model. The operator closed the holes present in the model and recreated the texture. This process only required five minutes. After the operator generated the texture, the model was reedited, consuming an additional twenty minutes. Because some geometry was less discernable prior to the texture being processed, it proved necessary for the east façade of the trial block to have additional editing with the primary objective of removing washout areas. The processing phase for the east façade of the trial block consumed a total of two hours and forty-five minutes, one hour longer than the time to produce the west façade. This time difference largely had to do with realigning the French Huguenot Church within the model. In total, the data processing needed to generate a photogrammetric model for both the west and east façades of the trial block consumed four hours and thirty minutes.

Data Post-Processing and Rendering

The processed data and generated three-dimensional photographic model were produced and saved within the Agisoft PhotoScan platform. The standard file format with which a PhotoScan project is saved is a .PSZ file. This file format limits accessibility and viewing by users; one must open the file in the proprietary Agisoft software. The post-processing or rendering phase of the photogrammetry project consisted of exporting the generated model as a .PDF file format.[306] Rendering and exporting the photogrammetric model allowed the data to be viewed by a wider audience; users do not need access to the Agisoft PhotoScan platform, but are able to view the project through Adobe platforms and other image viewing software programs. Users are able to navigate the project within the exported .PDF file; however, further editing must be completed within the PhotoScan software platform.

The photogrammetry project created a snapshot of the facades and the geometry of the structures on both the east and west side of the Church Street trial block. The methodology undertaken in the Agisoft PhotoScan platform for this trial created the most basic model achievable in terms of level of detail and resolution. Should an organization

[306] PhotoScan can export models in the following formats: Wavefront OBJ, 3DS file format, VRML, COLLADA, Stanford PLY, Autodesk DXF, U3D, Adobe PDF and KML file format for GIS applications. Adobe PDF was chosen as it is one of the most universally accessible file types.

chose, a different rendering technique could have been employed to generate a more detailed texture for the model. Additionally, photographs could have been captured at an angle during the data accumulation phase to model the sides of the structures visible between the buildings. The post-processing or rendering phase of the photogrammetry trial constituted a trivial amount of time, a total of twenty minutes exporting the photogrammetric model of the trial block. In total, five hours and fifty minutes were consumed creating the image-based photogrammetric model for the structures located on the trial block.

Figure 5.26 - *Final Photogrammetric Model - West.*
The image above shows the final photogrammetry product - after cropping - of the west side of the trial block. A smaller presence of trees and architectural voids on this facade produced a more successful rendering when compared to the adjacent facade.
Screen-capture in the Agisoft PhotoScan software by author

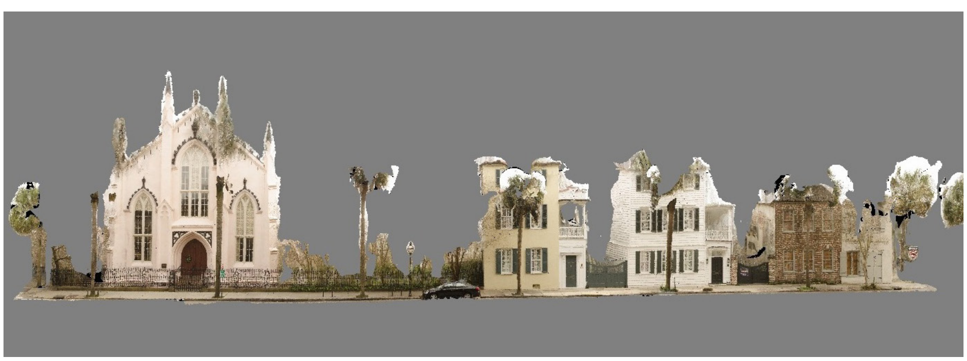

Figure 5.27 - *Final Photogrammetric Model - East.*
The image above shows the final photogrammetry product - after cropping - of the east side of the trial block. This photogrammetry campaign would have been more successful if an additional series of photographs had been captured for processing.
Screen-capture in the Agisoft PhotoScan software by author

Trial Three: Multimedia GIS

<u>Data Accumulation</u>

Data for the multimedia GIS trial for this thesis was accumulated from a multitude of sources, namely the Historic American Buildings Survey, the local South Carolina Room archive and Sanborn Fire Insurance maps. Due to the time restriction placed on the trial of a total of ten hours per digital documentation method, the fieldwork team limited data accumulation to allow for adequate time to enter the data into the GIS platform. As a result, an exhaustive collection of information on the trial block was not gathered from all local archives or available online resources. To thoroughly incorporate all data available for each of the structures located on the trial block would take an extremely large amount of time and would likely be an ongoing project for the sponsoring organization.

The fieldwork team collected data, in the form of text, photographs, and maps for each structure along the trial block. Some of the structures were researched, in addition to their address, under more specific names. These structures were: 127 Church Street, also recognized as the Charles Mouzon House; 128 Church Street known as the Keenan-O'Reilly House; 131 Church Street identified as the James Huston House; 132 Church Street acknowledged as the Douxsaint-Macaulay House; 134 Church Street identified as the French Huguenot Rectory; 135 Church Street well-known as the Dock Street Theatre and historic Planter's Hotel; and 136 Church Street widely recognized as the French Huguenot Church.

In researching these properties, the fieldwork team collected limited data for incorporation into the GIS platform. Accumulated data was limited to architecturally associated archival documents of the structures on the trial block. Approximately one hour was spent reviewing the vertical files for each structure at the South Carolina Room at the Charleston County Public Library on Calhoun Street. This research resulted primarily in the accumulation of photographs from the 1930s and 1970s. Additionally at this archive, the fieldwork team collected a rudimentary architectural description for the majority of the structures on the trial block from the 1973 Charleston, South Carolina Architectural Inventory.[307] The team spent one-half hour collecting data from Jonathan Poston's book, *The Buildings of Charleston.* The data accumulated from this source is textual, and will be integrated within the GIS platform to provide a brief narrative of each structure's history and its significance relating both to its architecture and its occupants. This resource also provided data detailing the construction phases and noted architects for the structures on the trial block.

Approximately two hours were spent gathering digitized data available online. This included historic information, architectural descriptions, fractions of chains of titles and historic photographs accumulated from the National Register, managed by the National Park Service.[308] The fieldwork team gathered additional digitized data from the Historic American Buildings Survey housed by the Library of Congress. Data collected from this source was limited to photographs primarily dating from the 1930s. The digital collections of the South Caroliniana Library, sponsored by the University of South Carolina, as well as ProQuest provided access to digitized copies of Sanborn Fire Insurance maps for the trial block. Maps depicting the Church Street trial block were downloaded for the years

[307] The descriptions of this inventory were verified on site.

[308] The Charleston French Quarter District, as recognized by the National Register of Historic Places, was designated in 1973 for historic significance in terms of architecture and events. The district is also known as Lodge Alley or Simmons Alley, and is bounded by Lodge Alley, Cumberland Street, East Bay and State Street. There is not an architectural style listed and the period of significance ranges from 1700 to 1849. Structures located at 127, 128, 129, 130, 131, 132 and 134 Church Street are contributing properties to this designation. Additionally, both the French Huguenot Church and the Dock Street Theatre were individually listed on the National Register of Historic Places in 1973. The French Huguenot Church was listed for its architectural significance, with a period of significance attributed to 1825 to 1849. The Dock Street Theatre was listed for its significance pertaining to architecture and social history. Its period of significance is defined as 1800 to 1824. Bull, "National Register of Historic Places Inventory - Nomination Form, Dock Street Theatre"; S.C. Dept. of Archives and History, "National Register of Historic Places Inventory - Nomination Form, Charleston's French Quarter District"; S.C. Dept. of Archives and History, "National Register of Historic Places Inventory - Nomination Form, The Huguenot Church."

1884, 1888 and 1938.[309] Locating and downloading digitized copies of the Sanborn Fire Insurance maps, as well as denoting where each structure was located with an editing program took approximately thirty minutes.

To provide a comparative to the historic photographs incorporated within the multimedia GIS platform and to simulate a step that any city could undertake if archival resources are not robust as those in Charleston relating to the trial block, the fieldwork team took a contemporary photograph from the street of each structure located on the trial block.

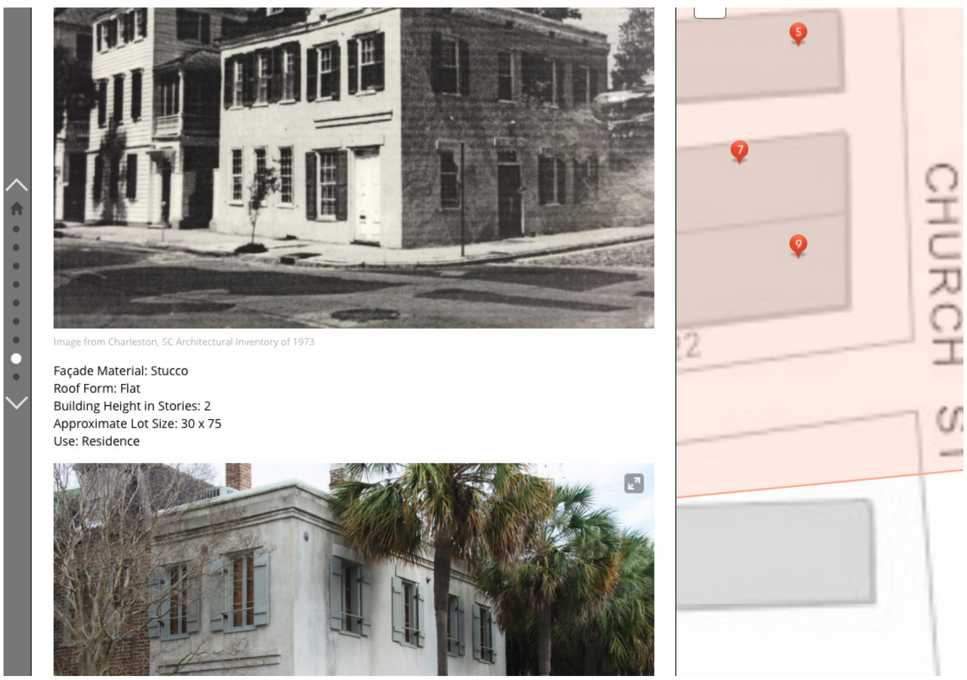

Figure 5.28 *- Contemporary Comparable for Multimedia GIS Platform.*
The image above depicts the relationship between historic and contemporary images within the multimedia GIS platform for each documented structure.
Screen-capture in the interactive ArcGIS platform by author

[309] The Sanborn Map Company is an American publisher of historic and current maps of cities within the United States. The maps were originally created in the late eighteenth century to assess fire insurance liability in urbanized areas. Today, the maps are frequently utilized for historical research, as well as for preservation and restoration efforts. The maps include outlines of each building and outbuilding, the location of windows and doors, street names, street and sidewalk widths, property boundaries, building use, house number, as well as the composition of the building's construction materials. The Sanborn maps are large-scale lithographed street plans at a scale of 50 feet to one inch, published in volumes. South Carolina's collection of Sanborn maps range from 1884 to 1935. Charleston was specifically documented for fire insurance risk in 1884, 1888, 1902, 1944, 1951 and 1955. "Sanborn Fire Insurance Maps of South Carolina" (Map, The University of South Carolina), South Caroliniana Library, Digital Collections, accessed December 17, 2015, http://digital.tcl.sc.edu; "Digital Sanborn Maps, 1867-1970" (Map, ProQuest), ProQuest, accessed December 18, 2015, http://sanborn.umi.com.

These images were captured with the Nikon D7000 digital SLR camera belonging to the Clemson University – College of Charleston Graduate Program in Historic Preservation and were marginally edited in Adobe Photoshop CC 2015. The images were saved as .JPEG files for the processing phase of the trial. To capture and edit the contemporary photographs of the Church Street trial block took forty minutes.

Paper copies of historic documents and photographs comprised a significant amount of the data necessary for this documentation technique. The textual information, discovered through *The Buildings of Charleston,* National Register nominations, the 1973 Architectural Inventory of Charleston and the vertical files located in the Charleston County Public Library's South Carolina Room were copied into a Microsoft Word file format. The narrative information copied was limited to architecturally related history and descriptions. Images included with these historic documents, primarily the architectural inventory and newspapers collected within the vertical files were photographed with an iPhone. These photographs were later cropped and rotated with Adobe Photoshop CC 2015 and exported in the form of high-resolution .JPEG files. The editing portion of the data accumulation phase, specifically data that was not previously digitized, took twenty minutes.

In total, data accumulation for the multimedia GIS digital documentation trial of this thesis took five hours of the allotted ten hours. Accumulation primarily required examining the local archival files on each of the structures located on the trial block. Data collection also entailed online enquiries for historic maps and photographs, as well as past documentation efforts. Minimal time on site was necessary; this time, approximately forty minutes as previously described, was used to photographically document the façade of each structure with the objective of providing a contemporary comparison to the historical data incorporated into the multimedia GIS platform. Time on site was constrained by weather conditions, like other methods, though pedestrian and vehicular traffic was not the same impediment as with laser scanning and photogrammetry.

Data Processing

The data processing phase and the creation of the multimedia GIS program were achieved through a Story Map. Story Maps are a Web Mapping Application available through ESRI's ArcGIS Online platform.[310] To create a Story Map required a subscription to ArcGIS Online and the formation of an account.[311] For the purpose of this thesis, the operator utilized the sixty-day ArcGIS free trial. To begin the development of the Story Map for the multimedia GIS trial, the operator chose a template application for the project. On the ArcGIS Story Map webpage supported by ESRI, there are six preloaded templates available for use: Map Tours, Map Journal, Map Series, Swipe, Spyglass and Basic. Research into the various template characteristics took approximately fifteen minutes and led to the decision to utilize the Map Journal template for this project.[312]

After the operator chose the template, the Map Journal Builder presented two layout options; the side panel option was selected. The platform seen by users is divided into the main stage and the side panel. For this application, the main stage content was delineated as a map of the trial block. An image or video could be substituted as the content in this area. The application gives the option of creating a base map or selecting a previously developed map. For this project, the operator created a new base map through ESRI's ArcGIS Online web map platform. The topographic base map was maximized to only

[310] Story maps are interactive web maps combined with text and other content to tell a story. Typically story maps are designed for non-technical audiences and include all elements required for a narration, such as map services, text and multimedia content. Story maps can include interactive elements that allow for an effective communication platform. ESRI's Story Maps are open source and do not require coding.

[311] Any account with ESRI allows access to this application. Additional information regarding pricing for a subscription to ArcGIS Online can be found at http://www.arcgis.com/features/plans/pricing.html.

[312] None of the templates available through the ArcGIS Online gallery require coding. The Map Journal template creates a map-based narrative presented as a set of journal entries. This template is ideal for creating multimedia projects that combine maps, text, images and video.

display the immediate area around the trial block.[313] Creating the base map for the trial project required one hour of active operator time.

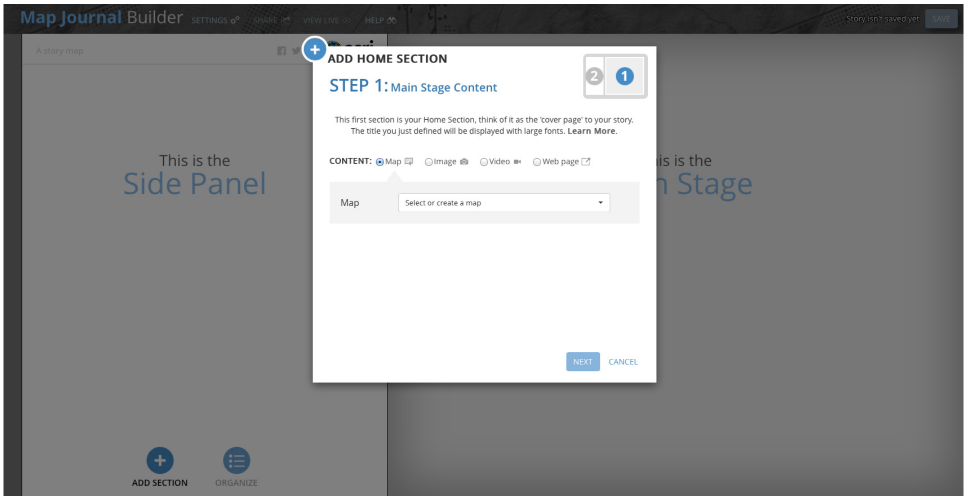

Figure 5.29 - *Template Builder and Layout.*
The image above the template selected for the multimedia GIS project. The division between the side panel and main stage sections can be seen in the background.
Screen-capture in the interactive ArcGIS platform by author

After correctly positioning the base map, features and map notes were added to the initial base layer. The operator indicated the outline of the trial area with a red translucent shaded region overlaying the map and marked each address under study with a pinpoint and number. The operator then uploaded the base map into the Map Journal platform.[314] Following the establishment of the main stage content, the operator developed the side panel content. The side panel is a series of journal sections with the uppermost section being the cover page and default home platform for the project. The corresponding sections beneath the cover page were issued a unique title. For the multimedia GIS trial, each structure

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[313] The web map creator provides twelve high-quality preloaded options for developing a base map published by ESRI. These base maps include imagery, street, topographic, demographic, terrain and the USGS National Map. However, at the level of detail and zoom required of this trial, several of the options were not compatible.
[314] Although they were not utilized for this trial, there are additional detail options within the web map creator including the layer, features and map notes tools. Within the configuration of the main stage content area, the specific focus on the base map, as well as options for content and popups could be altered.

located along the trial block had a separate section. These sections were numbered to correspond with the pinpoints on the base map.

The cover page and default home platform for the trial project provide an introduction to the history of the Church Street trial block. The main stage content features the base map depicting the area under investigation, as well as the identified location of each structure along the block. The side panel content consists of a short narrative introducing the trial block and its contribution to the French Quarter District National Register nomination. An image of the 1872 "Bird's Eye View of the City of Charleston" is positioned with a focus on the trial block and is included within the cover page side panel of the multimedia GIS platform.

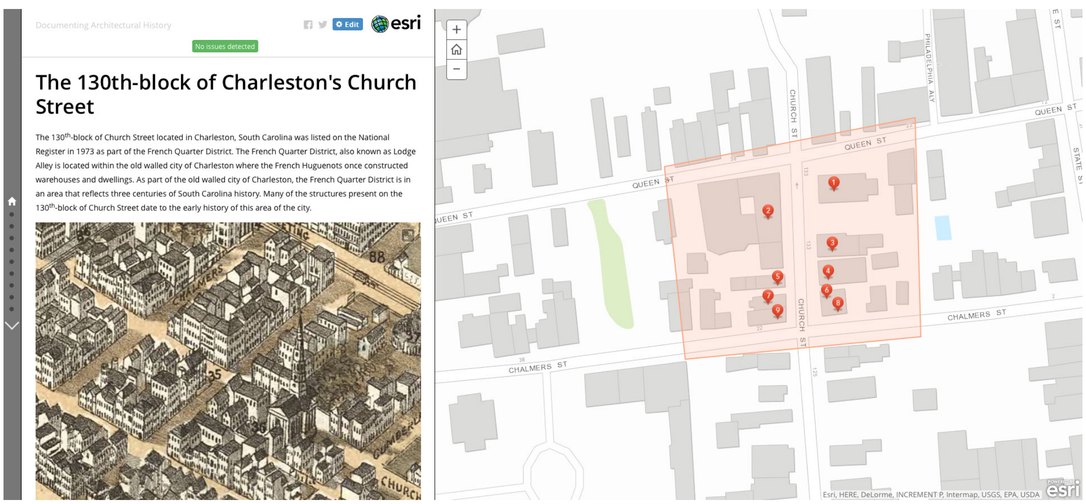

Figure 5.30 - *Default Cover Page for Interactive Platform.*
The image above shows the cover page and default home platform for the trial project. This section of the platform provides a base map and overview narrative of the trial block and its structures.
Screen-capture in the interactive ArcGIS platform by author

For each structure – 127, 128, 129, 130, 131, 132, 134, 135 and 136 Church Street – the operator created a new section beneath the cover page and home platform. The operator titled each section accordingly and established the primary content as the base map. However, the operator utilized a custom configuration for each base map. This configuration allowed for the journal section describing each address to portray a maximized map of the structure of study. With this arrangement, when the user scrolled to the narrative of an address, the base map relocated inward on the structure of study. After forming the main content for the section, the operator developed the side panel data utilizing the text and images collected during the data accumulation phase. The operator inserted the textual information discovered during data accumulation into the main box of the side panel content as the narrative for each structure.[315] Inserting the textual information into the Story Journal, as well as establishing individual layout options within the template consumed thirty minutes.

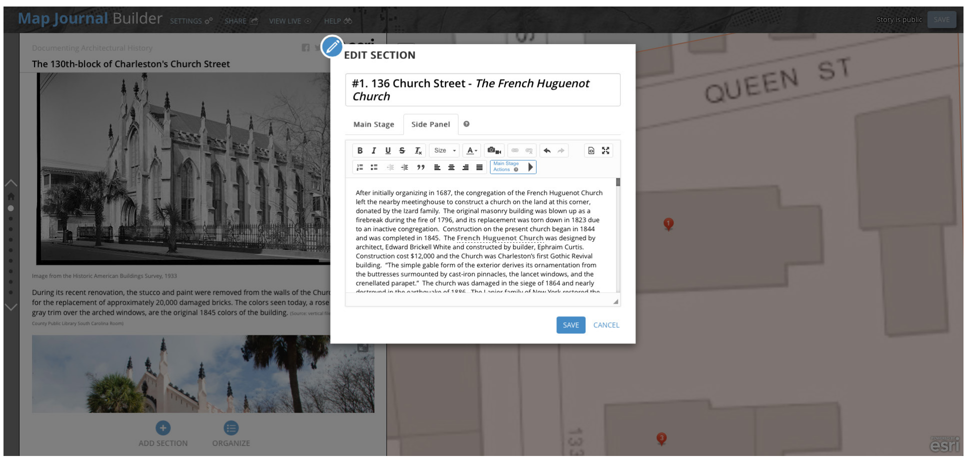

Figure 5.31 - *Text Editing Capabilities.*

The image above shows the process of typing and editing text and section titles within the multimedia GIS platform builder. A completed section of text is seen at the left side of the image.

Screen-capture in the interactive ArcGIS platform by author

To insert an image within the ArcGIS Online Web Mapping Application required that the image be uploaded from Facebook, Flickr or Picasa – all external web platforms supporting the sharing of photographs. For this trial, the images collected during the data accumulation phase were uploaded from the computer's desktop to the Flickr program through a Yahoo account, and then were individually uploaded into the corresponding

[315] Copying and pasting from the Microsoft Word file format to the multimedia GIS platform, easily converted the textual information collected during the data accumulation phase. The text could be furthered edited within the Story Journal platform, and the position and type of font were also editable.

journal section within the Story Map. The length of time to upload the images depended on the amount of images present, but generally required less than three minutes. Images were individually loaded into the sections and captioned; there was not an option for uploading multiple images at once. During import, the option for users to maximize each image was selected for increased viewing capacity. Uploading the images to the Flickr platform, importing individual images into the Story Map sections and editing the image captions took approximately two hours and forty-five minutes.

Figure 5.32 - *Embedded Historic Images.*
The image above portrays several historic images of the French Huguenot Church imported and integrated from the Historic American Buildings Survey. The base map is visible to the right and pinpoints the location of the building.
Screen-capture in the interactive ArcGIS platform by author

Each section of the multimedia GIS project – 127, 128, 129, 130, 131, 132, 134, 135 and 136 Church Street – was developed to include one contemporary photograph of the primary elevation of the structure; at least one historic photograph of the structure – many sections have multiple historic images of both the interior and exterior; and three historic maps – the 1884, 1888 and 1938 Sanborn Fire Insurance maps. Additionally, the processed GIS data for each structure includes a narrative and brief architectural description. When the user scrolls to and views the narrative for a structure located on the trial block, the web map redirects the focus to a maximized display of the specific location. Final editing and modification of the platform required a short fifteen minutes. In total, the processing phase of the multimedia GIS trial consumed a nearly equal amount of time to the data accumulation phase, with a total of four hours and forty-five minutes spent processing the data and creating the Story Map of the trial block.

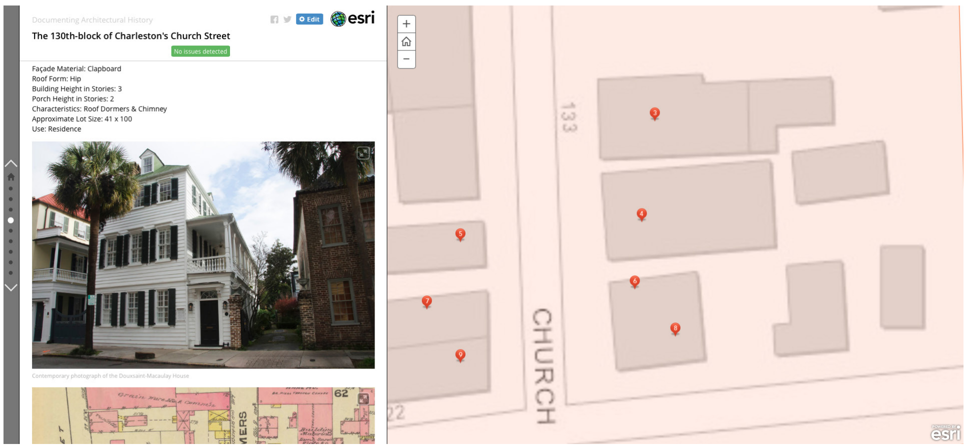

Figure 5.33 - *132 Church Street.*
The image above shows the completed section for 132 Church Street. This section of the platform incorporates a historic image, a contemporary image, Sanborn Fire Insurance maps, as well as a short history and architectural description of the building.
Screen-capture in the interactive ArcGIS platform by author

Data Post-Processing and Rendering

The processed data and generated multimedia GIS presentation were produced and stored within the ArcGIS Online Web Mapping Application.[316] During its creation, other parties could not view or operate the multimedia GIS project. The post-processing or rendering phase of the multimedia GIS project consisted of publishing the platform. Upon completion, the operator shared the mapping application with the public through an accessible URL link.[317] Rendering the multimedia GIS application through this link allowed the data to be viewed by a wider audience; users do not need an ArcGIS Online

[316] ArcGIS Online is a cloud-based platform with the ability to share geographic data, maps and content.
[317] ArcGIS Online provides three levels of control for sharing created maps, applications and data. Projects and data can be shared publicly, shared with specific groups or kept completely private. Organizations retain ownership of intellectual property rights for data published. "Put Your Maps to Work," *ArcGIS*, accessed October 7, 2015, https://www.arcgis.com/features/.

account, but are able to view the project through the shared URL link and a JavaScript platform.[318]

Although published, the project is still editable. Organizations have the opportunity to continuing editing or adding to the GIS Story Map once the data is rendered and publicly published. Continual editing is simple with the appropriate log-in credentials. Editability is an acknowledged asset of this digital documentation technique; the multimedia GIS application is a living document with the ability to be developed further with the addition of new data. The multimedia GIS project tells the architectural narrative of each structure on the trial block. The post-processing or rendering phase of the multimedia GIS trial required the least amount of time, with a total of five minutes spent publishing the Web Mapping Application and the Story Map of the trial block. In total, nine hours and fifty minutes were consumed creating a multimedia GIS application for the structures located on the trial block, though much more could have been invested.

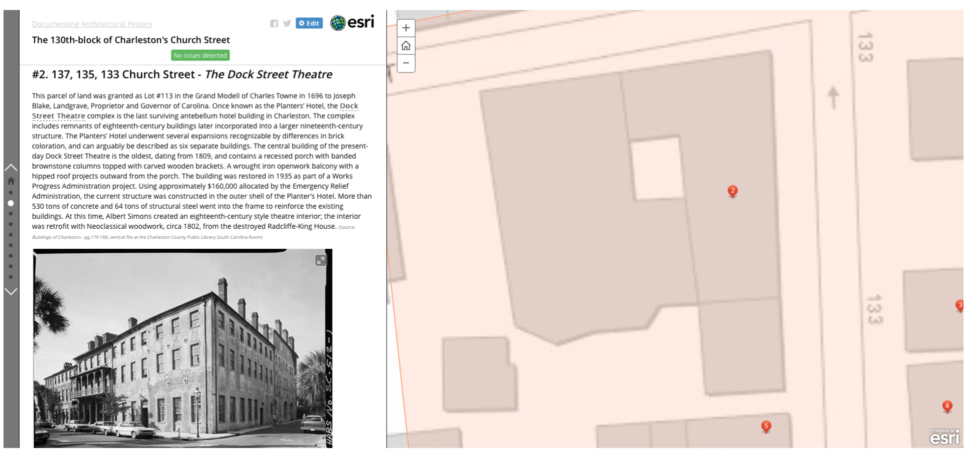

Figure 5.34 - *Dock Street Theatre.*
The image above displays a portion of the completed section for the Dock Street Theatre. In this image, the pinpointed base map of the structure, as well as a HABS photograph and historic narrative are visible.
Screen-capture in the interactive ArcGIS platform by author

[318] The link to access the Story Map of this trial is: http://arcg.is/1QSDG8d.

Trial Four: Three-Dimensional Modeling

<u>Data Accumulation</u>

The raw data for the three-dimensional modeling application of the documentation trial was primarily composed of the building footprints of the trial block – the block of Church Street between Queen and Chalmers streets. The outlines of the structures were assembled from the City of Charleston GIS data set. Freely available on the City of Charleston Data Portal, the GIS data was initially a series of separate layer files representing the street centerlines, location of the edge of the pavement, building outlines, rivers, green space and the historic district for Charleston County. Laurel Bartlett, a graduate of the Clemson University – College of Charleston Graduate Program in Historic Preservation

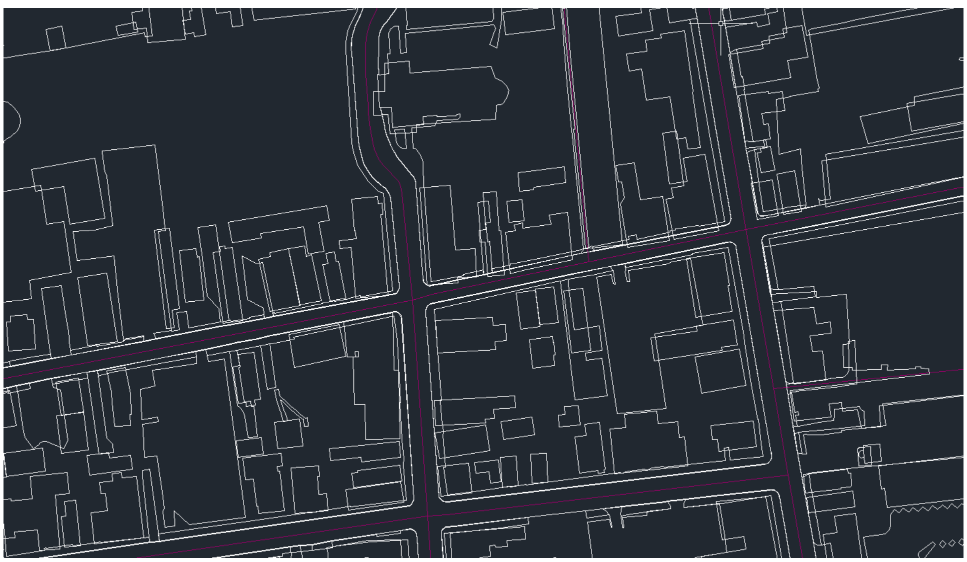

Figure 5.35 - *GIS Layers Converted to CAD File.*
The image above shows an enlarged portion of the City of Charleston's GIS data layers. The GIS data was converted to the CAD drawing seen here. After editing, the building outlines in this data were used to create the three-dimensional models of the structures on the trial block.
GIS data courtesy of Amalia Leifeste

and an architectural historian with SEARCH, Inc. converted the GIS layers to an Autodesk AutoCAD .DWG file. Assistant professor for the program, Amalia Leifeste provided the converted .DWG file for the purpose of this trial.[319]

The data accumulation stage of the three-dimensional modeling trial required assembling accurately scaled outlines of the structures on the trial block from the GIS data to give a two-dimensional plan view of the structures. Supplemental data was needed to model the third, vertical dimension. The fieldwork team produced this information using rectified photographs. At the start of the data accumulation phase, one hour was spent on site capturing a straight-on photograph of the façade of each structure on the trial block; the fieldwork team utilized the Nikon D7000 digital SLR camera belonging to the Clemson University – College of Charleston Graduate Program in Historic Preservation to capture the façade photographs. At this time, the fieldwork team also captured a vertical measurement for each structure with a metal tape to serve as a base reference against which to scale the photographs. The fieldwork team initiated this process by taking a measurement from the sidewalk to a designated location above, taking detailed notes to ensure that the location of the dimension could be accurately positioned when the photograph was inserted into AutoCAD. The reference measurements initially obtained on site, as well as the corresponding height and street frontage of the structures once scaled in AutoCAD can be referenced in the chart on the following page.

[319] A .DWG file is a file format used to store two-and-three-dimensional design data. This file type is the native file format for AutoCAD data files and is one of the most commonly used design data formats, as it is compatible with several other CAD packages. A .DWG file contains all information entered by the user, including designs, geometric data, maps, text and photographs. "What Is DWG?," *Autodesk*, accessed December 27, 2015, http://www.autodesk.com/products/dwg.

STREET NUMBER	REFERENCE MEASUREMENT	REFERENCE LOCATION	SCALED ROOF HEIGHT	SCALED STREET FRONTAGE
136	10 1/4”	Top of the brownstone curb beneath the ironwork at the sidewalk in front of the Huguenot Church	Approximately 23’-0” to gable break; 37’-0” to peak of gable	Unknown
135	35 1/4”	Top of the window sill	37’-8” to edge of roof (roof shape initially unknown)	Unknown
134	50”	Bottom of the window sill	32’-10” to gable break; 36’-4” to peak of gable	19’-8” (26’-10” including piazza)
132	42 1/2”	Bottom of the left window sill	30’-2” to gable break; 33’-0” to peak of gable	20’-0” (26’-6” including piazza)
131	39”	Top of the window sill	36’-2” to edge of roof (roof shape initially unknown)	Unknown
130	*Reference 128 Church Street		23’-1” to gable break; 31’-7” to peak of gable	Unknown
129	51”	Bottom of the window sill	23’-2” to gable break; 30’-0” to peak of gable	16’-0”
128	23 1/2”	Bottom of the window sill located on the Church Street facade	24’-8” to top of the parapet (flat roof)	14’-10”
127	33”	Bottom of the window sill located on the Church Street facade	29’-8” to gable break; 36’-8” to peak of gable	20’-6”

***Table 5.0** - Three-Dimensional Modeling Reference Measurements.*
The table above communicates the vertical measurements initially obtained on site for each structure. These measurements served as a base reference to scale the rectified photographs in AutoCAD and helped to determine a scaled roof height and street frontage measurement.

After capturing the photographs on site, the images were transferred to a desktop computer and the .JPEG files were opened in Adobe Photoshop CC 2015. The operator rectified each image using the lens correction tool within the Photoshop platform.[320] With this tool, the operator applied a custom lens correction filter and transformed the vertical perspective; the vertical perspective was typically altered in the range of -5 to -15. Using

Figure 5.36 - *Rectified Photograph for Measurement Purposes.*
The image above is an example of one of the rectified photographs captured of each structure on the trial block. These images were used to obtain building heights.
Photograph by author

[320] For the purpose of taking measurements, the images needed to be rectified due to perspective distortion. Perspective distortion is the warping or transformation of the subject matter of a photograph due to the angle of view of the image, as captured. In this case, the upper portions of the structures appeared further away and smaller compared to the relative size of the building. Additionally, due to the angle of the camera and operator, the tops of the structures slanted inward. Rectifying the images resulted in more accurate measurements and a realistic interpretation of the structures.

this custom tool allowed for the images to be accurately rectified, making it appear as though the photographs were taken straight on, rather than from below looking slightly upwards at the structures. By rectifying the photographs, the tops of the buildings were tilted towards the viewer, correcting the vertical perspective of the photograph and allowing for a more accurate building height to be obtained. The rectifying process within Abode Photoshop took approximately thirty-five minutes.

After rectifying the photographs of each building, the .JPEG files were inserted into AutoCAD as an attachment. Using the single measurement and base reference taken from the façade of each structure while on site (see the chart above), the photographs were scaled to their actual size. By accurately scaling the photographs in AutoCAD, the relative height of the roof and roof pitches for each structure could be incorporated into the later modeling and processing phase of the trial. Photographing the structures and then extracting heights from the scaled images in AutoCAD proved the simplest and arguably cheapest means of gathering the building heights though it relied on access to the AutoCAD software.[321] Extracting building heights from the images in AutoCAD resulted in a lower level of accuracy. Although the photographs were rectified, the images were not entirely free of distortion, particularly where hipped roofs were involved. Alternatively, the building heights could have been gathered by taking hand measurements on ladders with the permission of the structures' owners, or through the use of a total station.[322]

The operator initially opened the .DWG file of the GIS data in Autodesk's 2015 version of AutoCAD. In this program, unnecessary data – streets and building outlines

[321] Gathering data related to the heights and roof pitches of the structures could have also been obtained through the use of the laser scanning data, a total station or a measuring pole. However, the combination of rectified images of the structures and the Autodesk AutoCAD platform is arguably the most accessible, cost-effective, quickest and most user-friendly application for this objective. Time amassed in AutoCAD to realize the building and roof heights is incorporated into the following phase of data processing and the modeling stage.

[322] A total station is a piece of modern surveying equipment with the ability to electronically read distances from the instrument to a particular point.

outside of the parameters of the trial – was deleted to provide a less cluttered underlay for modeling; this modification took approximately five minutes. Data remaining in the file was limited to the street centerlines of Church, Chalmers and Queen streets, as well as the outline of the structures located on the trial block. When initially brought into AutoCAD the GIS data proved to not be to scale.[323] The street frontage of the structure at 127 Church Street was measured off of the rectified and scaled façade photograph in AutoCAD.[324] With this dimension, it took approximately five minutes to accurately scale the GIS file in AutoCAD. From the measurement collected from 127 Church Street, after scaling, all other buildings were within six inches of their measured street frontage dimension. The operator considered this variability acceptable, as this type of documentation serves as a height, mass and scale model, rather than a highly accurate depiction of the structures on the trial block.

After the operator reduced the .DWG file to only include the necessary data for the trial and correctly scaled the data, the AutoCAD file was exported as a .PDF. The .PDF was imported into 2015 SketchUp Make and set as the underlay representation of the building footprints; this underlayment served as the blueprint for modeling the structures on the trial block. However, after the operator imported the .PDF version of the AutoCAD file into the SketchUp platform, it was realized that the building outlines were again incorrectly scaled. The operator rescaled rescaled the .PDF within SketchUp to ensure an accurate

[323] Presumably, the building footprints were not to scale as a way of allowing GIS information for the entire Charleston County, an immense amount of data, to be operable and readable on all hard-drive sizes.
[324] To measure the street frontage of the structures on the trial block for scaling, data from Charleston County's online tax records was going to be utilized. This website provides easily accessible data for each structure's acreage and lot dimensions. However, data located on the Charleston County PropertyMax website proved useless. The online tax records document the street frontage for each property, however this dimension delineates the effective frontage of the parcel of land, not exclusively the structure's street facing façade. As a result, to ensure accuracy, frontage dimensions were accumulated from the rectified photographs instead. The frontage of 127 Church Street was chosen as the base for scaling the remainder of the .DWG file. The structure at 127 Church Street was chosen, as this was the only rectified photograph in which both corners of the base of the building were clearly visible for an accurate measurement of structure's street frontage.

representation of the general masses of the structures. Ultimately, the process of scaling the GIS data in AutoCAD could have been omitted, and the file could have simply been scaled through the SketchUp software. Importing the .PDF into SketchUp and rescaling the file took ten minutes. The various segments of the data accumulation phase took a total of one hour and thirty-five minutes.

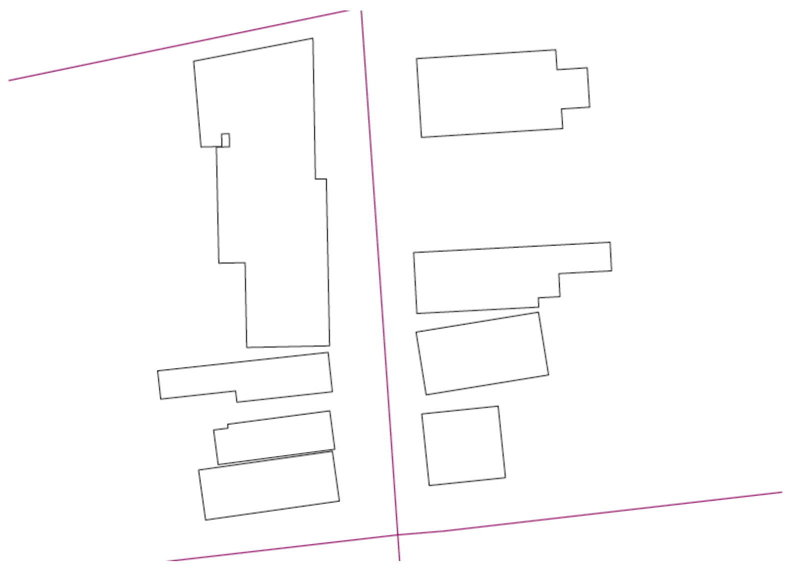

Figure 5.37 - *Simplified CAD File of the GIS Data.*
The image above shows a simplified - cleaned of unnecessary data - PDF file created from the GIS data. This PDF was used to model the building footprints.
GIS data courtesy of Amalia Leifeste

Data Processing

2015 SketchUp Make was the computer software utilized for the three-dimensional modeling technique of the trial. Modeling of the mass of the structures on the trial block began by importing the raw data, the .PDF version of Charleston County's GIS map. This underlay provided the footprints of the structures to be extracted. However, by observing aerial photographs available through Google Earth, there was a recognizable difference between the actual aerial views of the structures and the building outlines afforded through the GIS data. The footprints in the GIS data were large blocks that encompassed not only the primary structure, but also all dependencies located on the lot; lines separating the various structures were absent. The operator used Google Earth to divide the footprint blocks from the GIS data into individual structures.[325] The location of the divisions separating the main structure from dependencies and additions is therefore estimated.[326] The aerial photographs available through Google Earth rendered it difficult to decipher building divisions, namely where the dependencies began and ended. This obstacle stimulates the argument against the accuracy of this digital documentation technique and will be discussed in the later concluding analysis. However, despite the obscurity, the masses of the structures on the trial block could be modeled to an acceptable level of realistic representation.

To begin the data processing or modeling phase the operator traced the outline of each structure on the trial block with SketchUp's line tool. The connection of these lines automatically formed a plane to be vertically "extruded" shaping the building form. Using

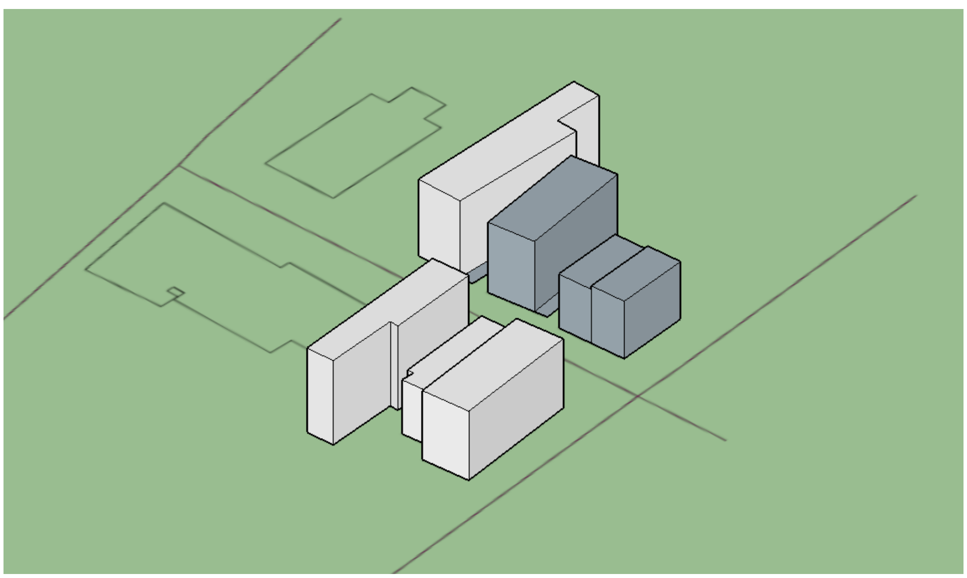

Figure 5.38 - *3D Modeling Progress.*
The image above is an in-process depiction of the 3D model prior to the modeling of the roof forms. In this image, the building outlines are being traced from the GIS data.
Screen-capture in SketchUp by author

[325] The previously discussed methodology for this trial was not to include modeling dependency structures located on the lots of the trial block. All four digital documentation techniques explored through the trials of this thesis were confined to only accumulating data for the main structures with street frontage along Church Street.
[326] Without access on to private property, there was not a means of accurately locating the separations between the main structures and their corresponding dependencies.

the previously scaled rectified photographs from the data accumulation phase, the operator measured the vertical dimension to the gable break or edge of the roof in AutoCAD and the profile plane of each structure was extracted to this height.[327] This process formed the general mass of each structure, excluding the roof height and form.

To model the roof shape for each structure required looking at Google Earth, Google Street View and the rectified photographs. The structures with gable roofs – 134, 132, 129 and 127 Church Street – were the simplest to shape and are arguably modeled the most accurately because the gable end of the roof faced the street. With the structures orientated this way, the gable peak was vertically aligned with the front plane of the structure, unlike the hipped roofs where the roof peak sat back from the façade of the building, forming a diagonal measurement. With these structures, the operator measured the height to the peak of the gable from the rectified photograph in AutoCAD and then modeled accordingly in SketchUp using the line tool. The gable roofs could be more precisely developed, as the gable ends of the roofs faced the street and an accurate dimension could be gathered from the façade elevations. In contrast, the hipped roofs on 135, 131 and 130 Church Street do not present a dimensioned pitch and height. The vertical height of the hip was obtained from the photographs, however, as the roof slopes upwards and away from the street, it is unlikely that this is a true dimension. The operator used this measurement in conjunction with the knowledge that the most common hip roof pitch ratios fall between 4:12 and 6:12, to model the roofs for these structures. The hipped roofs in the three-dimensional model are visual representations of the roof forms; however, it is acknowledged that their precision is a shortcoming within the trial.

The roof at 128 Church Street is low-sloped with a parapet and proved relatively easy

[327] SketchUp Make incorporates a tool called "Push/Pull", which allows for the creation of three-dimensional shapes from a face. After forming a plane by tracing the lines on a blueprint, this tool allows for the plane to be pulled upwards or pushed downwards to a determined length. This tool provides a quick method for forming building masses.

to model. The operator measured the height of the parapet from the rectified photograph. The lower height of the roof form was then estimated from Google Earth and depressed into the structure's mass using SketchUp's line and push/pull tools. Modeling the unique roof form of the French Huguenot Church proved more cumbersome. Dimensions to the gable break, as well as the peak of the stucco gable were determined from the rectified photographs. These measurements were used to model the structure and roof form; yet, the Church visually appeared too short when compared to the surrounding structures on the trial block. The operator verified the height of the structure utilizing different rectified photographs and determined that the Church's location, set back from the sidewalk of Church Street, made for an inaccurate measurement from the photographs.

The roof form of the French Huguenot Church is a smaller gable behind the larger, decorative stucco gable ends. At the gable break, a lower pitch slopes downward, beneath the raised parapet sides to filter water presumably to interior gutters. Modeling these forms required looking primarily at aerial views from Google Earth due to lack of accessibility. The length and slopes of the roofs were estimated and could not be precisely measured from the public right-of-way. Although it was previously determined that structural details would not be modeled for this trial, the buttresses of the French Huguenot Church were incorporated as means to visually orient users through a recognizable structure.[328] The buttresses crowned with pinnacles that separate each bay of the Church were roughly modeled. The operator did not measure either the height or the width of these features prior to modeling.

[328] The idea of incorporating select details on specific landmark buildings was a method suggested by Dr. Robin Williams, Director of the Virtual Historic Savannah Project. He argued that within a three-dimensional massing model, most structures could be modeled as simple cubes. However, he asserted that certain structures needed detail and privileging following the concept that if a user was going to navigate a model, some buildings needed to be recognizable for orientation. Robin Williams, Virtual Historic Savannah Project, Phone, October 30, 2015.

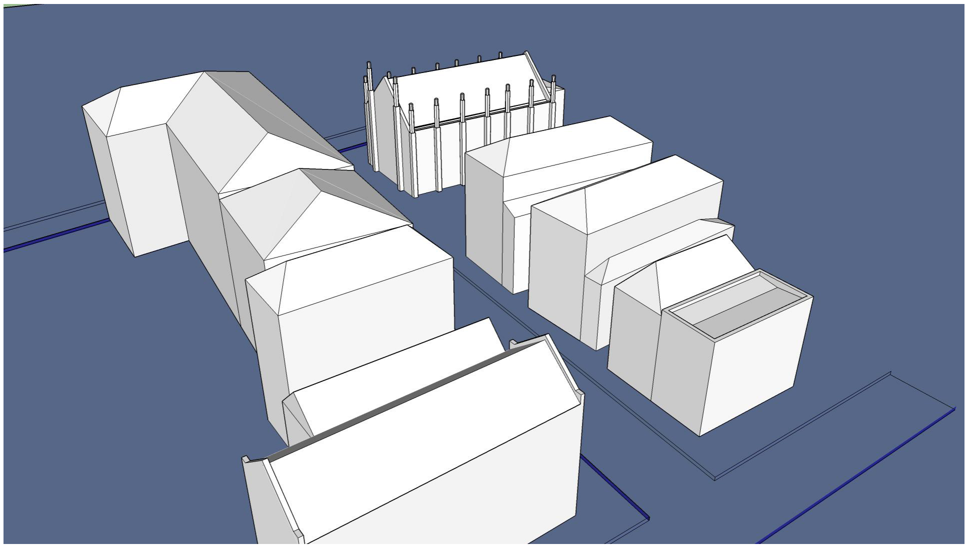

Figure 5.39 - *French Huguenot Church Modeled Isometric.*
The image portrays an isometric view of the modeled trial block. The French Huguenot Church with its raised parapet sides, buttresses and pinnacles is more elaborately modeled than the other buildings and serves to orient viewers.
Screen-capture in SketchUp by author

Processed data for the three-dimensional modeling trial resulted in building masses and roof forms depicting the relationship of the architecture on the trial block. Building heights, roof forms and roof pitches were obtained from aerial photography available through Google Earth and rectified photographs captured at street level. Within the data processing phase of this trial, significant assumptions were generated regarding the structures' roofs. Acknowledging the pre-established parameter of only collecting data from the public right-of-way, the operator encountered a major limitation in regards to the accuracy of the data accumulation and data modeling. Additionally, with this documentation technique, it was difficult to align building components and shapes. Unnecessary lines were drawn to form planes when the SketchUp platform would not automatically create the face due to misalignment. These lines were temporarily hidden, yet their presence contributes to the size of the file.

The level of detail developed within the model was confined to massing; fenestrations and major architectural features were not incorporated. Although fenestrations were not modeled, the piazzas on 134 and 132 Church Street were included, because these structural components occupy area along the façade and are representative of mass along the street frontage. Time spent processing the data for this trial was exclusively active time; there was no passive time encountered during the modeling phase. The processing phase of the three-dimensional modeling trial consumed the majority of the inclusive time limitation for the technique, with a total of seven hours spent modeling the structures on the Church Street trial block.

Data Post-Processing and Rendering

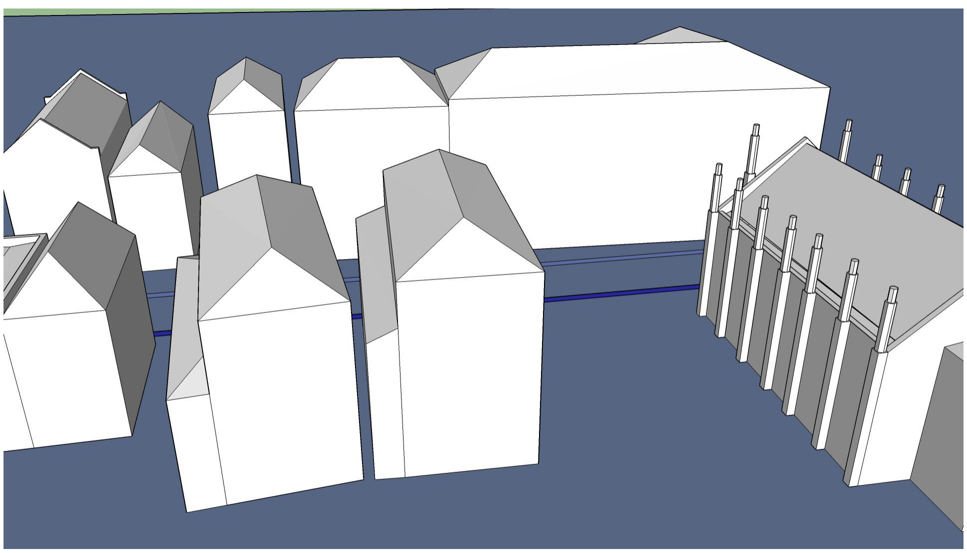

Figure 5.40 - *Aerial Perspective of the 3D Model.*
The image above showcases the completed 3D massing model of the trial block.
Screen-capture in SketchUp by author

Processed data and the general trial model were produced as the standard .SKP SketchUp file. To allow the data to be viewed by a wider audience who may not have access to the SketchUp software, the operator rendered the digital model into images. The post-processing or rendering phase of the three-dimensional model primarily consisted of creating scenes or screen captures of the model.[329] Approximately thirty scenes were captured of the trial model from various vantage points including street-level, isometric and plan views, creating perspective presentations of the modeled block. The scenes were then individually exported as raster images in a .JPEG file format. The exported scenes depicting the model are separate processed data from the larger SketchUp file and can be easily uploaded to other viewing platforms.

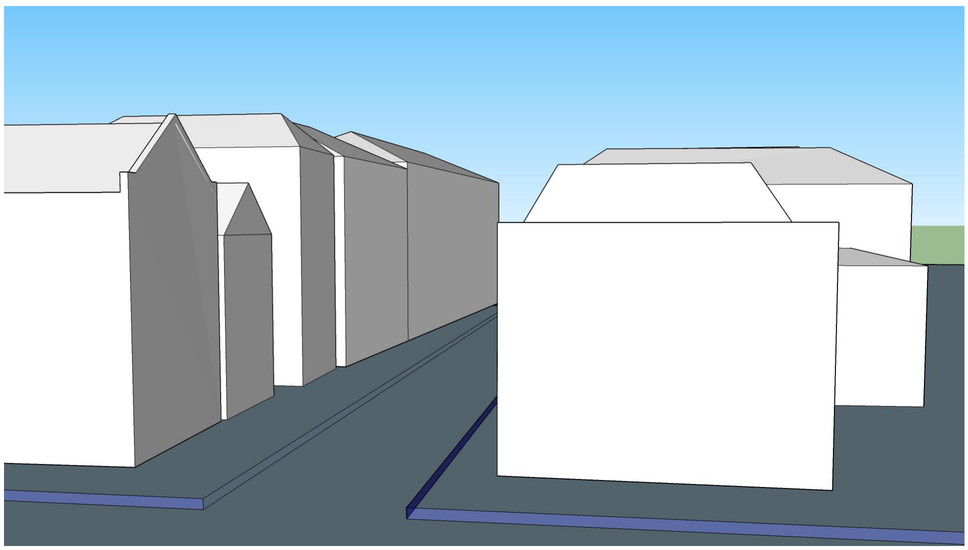

Figure 5.41- *Exported Scene from the SketchUp Platform.*
The image above is an example of one of the scenes exported from SketchUp. This image illustrates the modeled trial block looking north from the corner at Chalmers and Church streets.
Screen-capture in SketchUp by author

The structures modeled are devoid of fenestrations, textures and details, and rely on height, form and setback for interpretation. This is the intended visual from the initial documentation objective. The three-dimensional models do not serve to document the architectural styles or characteristics of the structures; the models are purely representative of the buildings' mass and relationship to the surrounding structures on the trial block. The

[329] Within the SketchUp platform, the scene tool allows the user to set the view as desired with the option to adjust the eye-height position, creating perspective presentations of the model. The scene is then added to the SketchUp file. The scenes dialog box maintains a record of all scenes captured within the data file.

post-processing or rendering phase of the three-dimensional modeling trial constituted the least amount of the inclusive time limitation for the documentation method, with a total of one hour spent rendering the massing model of the structures on the trial block. In total, nine hours and thirty-five minutes were expended creating a three-dimensional model of the masses located on the Church Street trial block for this thesis.

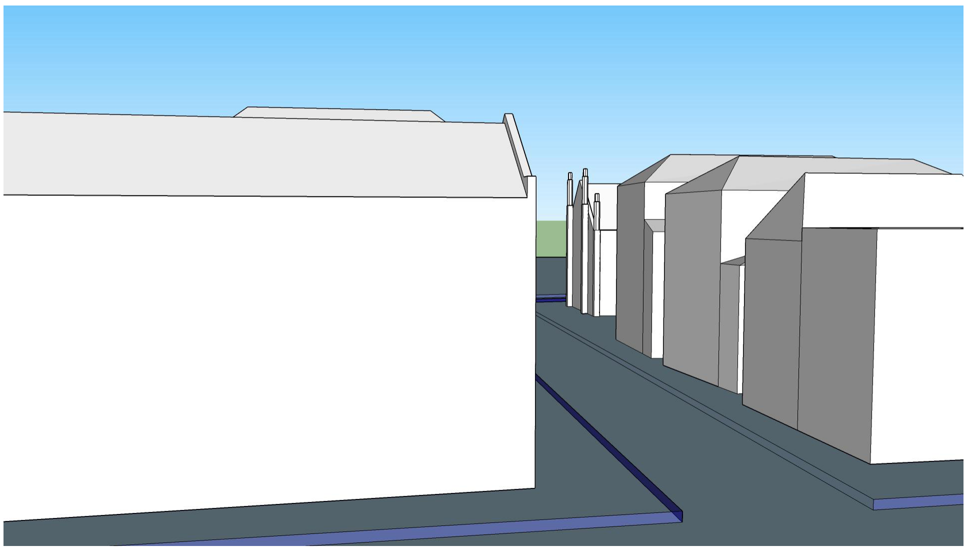

Figure 5.42 - *Perspective View of the 3D Model.*
The image above is an exported street-level perspective looking north up Church Street towards the French Huguenot Church.
Screen-capture in SketchUp by author

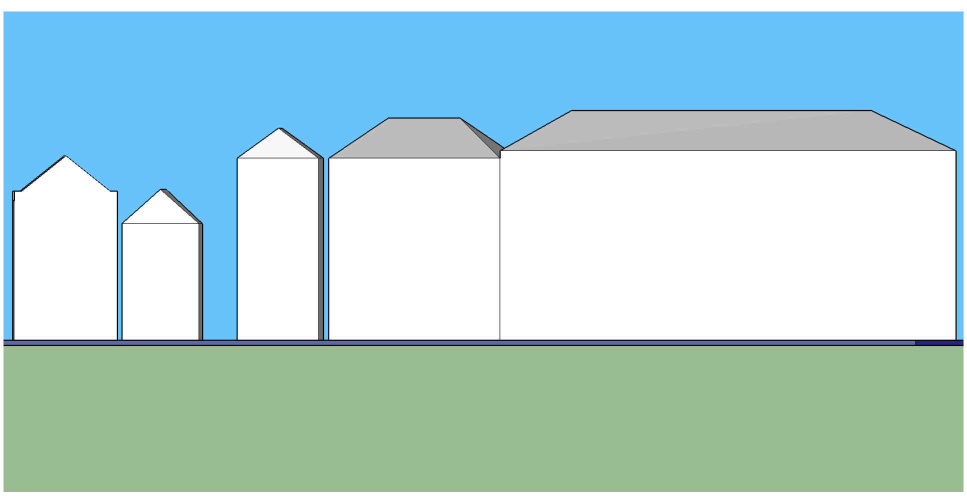

Figure 5.43 - *Rectified Perspective of the 3D Model.*
The image above is a rectified view of the west side of the trial block looking at the Dock Street Theatre and the structures at 131, 129 and 127 Church Street.
Screen-capture in SketchUp by author

Trial Investigation Intervals

The visual below is a representation of the total time allocation, as well as the approximate divisions of time required for the data accumulation, data processing and data post-processing stages for each of the four digital documentation trials. The darkest hue represents the fieldwork and data accumulation stage. The middle hue represents the data processing phase. The lightest hue represents the post-processing and rendering phase.

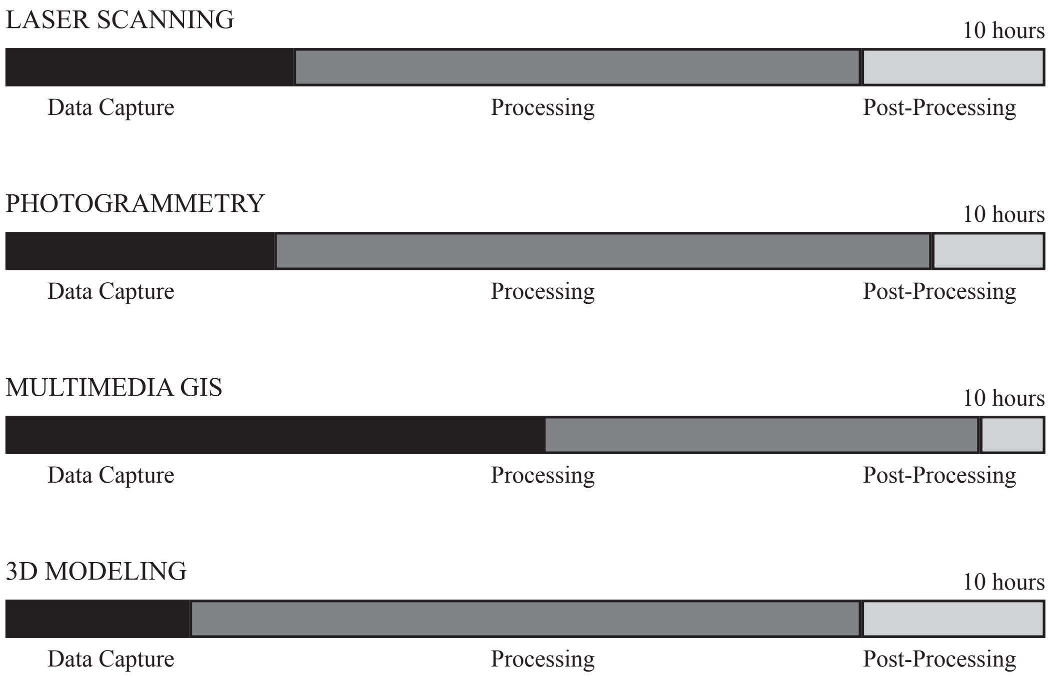

Figure 5.44 *- Trial Investigation Intervals.*
The visual above represents the total time allocation, as well as the approximate divisions of time required for the data accumulation, data processing and data post-processing phases of each trial - laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling.

Laser scanning requires nearly equal time for data capture and post-processing. Processing the scans takes a greater amount of time and is largely active in contrast to the more passive data accumulation stage. Photogrammetry requires a significant amount of processing time; however, this is largely automated. The GIS technology requires a large amount of preparation. Three-dimensional modeling requires less time for accumulation and post-processing, but a significant level of time for actively constructing the model.

CHAPTER SIX

CONCLUDING ANALYSIS

The objective of the investigative trial was to generate a digital deliverable for each of the four documentation technologies – laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling. These trials generated the primary data necessary to establish a parallel comparison of the technologies' efficacy for use by cities for architectural heritage documentation. The following discussion uses the parameters outlined in the methodology to analyze and evaluate the trial results of the four digital documentation techniques. The trials of the documentation technologies resulted in four considerably different preservation products and deliverables. Arguably, each of the techniques analyzed could successfully document historic architecture if implemented by a city or historic community. However, this parallel analysis will help to inform the selection of a specific method when a city or community embarks on a digital architectural heritage documentation campaign.

Chapter Six is divided according to the parameters used to analyze the four digital documentation technologies: perceived target audience; effective application; ability to record urban and architectural features; degree of refinement; technical expertise required; manageability; labor intensity; institutional capacity; and potential obstacles and areas of failure. Each section within the chapter is accompanied by a matrix, which visually represents the level of success and efficacy of the documentation techniques with respect to the parameter being evaluated. Within the individual matrices, the parameters are further divided into subcategories. This results in a more comprehensive understanding of the capacities and limitations of the documentation technologies. The parameters and their subdivisions are appraised on a three-tiered scale from most desirable and successful elements achieved through the documentation technology to the least preferable results. The darkest hue represents a preferred capacity or highly successful component of the technique. The lightest hue indicates a less effective result or an unfavorable capacity for the specific parameter. The median hue symbolizes an average efficacy achieved within the analyzed parameter; this represents neither a highly applicable nor a detrimental element realized through the documentation procedure. A rectangle with a line symbolizes a parameter that is not applicable.

The matrices – a visual representation of the analytical parameters – and the resulting parallel comparison of the technologies are specific to the methodology and software used in this thesis. This ranking takes into consideration all phases of the data accumulation, data processing and data post-processing stages, as well as the equipment, software and hardware employed. For the laser scanning and photogrammetry technologies, this disclaimer is less critical. If different equipment and platforms were used to capture and process the data for these two techniques, a methodology incredibly similar to that undertaken through this thesis would ensue. The findings are comprehensive for the broader category of laser scanning and photogrammetry technologies. The equipment and software used for both laser scanning and photogrammetry are generic, and the data capture and processing stages would not be significantly altered if a city used hardware and processing platforms different from that presented in this thesis. The parameters analyzed to generate the parallel comparison would present relatively similar results if different technologies such as a Leica or Trimble scanner, or the ReCap, Cyclone or Pix4D software were employed.

However, for the multimedia GIS and the three-dimensional modeling techniques, the value quantified for each parameter is specific to the software platforms used in this thesis. The analysis of the parameters in regards to these two technologies would likely be incredibly different if an alternate technique or technological platform, of the same documentation category, was used. For instance, creating a model through the Autodesk Revit or ESRI CityEngine platforms would likely change the parameters concerning economics, refinement and expertise. Similarly, using a multimedia GIS platform more advanced than the ESRI web-mapping application would alter the analysis presented in this thesis. If a city is considering using either the multimedia GIS or three-dimensional modeling technique for an architectural heritage documentation campaign, further research into the efficacy of the technology will be required if the institution employs methodology and software different than what is presented in this thesis.

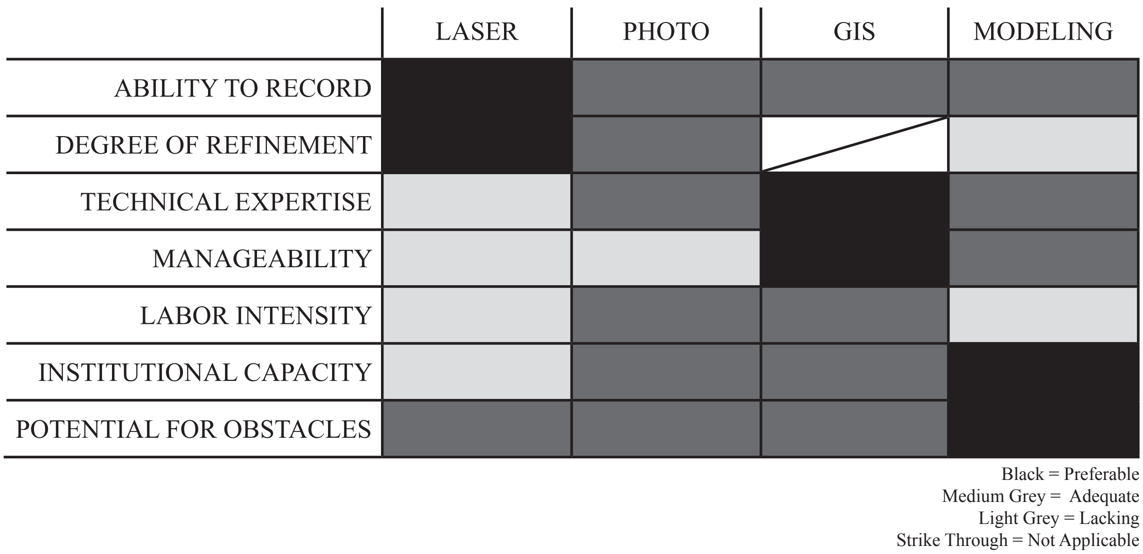

Table 6.0 *- Analytical Parameters.*
The table above represents the accumulation and average of the finer headings to be discussed later in the chapter for the digital documentation technologies - laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling.

The matrix above shows a summary rank for each of the seven parameters. Subdivisions of these parameters are discussed throughout the chapter. This matrix aggregates the finer subsections and illustrates a relative average of the subdivisions of each parameter, allowing cities and interested parties to understand a more macro sense of the capacity for the parameters. The subsections detailing each parameter show how the aggregate rank was analyzed and developed. Note that the matrix does not illustrate the target audience and effective application parameters. There is not a logical way to average the most successful audience and application for each technology. These two parameters require a deeper discussion and cannot be conveyed through a common median. Instead, these two parameters, as well as the others – ability to record urban and architectural features; degree of refinement; technical expertise required; manageability; labor intensity; institutional capacity; and potential obstacles and areas of failure – will be discussed at greater detail later in the chapter.

Perceived Target Audience

	LASER	PHOTO	GIS	MODELING
STUDENTS	Light Grey	Light Grey	Black	Black
TOURISTS	Light Grey	Light Grey	Black	Medium Grey
RESEARCHERS	Light Grey	Light Grey	Black	Light Grey
GOVERNMENT ENTITY	Medium Grey	Medium Grey	Light Grey	Black
ARCHITECTS	Medium Grey	Medium Grey	Light Grey	Black
RESTORATION CONTRACTORS	Medium Grey	Medium Grey	Medium Grey	Light Grey
CONSERVATORS	Black	Medium Grey	Light Grey	Light Grey
PRESERVATIONISTS	Black	Black	Black	Light Grey

Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking

Table 6.1 *- Perceived Target Audience.*
The table above communicates the perceived target audiences and intended users for the digital documentation technologies.

The documentation deliverables targeted different audiences and were geared toward specific intended users. The audiences addressed through this parameter include users in the education realm, as well as preservation and urban development fields. The broad audience of academics encompasses students of all ranks, tourists and researchers interested in the documented architecture. Audiences related to the urban development field are more narrowly defined as architects and government entities. These are typically interested parties linked to the new construction discipline. Government entities are likely to interact at a local or regional scale, and include planning and zoning departments and architectural review boards. In contrast to government entities and architects addressing new construction, the historic preservation field draws an audience from restoration contractors, conservators and preservationists. Restoration contractors are involved with the rehabilitation or restoration of a historic property. Conservators, for the purpose of this thesis, are narrowly defined as practitioners working to conserve or preserve historic building materials and fabric. Preservationists are more broadly tasked with protecting historic structures and interpreting the surrounding built environment.

In terms of appearance, the laser scanning and photogrammetry trials developed the most visually realistic products. As a result, these two technologies have great application for audiences who are not trained in reading architectural renderings or who have a more difficult time with abstract representations (often children). In contrast, the multimedia GIS and three-dimensional modeling trials each address different users. The multimedia GIS trial generated the most interactive platform, encompassing both architectural and social history, and is therefore most appropriate for and successful with students, tourists and researchers. The multimedia GIS platform amassed information found elsewhere – some already present in digitized archives – but became a single stop for those with a causal interest in viewing the historic and social dimension over time or as a starting point for those researching. The platform successfully documents and preserves architectural heritage, however, the technology would be less attractive to government entities such as urban planning departments, or restorers and conservationists because of the lack of three-dimensionality and its inferior level of detail. The multimedia GIS platform presents a more curated depiction of the properties and does not produce raw data to draw observations from.

Arguably though, the historic photographs included in the platform could aid restorers if necessary.[330] Of the four documentation technologies analyzed, the multimedia GIS technique would be the most effective for a broad academic audience addressing history and intangible contexts as well as a description of the physical structures. Academics interested in the material condition and technicalities of the physical fabric are considered a different audience; this category of "broad academics" includes students of all grades, tourists and the general public.

There is an element of interaction with the three-dimensional modeling technique, which suggests specific target audiences. This technique is still pertinent for students; however, the model is more applicable to students studying architecture and urban design. The model does not incorporate the larger historic and cultural narrative as with the multimedia GIS platform, nor does the technology integrate historic data. Researchers will likely find little value as an audience for the technology because of the lack of social history data. As a massing model, tourists and researchers looking to discover a city's architectural heritage are less engaged with the three-dimensional modeling technique because of the degree of abstraction. A massing model depicts urban context in very useful ways for preservationists, architects and planners to consider factors like the height, scale and mass environment around a proposed building. A government entity such as a city planning department or architectural review board would be the most appropriate audience for documentation through a three-dimensional model. Since the model incorporates minimal architectural details and primarily represents height, scale and mass, the technology has limited applications for heritage restorers, conservationists or preservationists. Architects,

[330] The multimedia GIS technology preserves archival documents through an interactive platform. Although the program is not predominately intended for restoration projects, the historic images incorporated into the platform could provide visual evidence for previous interpretations and styles of the structure. The historic images and narratives integrated within the platform may help to determine the architectural integrity, or lack of for a specific structure.

preservationists and planners may use the digital model to understand the contextual implications of new construction within a historic district.

As previously indicated, the laser scanning and photogrammetry trials generated visually similar deliverables. This resemblance resulted in nearly identical target audiences and intended users. Both the laser scanning and photogrammetry trials are highly applicable to the objectives of preservationists and general heritage documentation. Both technologies are only moderately useful for government entities, planning departments, architects and those engaged in restoration. The rectified and photorealistic nature of the products is visually enthralling, but is less pertinent to users looking for massing models and a visual for urban planning. Without abstraction, there is almost too much graphic data to sieve and the produced images and models are not easily manipulated to introduce proposed new construction. The products generated from the laser scanning and photogrammetry technologies lack the interactive elements seen in the multimedia GIS and three-dimensional modeling platforms. While a flattened .JPEG or similarly formatted image of the model might be compelling to tourists or a broad academic audience, the interest is not much beyond what is captured by a photograph. Although broad academic audiences and tourists may be less engaged by the solitary images and time capsule characteristic produced from the technologies, laser scanning and photogrammetry products gain value as a record of the past as architecture evolves and may be a valuable upfront investment to future tourists or academic audiences. The laser scanning and photogrammetry deliverables limit researchers to studying the architectural forms and details captured at single specific moment in time.

Although these two technologies have proven incredibly similar in targeted users, the laser scanning technology when contrasted with photogrammetry, may find an additional audience in the conservation field. The high level of textured detail generated through the laser scanning process provides a platform for which material change can be monitored at a superior level of accuracy, than what could be accomplished through the rectified images of a photogrammetric model. As will be further discussed through the parameters addressing degree of refinement and ability to record architectural features and surface texture, laser scan products generate highly accurate, photorealistic renderings and present an exceptional level of clarity. The photorealistic nature of these deliverables provides a strong platform for users interested in material conservation, as well as the monitoring of the degradation of historic fabric. The surface texture of the structures is clearly represented by the laser scanning technology, where in contrast the photogrammetry technique depicted surface texture to only a moderate level. The degree of resolution for the materiality and architectural elements recorded does not possess the clarity experienced in the laser scan product. The unhindered ability to perceive detail, as experienced with the laser scan data, was significantly inferior in the photogrammetric model, making it difficult for conservationists to address the analysis of material stability.

Effective Application

	LASER	PHOTO	GIS	MODELING
EDUCATION	Medium Grey	Medium Grey	Black	Medium Grey
HERITAGE TOURISM	Light Grey	Light Grey	Black	Light Grey
RESEARCH	Light Grey	Light Grey	Black	Light Grey
INTERPRETATION	Light Grey	Light Grey	Black	Light Grey
URBAN PLANNING	Medium Grey	Medium Grey	Light Grey	Black
PRESERVATION	Black	Black	Medium Grey	Light Grey
CONSERVATION	Medium Grey	Medium Grey	Light Grey	Light Grey
RECONSTRUCTION	Black	Medium Grey	Light Grey	Medium Grey
TRACKING EVOLUTION	Light Grey	Medium Grey	Medium Grey	Light Grey

Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking

Table 6.2 - *Effective Application.*
The table above communicates the most effective applications for the digital documentation technologies.

Each technology was evaluated to achieve a better understanding of its most effective application to accomplish heritage preservation objectives. For each of the four digital documentation technologies studied, the primary application as well as additional secondary applications are directly associated with the perceived target audiences previously discussed. Arguably, the audience and the application are interrelated; the appropriate preservation application for the technology determines the interested users, and the engaged audience defines the most effective application for the technology. The applications considered through this parameter include the broad categories of academics, urban development and historic preservation. Academic applications are addressed through the subcategories of general education, research and interpretation, as well as through the heritage tourism field. While tourism and interpretation arguably have educational purposes, as considered in this thesis, education is more narrowly defined by primary and secondary schooling. The urban planning application correlates with city development, design review boards, and planning and zoning commissions. This application addresses the relationship between new and existing construction. Preservation focuses on the mission of documenting and protecting historic structures, and recording their contextual environment. Conservation, as addressed in this thesis, is the long-term preservation of historic building fabric and materials. This application is defined by the analysis and assessment of material condition, monitoring of deterioration and the implementation of conservation treatment. Reconstruction is the applicability to recreate a non-surviving building or environment with new materials. Tracking or documenting evolution discusses the applicability of the technology to record how a structure or area of structures has evolved through alterations, additions or demolitions.

Like was seen with their audiences, the laser scanning and photogrammetry technologies are aligned in terms of their most applicable purposes. Both technologies have time capsule-like characteristics that limit their use for heritage tourism, research or architectural interpretation. However, the products of these technologies gain value as a record of the past and may be a valuable investment for future tourism and academic applications. In contrast, the multimedia GIS technique is the ideal and most preferred technology to implement for educational, interpretation or broad, academic purposes. The interactive component of this product, an element not present with the laser scanning and photogrammetry deliverables, renders this technology highly appropriate for scholastic and informative objectives. Although not the most effective application for either the laser scanning or photogrammetry products, both technologies could be used for educational purposes, though this would likely be limited to architecturally related studies. A similar argument could be made for three-dimensional modeling. If used for scholastic functions, three-dimensional modeling would be most appropriate for studies of the built environment or civic planning.

Three-dimensional modeling is most suitable for urban design and city planning applications. Of the four technologies evaluated, three-dimensional modeling generates the strongest massing visual. The modeling platform can powerfully represent the height, scale and mass of an area, an objective that cannot be achieved with the other documentation techniques. However, it is possible to utilize laser scanning and photogrammetry products for urban planning and design as well. The deliverables from these technologies do provide a sense of structural scale and height; however, this is a less effective application as the primary visuals are achieved through rectified images and street level viewpoints, rather than isometric or aerial perspectives. Additionally, neither of these technologies captures roof forms and therefore cannot provide a comprehensive massing study. While the multimedia GIS technology documents height, scale and mass seen in photographs, the images do not display the relationship of the structures to each other or allow for an accurate read of dimension, therefore proving ineffectual for city planning initiatives. The use of multimedia GIS, laser scanning or photogrammetry for the generation of massing models or urban planning objectives has limited application.

Both laser scanning and photogrammetry are highly successful in documenting and digitally preserving architectural heritage. With these technologies, both the historic structure and its relationship to the surrounding built environment are preserved. Laser scanning is more likely to be employed for conservation purposes due to the product's high level of detail and resolution. These characteristics allow for conservators to track material changes or deterioration in the documented structures. The photogrammetry product is less suitable for material conservation objectives due to its deficiency of detail and texture. The three-dimensional modeling deliverable lacked surface texture altogether, and is therefore impractical for conservation applications. Since the multimedia GIS product is not restricted to architectural documentation and incorporates historical narratives, the technology is not preferred for conservation and reconstruction applications.[331] The multimedia GIS technique is better suited to chronicle big picture evolutions, not a material conservation level minutia. In contrast, the team at CyArk – a nonprofit organization documenting cultural heritage sites through laser scanning – argues that the high level of detail and accuracy obtained through the scanning technique can produce a rebuilding guide and foster architectural reconstruction if necessary.[332] Photogrammetry and three-dimensional modeling do not have this level of detail, resolution or accuracy. Photogrammetry though, has potential as a means of documenting architectural evolution. Architectural evolution is the change or transition of architectural styles, elements, buildings or materials over time. Documenting this progression records broad urban development, architectural alterations or additions made to specific buildings, or the deterioration and loss of materiality and

[331] The multimedia GIS technique would be unsuccessful for this reconstruction application since the product generated lacks measurable data.

[332] Brinker Ferguson, CyArk's Laser Scan of New Orleans, Phone, November 13, 2015; "CyArk," accessed September 11, 2015, http://www.cyark.org/; John Ristevski, Anthony Fassero, and John Loomis, "Historic Preservation through Hi-Def Documentation," *CyArk*, February 7, 2007, http://cyark.org.

historic fabric. The technique is relatively quick and cost-efficient, characteristics that enable cities to undertake architectural documentation campaigns more frequently. Through the integration of historic and contemporary images, the multimedia GIS technique can also be employed to document and portray architectural evolution.[333]

Ability to Record Urban and Architectural Features

	LASER	PHOTO	GIS	MODELING
SOLID VS. VOID	Black	Medium Grey	Light Grey	Black
HEIGHT, SCALE, MASS	Medium Grey	Medium Grey	Medium Grey	Black
ROOF FORM	Light Grey	Light Grey	Black	Black
FENESTRATIONS	Black	Black	Black	Light Grey
SURFACE TEXTURE	Black	Medium Grey	Medium Grey	Light Grey

Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking

Table 6.3 *- Ability to Record Urban and Architectural Features.*
The table above communicates the ability for the digital documentation technologies to record urban and architectural features.

By addressing a series of subcategories –large-scale and detail elements – the

[333] The multimedia GIS technology is the only digital documentation technique that is successfully able to record and visualize changes to the structures documented. This visualization is achieved through the integration of a series of historic images combined with contemporary photographs. By including historic data dating from several decades, users are able to depict and understand changes that have occurred to the structures. These changes encompass both alterations in materiality, as well as structural additions and deterioration. In contrast to this technique, the ability to visualize changes is absent from the documentation generated with the laser scanning, photogrammetry and three-dimensional modeling technologies. Documentation achieved through laser scanning and photogrammetry renders an image of the structures at a specific point in time. This methodology does not allow for a visual comparison of the structures at different times. Arguably, to be able to visualize changes, the laser scanning and photogrammetry documentation campaigns would have be to undertaken at frequent intervals. Using these two technologies to document the structures every five or ten years would provide the opportunity to visualize changes that had occurred to the buildings. Recording through a three-dimensional modeling technology requires a similar undertaking. Currently, the platform renders the massing of the structures at a specific point in time – when the data was initially collected. Recreating or updating the model to record additions, new construction or demolition – with the objective of fostering the ability to visualize changes – would be a nonsensical campaign.

technologies were analyzed for their ability to record urban and architectural features. The subcategories used to evaluate this parameter are: solid versus void; height, scale and mass; roof form; fenestration; and display of surface texture. The images below, captured from the trials of the four digital documentation techniques help to demonstrate each technology's ability or inability to record urban and architectural features. These images visually describe the subsections used to evaluate this analytical parameter.

Figure 6.1 - *Laser Scanning.*
This technology successfully records areas of solid versus void, fenestration and surface texture. The technology adequately portrays the massing of the architecture.

Figure 6.2 - *Photogrammetry.*
The technology portrayed above is successful depicting fenestration, however, only adequately records the relationship of solid to void, height, scale, mass, and surface texture. The technique is unsuccessful documenting roof forms.

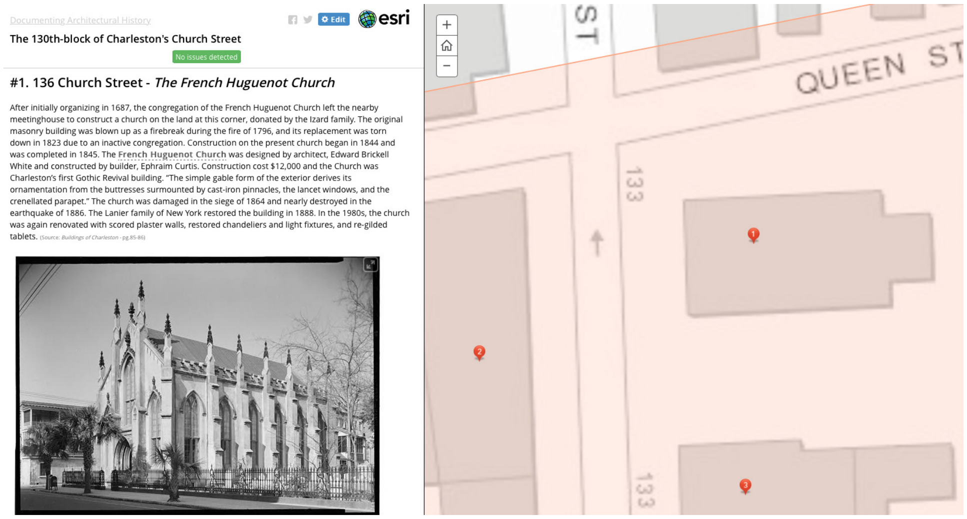

Figure 6.3 - *Multimedia GIS.*

This technology successfully records roof forms and fenestration, but due to the structure specific photographs, the technique does not effectively record areas of solid versus void. The technology adequately documents height, scale and mass, as well as surface texture.

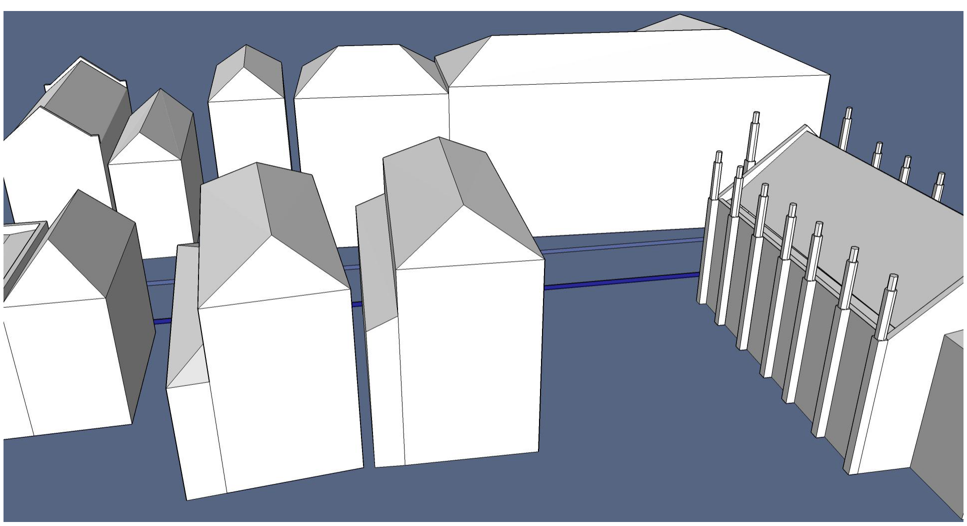

Figure 6.4 - *Three-Dimensional Modeling.*

Three-dimensional modeling effectively records areas of solid versus void, height, scale and mass, as well as roof forms. As seen above, the technique is unsuccessful recording fenestration and surface texture.

The ability to record solid versus void, or areas where structural massing is present in contrast to architectural cavities such as alleys, driveways and natural features like gardens and yards is highly successful through the laser scanning and three-dimensional modeling techniques. With these two technologies, the difference between structures and voids is clearly evident. The laser scanning and three-dimensional modeling techniques are able to effectively communication the relationship of solid features to void features without sacrificing resolution. Additionally, laser scanning is able to capture complex geometry in a large area of coverage. Photogrammetry is marginally successful in this endeavor. Solid massing is sufficiently captured and rendered, however, the cavities between structures are areas of severe data loss. This results in a visual disconnect between the "solids".[334] This deficiency may be more or less problematic depending on if the buildings present a near continuous facade along the street, or if the architecture to be documented is bungalows set apart from the next structure by a large yard. The multimedia GIS technique does not display an expansive view of the structures and therefore cannot record the relationship between solid and void areas. More comprehensive street views may show patterns of solid and void massing from an oblique perspective.

Three-dimensional modeling is the most successful technique for recording height, scale and mass. This technology generates a massing model that provides a clear visual of the height, scale and mass of the structures relative to each other. Neither the laser scanning nor photogrammetry technology record the large-scale massing of the structures as adequately as three-dimensional modeling. These technologies rely too heavily on

[334] Through the photogrammetry documentation technique, areas between structures as well as large expanses of vegetation are interpreted as blank areas where data is not present. This results in visually isolated structures rather than a relationship between the street-fronting facades. In contrast, the laser scanning technique captures the sides of the structures and is able to render perspective views of the area that more effectively demonstrate the ratio of solid to void areas.

rectified images and street-level data to be able to generate an effectual massing model.[335] The multimedia GIS technology is able to record the height, scale and mass of the structures through historic and contemporary images incorporated into the published platform. While this method is not unsuccessful in recording architectural massing, it is not preferable being from oblique views and unmeasurable. The ability for the laser scanning, photogrammetry and multimedia GIS technologies to record height, scale and mass exists at a small degree, but is clearly secondary to the three-dimensional modeling technique.

The ability to record the roof forms of the structures is a significant shortcoming for several of the documentation technologies. With terrestrial photogrammetry, the technology is only able to capture data that is parallel to the front elevation of the building, the roof forms are limited to rectified images of the street-fronting elevations of the structures.[336] For structures with a front facing gable, the photogrammetry technology is able to represent the shape of the roof; however, data beyond the immediate front elevation is lost. The roof form is incomplete and does not extend the length of the structure. On structures with hipped or flat roofs, the rendered imagery stops at the upper portions of the structure's massing; data representing the hip shape is entirely absent. Roof dormers appear to float above the building, not connected to any portion of the roof form. While still not an adequate representation, the laser scanning technology is able to record the

[335] Laser scanning and photogrammetry document the height of the structures which visually provides a relative scale of the buildings to each other; however, this interpretation is facilitated only through the street facing facades. The length of the buildings is not recorded and therefore the technologies do not generate a comprehensive sense of massing and scale.

[336] Capturing the roof form through photogrammetry is possible, however, this requires an additional means of data collection off of the ground. This endeavor would presumably be achieved by using a tall tripod or attaching a small camera to a UAV (Unmanned Aerial Vehicle) or drone. The use of drones for the documentation of existing structures and material analysis objectives is becoming more popular within the United States's preservation field.

roof forms more effectively than the photogrammetry technique.[337] Structures situated on corner lots possess a greater amount of roof form data, presenting a more intact view of the roof. Similarly, structures not directly adjacent to another building typically have a better rendered roof form, although the entirety of the shape is still not present. For both the photogrammetry and laser scanning techniques the difficulty recording roof forms is a result of data being captured at street level. Integrating aerial accumulated data may remedy this inadequacy.[338] By utilizing Google Earth and other aerial perspectives, the three-dimensional modeling technique successfully models roof forms. The roof shapes are clearly visible and highly informative in the generated aerial perspectives views. With this technology, both the overall roof shapes, as well as any details such as parapets are effectively recorded. The multimedia GIS technology is also successful in recording and depicting roof forms. This success is attributed to the ability to integrate a variety of photographs though the roof forms are not measureable and are depicted from oblique views. Of the four technologies analyzed, three-dimensional modeling best records and renders the roof forms and shapes of the structures.

The laser scanning, photogrammetry and multimedia GIS technologies are able to successfully record building fenestration, or the arrangement of the openings in the surface of the structure's front facade. These three technologies document the fenestration with photorealistic quality. Additionally, the location and size of the openings are accurately represented. However, with the multimedia GIS technique, this accuracy is dependent on the quality of the photographs and the point of view from which they were captured.[339]

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[337] Recording roof forms through the laser scanning technology develops characteristics similar those seen in the photogrammetry campaign. However, since laser scanning does not rely on rectified images, the technology is able to capture slightly more data than is rendered with photogrammetry. Specifically, the laser scanning technology is able to capture roof shapes located at a further distance from the scanner.

[338] For laser scanning, this would entail capturing scans from adjacent roofs, as the scanner needs a platform base for data capture and UAV cannot be used, as is suggested with photogrammetry.

[339] This capacity is true of the multimedia GIS technology for most of the parameters addressed through this analysis.

Photographs incorporated into the multimedia GIS platform may have been captured at an oblique perspective and may not accurately depict the location and size of the building's fenestration. In contrast, with the three-dimensional modeling technique fenestration was not recorded at all.[340] This is not an inherent shortcoming of the technology; with increased time and labor, structural openings can be modeled with the three-dimensional modeling technique. Cities wishing to undertake the endeavor of accurately modeling fenestration need to determine a different method for data accumulation. To model the fenestration requires access to the property to measure the size and location of the doors and windows, as well as porch openings. Recording fenestration with the three-dimensional modeling technology does not require additional technical expertise; rather, the inclusion of fenestration merely elongates the documentation and modeling process. An argument can be made that a visual representation of the fenestration is not necessary if the primary objective of the documentation campaign is to create a massing model. The technology produces an effective depiction of the height, scale and mass of the structures without modeling the location and size of window and door openings.

The ability for the technologies to record surface texture is tied to their capacity to produce photorealistic deliverables. The surface texture of the structures is most successfully recorded through the laser scanning and multimedia GIS technologies. Laser scanning generates relatively photorealistic renderings. The various materials on the structures are easily discernable and feature a high level of detail. Similarly, the photographs incorporated into the multimedia GIS platform can effectively document the surface texture of the recorded structures if photographs are captured with adequate

[340] It was previously determined that for the purpose of this thesis and the trial, fenestration would not be modeled through the SketchUp platform, but rather the trial would focus on generating a massing model of the unit of analysis. The incorporation of fenestration is possible with all three-dimensional modeling platforms. However, including these architectural elements in this thesis would have caused the trial to extend beyond the ten hour limitation.

resolution or up-close, material specific photographs are captured. Conceivably, the laser scanning technique is more successful than the multimedia GIS technique for recording surface texture, in that minimal resolution is lost when users enlarge the area to exam surface details. In contrast, the photographs integrated into the multimedia GIS platform may not possess the same degree of resolution depending on the quality of the camera used for data capture. To a lesser degree, photogrammetry does record surface texture. The various materials are distinguishable; however, the surface materials recorded through photogrammetry possess significantly less detail and clarity compared to those recorded through laser scanning. Materials with a high level of texture and discernable horizontal and vertical lines, such as brick and clapboard siding, are more effectively rendered, than the areas of stucco and plaster work. In stark contrast to laser scanning's ability to record surface texture is the three-dimensional modeling technology. With this technique, the structures are devoid of texture and present smooth, flat planes. Like fenestration patterns, the modeling platforms have the capacity to depict materials for the faces of structures.[341] These materials typically have both a color and optical texture, and are applied as bump maps.[342] Employing this methodology provides a sense of material texture for the three-dimensional modeling technique, however, it does not accurately depict the texture, but instead relies on a generic material, like a stock brick.

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[341] For the purpose of this thesis and the trial, it was previously determined that surface texture and materials would not be modeled through the SketchUp platform, but rather the trial would focus on height, scale and mass. However, the incorporation of materials is possible with all three-dimensional modeling platforms, but including this component in this thesis would have caused the trial to extend beyond the ten hour limitation.

[342] To imitate surface material, rectified photographs can be "mapped" as surface textures to the models. Bump mapping is a computer graphics technique for simulating textures and ridges on the rendered surface of an object. This technique makes a rendering appear more realistic by simulating small displacements on the surface. Typically, to apply a material to the surface of a modeled structure, a digital photograph of the actual material is converted to a bump map graphic. This bump map is then "applied" or pasted onto the structure's mass.

Degree of Refinement

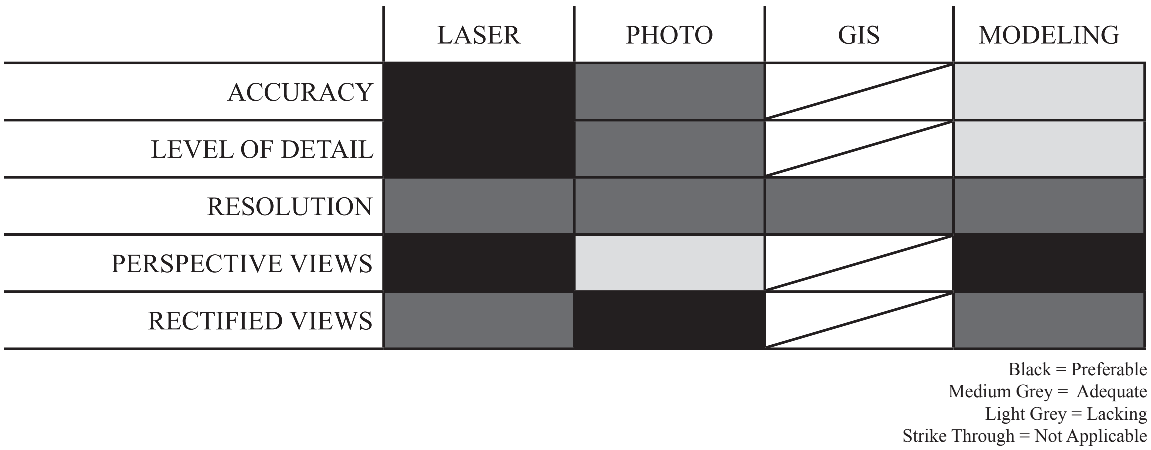

Table 6.4 *- Degree of Refinement.*
The table above communicates the degree of refinement achieved by each digital documentation technology.

The parameters of accuracy, level of detail, resolution, capacity to generate perspective views and ability to generate rectified views help to determine the degree of refinement for each of the technologies. Laser scanning is the most successful in the majority of the categories, while a level of refinement is not generally relevant to the multimedia GIS technique. Photogrammetry and three-dimensional modeling have a moderate degree of refinement, although specific parameters foster greater success than others. The laser scanning technology generates a product with the utmost level of accuracy. With this documentation method, the structures are documented to an accuracy of two millimeters and the operator can take precise measurements within the processing platform. The high level of accuracy achievable through this technology makes laser scanning an appropriate technique for reconstruction objectives. In contrast, the three-dimensional modeling technology is the most inaccurate and unreliable deliverable. The technology relies on prior data for measuring building footprints that is not necessarily correctly scaled.[343] However, the building footprint of the structures is more accurate than the roof height and roof pitch.[344] Data to model the roof forms is unobtainable from the public right-of-way. Fieldwork teams would either need permission to access private property, or will have to rely on rectified photographs and aerial perspectives to model the approximate height and angle of the roof forms. If the intended objective of the three-dimensional modeling technique is to generate a massing model for planning purposes, then modeling accurate roof forms is not a priority of this documentation technology. Visual modeling will sufficiently provide a truthful depiction of the principal massing of the structures documented. If a high level of accuracy is a fundamental characteristic for a city undertaking architectural documentation, then three-dimensional modeling is not the best-suited technology.

In terms of level of accuracy, photogrammetry is less accurate than laser scanning, but significantly more accurate than three-dimensional modeling. The photogrammetry technique relies on rectified photographs for rendering and measurement. With photogrammetry, accuracy is determined by the resolution of the photographs taken; a higher resolution results in a higher accuracy, because the pixels in the images can be more precisely located by the processing platform. The angles between the photographs, as well

[343] For this thesis, the model was constructed from Charleston's GIS data. However, it was realized that this data was not accurate, nor was it scaled correctly. Additionally, the length of the front facades of the buildings, when measured from the GIS data did not match the reference measurements taken on site. Since the intention of the trial was to create a massing model, not a precisely rendered depiction of the unit of analysis, the GIS data was still used as the modeling blueprint. With this data, the building footprints were at a level of accuracy between six inches and one foot.

[344] The fault in accuracy encountered with the three-dimensional modeling technology is primarily a result of restricted access onto private property. However, there are additional means from which more accurate dimensions for modeling can be collected. A highly accurate model can be generated if the ability to measure the perimeter of the structures is possible. Additionally, rather than relying on rectified photographs to provide vertical dimensions, an organization may employ a different method of gathering the vertical heights of the structures. Combining documentation techniques such as the three-dimensional modeling with laser scanning or total station technology would enabled a fieldwork team to attain an accurate height of the structures.

as pixel redundancy can help to increase photogrammetry accuracy.[345] Although the level of accuracy can fluctuate within the photogrammetry technology, it does not maintain a level of accuracy comparable to that of laser scanning. The photogrammetry technology has difficulty rendering and rectifying projecting elements such as sills, lintels and porches; this limitation may provide viewers with an inaccurate portrayal of the architecture. The multimedia GIS technique is unique because a level of accuracy cannot be determined within the platform. Conceptually, there can be low accuracy within the documents made accessible by the platform – the photographs, maps, prints – however, the level of detail is not determined by the GIS technology. Thus the level of accuracy is unscored in the "degree of refinement" matrix.

The level of detail rendered in the output of each technology corresponds with the level of accuracy depicted. Level of detail is defined by the resulting visual quality of the three-dimensional graphic. Photorealistic characteristics, pixel complexity and a finer representation of material texture exemplify a high level of detail. Level of accuracy is the degree of closeness of a measurement to the true value. With digital documentation, level of accuracy corresponds with how precisely the documentation represents the actual architectural heritage. The laser scanning technology produces the greatest level of detail; the technology cultivates photorealistic details and points that depict geometries in measureable ways with a quality incomparable to the other technologies. With laser scanning, surface textures and material characteristics are clearly legible and possess incredible detail. The level of detail is so extreme that impurities in bricks can be individually distinguishable.

[345] W. Boehler and A. Marbs, "3D Scanning and Photogrammetry for Heritage Recording: A Comparison" (12th International Conference on Geoinformatics, University of Gavle, Sweden: Geoinformatics, 2004); Jason Church, "A Comparative Study Using LiDAR Digital Scanning and Photogrammetry" (Lecture, 3D Digital Documentation Summit, Presidio, San Francisco, CA, July 10, 2012), https://ncptt.nps.gov/blog/a-comparative-study-using-lidar-digital-scanning-and-photogrammetry/; G. Forlani, R. Roncella, and C. Nardinocchi, "Where Is Photogrammetry Heading To? State-of-Art and Trends." (Geodesy and Geomatics, Accademic Nazionale dei Lincei in Rome: DICATeA, 2014); "Agisoft PhotoScan," *Agisoft*, accessed November 30, 2015, http://www.agisoft.com.

In this thesis, the photogrammetry technology produced a deliverable with less detail than laser scanning; however, this finding is contingent on data input – a more sophisticated camera could produce a highly detailed product. The surface texture and materials of the structures' facades are still apparent, as are architectural details such as ironwork and stone carvings, however, the details are not as crisp and defined. The photogrammetric model lacks the clarity, definition and photorealistic qualities attained through laser scanning. In contrast to the vibrant detail seen in the laser scanning product and the median level of detail experienced in the photogrammetric model, the three-dimensional model lacks detail entirely. The technology generates a product entirely reliant on massing for interpretation.[346] Similar to the parameter of accuracy, the multimedia GIS technique is unique because a level of detail cannot be determined with the technology. For the multimedia GIS technology, level of detail is dependent on the archival materials integrated with the platform. High quality contemporary photographs may furnish a greater level of detail to better render the architectural features of the structures. This factor is less contingent on the GIS platform and more a result of the input data. For the multimedia GIS technique, level of detail is dependent on the city's choice of documents and images to include.

The quality of resolution generated by each technology is approximately the same. None of the technologies render products with a high amount of resolution, nor do any of the technologies result in exceedingly low levels of resolution. Areas within the laser scan product, in close proximity to the scanner, have a higher resolution and more detailed data. However, large-scale perspectives and rectified images only appear to be of medium resolution. The photogrammetric model is comparable to a mid-distance scan resolution.

[346] For the purposes of this trial, material texture and architectural details were not considered for the documentation procedure, therefore a definition for the level of detail is unobtainable. Similar to the previous discussion of the technology's ability to record surface texture, with additional time and labor, material detail could be included in the three-dimensional model. However, the level of detail is basic and incomparable to what is achieved through the laser scanning technology.

The lack of material texture and details in the three-dimensional model makes the degree of resolution difficult to define. Similar to the argument for accuracy, within the multimedia GIS platform resolution is defined by the input data. Some of the archival documents depict a lower quality of resolution, however this is not inherent to the technology, but determined by the documents uploaded to the database.[347]

For architectural heritage documentation, perspective and rectified renderings communicate information more pertinent to preservation objectives than compared to isometric or aerial perspectives. As a result of its data collection methodology, laser scanning produces highly successful street-level perspective renderings. These images present users with views similar to what would be experienced in person. The laser scanning technology can also produce aerial or isometric perspectives. However, these renderings are less effective as many of the roof components lack geometry.[348] The three-dimensional modeling technology can also produce highly effective perspectives and rectified elevations of the architecture. In contrast to the terrestrial laser scanning process, the three-dimensional modeling technique is capable of producing strong aerial perspectives and isometric views. This characteristic makes three-dimensional modeling an effective documentation technology for city planning.

On the contrary, the photogrammetry technology – when used for architectural façade documentation – does not produce effective perspective views of the structures. The methodology creates rectified views, perpendicular to the structures' facades.[349] Although the photogrammetry technology is not successful in creating perspective views of the

[347] The multimedia GIS technology cannot achieve a high degree of resolution, because the graphics loaded into the platform are down-sampled by the site.

[348] This shortcoming is a result of the street-level position on the scanner.

[349] This is a result of the methodology employed. Conceivably, if a fieldwork team documented a singular structure from all four elevations, three-dimensional perspective views could be produced. However, in the case of large-scale architectural heritage documentation, the photogrammetry technique is most recognized for its ability to produce ortho-rectified elevations.

rendered data, the rectified images created by the technology are highly effective. Of the four technologies analyzed, photogrammetry generates the strongest rectified views of the architecture. Producing rectified views through the laser scanning technology is possible, however, the rectified images possess significantly less data. The quality of the deliverable in terms of resolution and level of detail is degraded compared to the perspective views produced through the laser scanning platform and the rectified images generated within the photogrammetry platform. It is not possible to analyze the success of perspectival or rectified views generated through the multimedia GIS technology. This technology does not produce perspective viewpoints, but rather photographs taken from various perspectives are loaded into the platform's database.

Technical Expertise Required

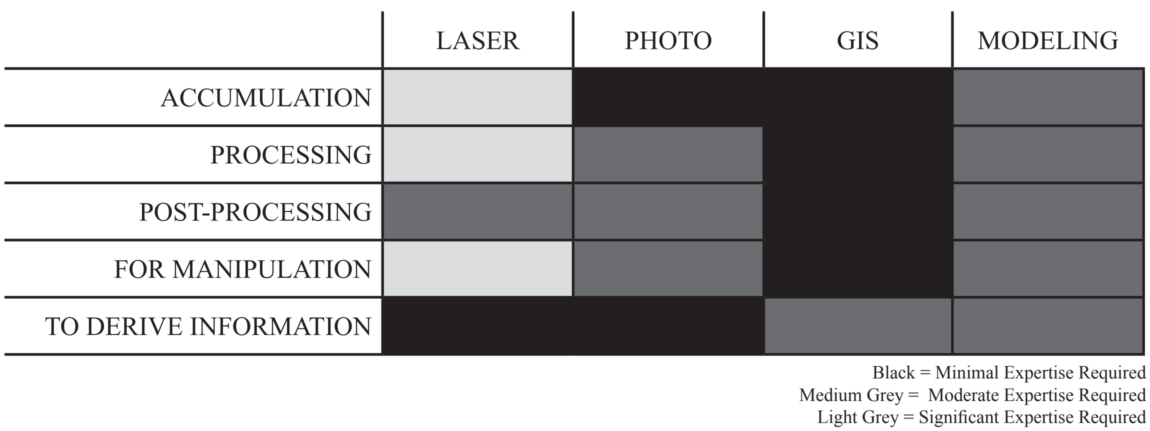

Table 6.5 *- Technical Expertise Required.*
The table above communicates the level of technical expertise required for the digital documentation technologies.

Required technical expertise is analyzed through the stages of data accumulation, data processing and data post-processing, as well as the technical expertise required for the operator to manipulate data after processing. In addition, this parameter evaluates the technical expertise required for the end-user or audience to derive information from the published deliverable. The technical expertise required for the initial collection of data varies significantly among the four technologies. The multimedia GIS and photogrammetry technologies are the most simple in terms of data accumulation; these two technologies require low technical expertise for the initial fieldwork stages. With photogrammetry, minimal prior knowledge of the technique, equipment and processing platform are necessary. The fieldwork team should be familiar with a digital camera and have some knowledge regarding the aperture, ISO and shutter speed settings. Familiarity with camera operation results in more consistent images.[350] The initial data accumulation phase for the multimedia GIS technology requires less technical expertise than the photogrammetry technique. Expertise is actually not required at all, although familiarity with local and online archives and their collections is helpful.

Data accumulation for three-dimensional modeling requires marginal expertise. Knowledge is required to generate the building footprints for the processing stage of the technique.[351] This proficiency may pertain to the Autodesk AutoCAD platform – as experienced with this thesis – or it may involve familiarity with onsite measuring techniques. Neither of these options require a significant degree of expertise, but rather a familiarity with basic architectural documentation practices. Laser scanning, by far, requires the highest level of technical expertise for the data accumulation phase. Previous knowledge of the equipment and the documentation methodology is necessary.[352] An understanding

[350] Prior to the start of the fieldwork, it is recommended that a small amount of time is spent researching preferred methods for data capture, as well as ideal camera positions and settings. This inquiry will ensure that the time spent on site for data accumulation proceeds smoothly and furnishes successful photographs for the processing phase.

[351] For this thesis, familiarity with the Autodesk AutoCAD platform was necessary to accurately scale the converted GIS document. However, should a city choose to develop a more accurate model by measuring the building footprints of the structures to be modeled, then familiarity with standard measuring tools and documentation strategies would be necessary.

[352] For this thesis, Amy Elizabeth Uebel of the Clemson University Warren Lasch Conservation Center was on site to guide the documentation process; Uebel's knowledge of the FARO Focus scanner and past experience with laser scanning was an invaluable help for the process.

of a laser scanner – how the equipment captures data, the settings available within the scanning platform and typical methodologies employed to capture the data – is necessary with this digital documentation technique. A user lacking experience with the laser scanner will have difficulty adjusting the parameters of the equipment for a successful scan. This prerequisite makes the data accumulation phase of laser scanning significantly less feasible and appealing for inexperienced users. However, once the parameters are established within the scanner's software, the process becomes significantly more simplistic and manageable, requiring less technical expertise.[353]

Expertise required for the processing phase of each of the documentation technologies is very similar to the knowledge required for the accumulation stage. Of the four documentation technologies, the multimedia GIS technology involves the least amount of technical proficiency for the processing of the data. The processing software is arguably created for a wider audience of varying levels of competency. Although the technology is easier for operators familiar with basic computer programs or website development platforms, the processing phase can be directed with simple tutorials. The GIS platform provides a simple database with preloaded templates for the upload of archival documents. With this platform, it is easy to move and manipulate the position of the data within the project. The tools used to upload and arrange data are simplistic and self-explanatory. The system prompts the operator for the next step, making the processing phase streamlined.[354] For the multimedia GIS technology, computer experience is necessary, however the technology does not require more specialized computer proficiency.

Both the photogrammetry and the three-dimensional modeling technologies require knowledge of the processing software; however, this familiarity is easily achieved

[353] Most manufacturers train users if you purchase their laser scan equipment.

[354] This is true for the ArcGIS Online web mapping application. Use of ArcGIS for Desktops or the Arches inventory platform may require additional technical expertise and program coding.

through literature and online tutorials. Once the operator has a base understanding of the platform, the data becomes significantly easier to manipulate. The photogrammetry processing phase is impossible without prior experience or textual guidance explaining the methodical, step-by-step process of data input and refinement.[355] An exhaustive manual of the software platform is not needed; the operator simply needs to understand the basic order of the processing steps to be initiated. By electing to retain the software's default settings, minimal technical expertise is necessary; however, this generates a generic photogrammetric model. Additional understanding of the technology would be required to accurately and successfully adjust the settings and parameters of the platform to create a more thorough rendering. In general, the processing phase for the photogrammetry is principally passive time with expertise only required for an understanding of the order of workflow commands to be initiated.

The processing phase associated with the three-dimensional modeling technology involves a level of expertise similar to that experienced with the photogrammetry technology. The immense amount of active time required for the processing phase of the three-dimensional technology lends the impression that the technique requires a greater level of expertise; however the platform is user-friendly. The platform involves basic commands for creating geometry at any level of detail. With an intermediate level of technical expertise, operators can generate generic massing models. However, greater technical expertise could take the project to a more refined and detailed stage with realistic renderings. Conceivably, with three-dimensional modeling – and this is the only case of the four technologies analyzed – the level of expertise required for processing data would be determined by the objective of the organization undertaking the documentation campaign.

Processing laser scan data requires a high level of expertise and familiarity with

[355] For this trial, a condensed user's manual was followed verbatim as a reference for the processing commands to be initiated.

the processing software. This phase is similar to the processing of photogrammetric data in that a methodological progression is necessary. However, processing within the laser scanning software is more complex and sophisticated than that of photogrammetry and requires a significant amount of active time. The laser scanning processing platform is not self-explanatory nor does the software provide prompts for the data processing. Knowing the appropriate sequence for the processing steps is necessary; the technology is too intricate and complicated to understand by following a user manual. In contrast to the photogrammetry technology, it does not appear that the laser scanning technology responds well to default settings. Undoubtedly, a training course providing insight into the software and processing phase would foster more successful renderings. A significant level of experience with the technology would prove more helpful than textual instructions. Most likely, processing data produced through the laser scanning technology would be a specialized position within a larger firm.

Compared to the data accumulation and data processing phases, significantly less technical expertise is required for the post-processing and publishing of the rendered data for all four technologies. The multimedia GIS technique involves the least amount of expertise to make the platform publicly available.[356] The laser scanning, photogrammetry and three-dimensional modeling technologies necessitate a moderate level of technical expertise for post-processing. Post-processing within these technologies is comparable as the operator manipulates the viewport and perspectives within the platforms to generate desirable images. With these three technologies, perspectives can be taken from a variety of positions, however, the physical data is never manipulated or altered. Therefore, less technical expertise is required for this stage than was required during the accumulation

[356] For this thesis, using the ArcGIS Online mapping platform, the project was saved and shared with users through a uniform resource locator (URL) link. The link could be embedded in a website or shared through a document or email.

and processing phases. If desired, the operator can achieve further post-processing by exporting the model to a secondary, external platform.[357]

The technical expertise necessary to manipulate the data within each technology after post-processing is directly correlated to the proficiency required during the processing stages. To alter the data after initial post-processing, the laser scanning technology requires high technical expertise. Just as much proficiency is necessary to return to the platform to manipulate – crop, edit and refine – the data, than what was required during processing. For laser scanning, data manipulation involves familiarity with the program. With the photogrammetry technology, a sufficient level of proficiency with the processing platform, the degree required for initial processing, is necessary for further refinement of the rectified images. In this case, manipulating the data is primarily confined to removing unwanted pixels. Manipulating the three-dimensional model after post-processing provides the opportunity for the operator to add or remove additional geometry. This requires a moderate level of technical expertise, as the operator should be familiar with how the geometry is built within the processing platform. The multimedia GIS technology can be manipulated with a low level of technical expertise. With this technology it is an uncomplicated procedure to alter the layouts, imagery and text displayed through the multimedia GIS platform. Familiarity with the technology or other website building software may prove helpful, but is not necessary.

In addition to evaluating the technical expertise necessary to generate a digital documentation product, this parameter also evaluates the technical proficiency required for the user or audience to derive information from the published deliverable. The level of expertise required for users to find the architectural documentation informative significantly influences the engagement and effectiveness of the product. For preservation applications,

[357] This step would require greater technical expertise.

the laser scanning and photogrammetry technologies produce perspectival and rectified images of the documented architecture. With this deliverable, the information portrayed is both easily accessible and easily interpretable. The rendered data attracts a variety of audiences and is flexible in both its publication and application. The interpretation of the laser scanning and photogrammetry data requires minimal expertise to be informative. On the contrary, both the multimedia GIS and the three-dimensional modeling technologies and their respective deliverables are defined by an element of interaction. This characteristic results in a higher level of technical expertise needed on the part of the audience. Both technologies require the user to manipulate the platform in order to interact with the data and understand information presented about the documented architectural heritage. The multimedia GIS technology requires basic computer skills as the user engages with textual and graphic information presented in map-form. With the three-dimensional modeling technology, users are prompted to position themselves within the model, manipulating viewpoints to observe the documented structural massing.

Manageability

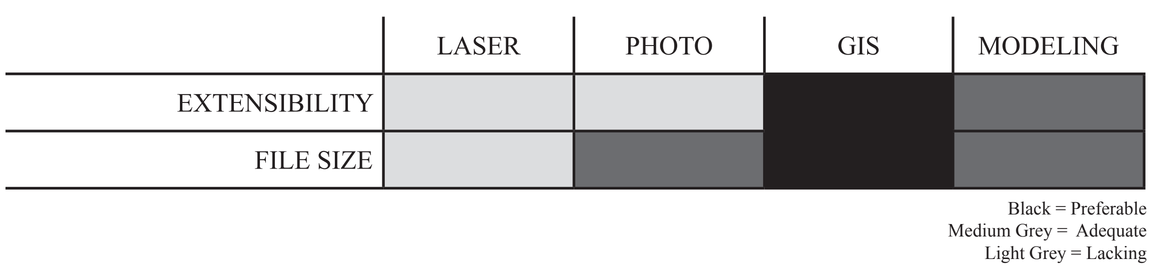

Table 6.6 *- Manageability.*
The table above communicates the degree of internal manageability for the digital documentation technologies.

The manageability of the digital documentation technologies is evaluated as the ability of the generated product to be extended, enlarged or added to, as well as the resulting file size of the deliverable. The file size produced from the documentation campaign may determine the feasibility for an organization to maintain and manage the product. This parameter is addressed more thoroughly in the section analyzing institutional capacity and the hardware requirements for each documentation technology. Extensibility, or the ability for the product generated to be extended and expanded through the addition of data, may be a necessary characteristic for some cities and especially with some funding sources where a phased approach may be necessary. Laser scanning has limited ability for management and is not a preferred technology if extensibility characteristics are desired. The rendered point cloud is typically exported for public viewing as a high-resolution graphic image. If an organization wanted to extend or expand a laser scan project, another scanning campaign would need to be initiated and the separate project point clouds combined. Manual registration of the two point clouds would be required to ensure an accurate alignment of the input data. Multiple project point clouds can be combined within the processing platform, however laser scanning does not allow for the addition of restricted areas of point cloud data or the addition of small features to existing models. Combining separate projects would allow an organization to expand the area of documented architecture, but this endeavor would be as labor intensive and expensive as the initial scanning effort.

Similar to the laser scanning technology, photogrammetry does not allow for simple extension and expansion of the photogrammetric model. Additional photographs can be captured – for example, the next block of architecture – and can be uploaded with the previously captured data to the processing platform. However, this approach restarts the processing phase and might have the added difficulty of needing to obtain the same lighting in the photographs or risk surfaces looking more different than they actually are based on the exposure of the photograph. The operator now must repeat the alignment, point cloud, mesh and texture generation workflow for the images. Two rendered photogrammetric models cannot be effortlessly combined.[358] It would be simpler to document all studied areas of architecture at one time. If the campaign expands, it would be preferable to maintain the documentation endeavors as separate models and if necessary, the rendered rectified images could be combined through a graphics-editing platform such as Adobe Photoshop.

Of the four techniques, the multimedia GIS technology and its generated platform are the most uncomplicated and least time consuming to expand. At any stage, archival documents or images, or sections for new structures or neighborhoods can be added to the product. This process is as simple as the initial processing phase. Publishing the revised data is also undemanding. This technology maintains the most success with extensibility; the multimedia GIS technology was created to be a living document and a continuously developed preservation platform. The ability to be boundlessly expanded is one of the documentation technique's most compelling characteristics.

The three-dimensional modeling technology requires further effort for manageability and expansion than the multimedia GIS technique. Yet, expanding the generated model is significantly less demanding than the laser scanning or photogrammetry technologies. With three-dimensional modeling, if data is added to the project the processing phase does not have to be initiated again. Additional structures can be modeled within the current workspace. Furthermore, the three-dimensional modeling technique provides the opportunity to append additional geometry onto existing modeled structures to present new additions. If the model was exported or published as perspectival scenes, the organization would need to recapture this data.[359]

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[358] The photogrammetry software must verify the accuracy of the alignment between the photographs. Verifying the alignment between the photographs removes the previously constructed mesh and textured models, placing the operator back at step one.

[359] This is not a time consuming or labor intensive process because the modeling platform saves previously referenced perspective positions.

The file size of the digital documentation deliverable is influenced by the amount of data input and the resolution of the data. Laser scanning typically produces a large file due to the immense number of individual data points captured during the accumulation phase. The file size is significantly increased once the project point cloud is created and overlaying photographs colorize the data. The large file size produced from the laser scan technology would be difficult for internal management and storage. Some large institutions with the capacity to support data of this size choose to outsource their data storage to companies such as Dropbox.[360] If an organization undertakes a laser scanning campaign it is likely not feasible, or preferable, for the rendered data to be maintained in-house. In contrast, the multimedia GIS project is not internally managed and therefore equates a low and preferable file size. The generated deliverable is accessed and saved through ArcGIS's online storage facility. The platform is a cloud-base service where each subscribed organization has an allocated space for saved content and projects. This ensures that the data from the documentation campaign does not occupy storage on the organization's internal workstations.

The file size generated from both photogrammetry and three-dimensional modeling is generally considered to be in the intermediate range. With both of these technologies, the file size is dependent on the amount of data input. A photogrammetry product is not as large as a laser scan product because the technology relies on photographs rather than individual points for data. Ultimately, the size of the file is dependent on the number of photographs included in the model and the parameters chosen during the processing stage. It is likely that the photogrammetric model could be internally managed contingent on the size of the area documented and the scale of the project. The three-dimensional modeling technology is closely aligned to the photogrammetry technology in terms of file size. The

[360] Amy Elizabeth Uebel, Thesis Methodology Questions, Email, October 26, 2015.

size of the three-dimensional model is dependent on the amount of geometry present in the model. Additionally, the incorporation of material texture or base imagery increases the size of the file. File size was greatest for laser scanning with a final working model size of 1428.52 megabytes. The photogrammetry file is substantially smaller at 313.484 megabytes. The SketchUp model descends another considerable step as the final three-dimensional model was 1.2 megabytes. The multimedia GIS platform is the smallest file thus far, at 1 kilobyte or 0.001 megabytes.

Labor Intensity

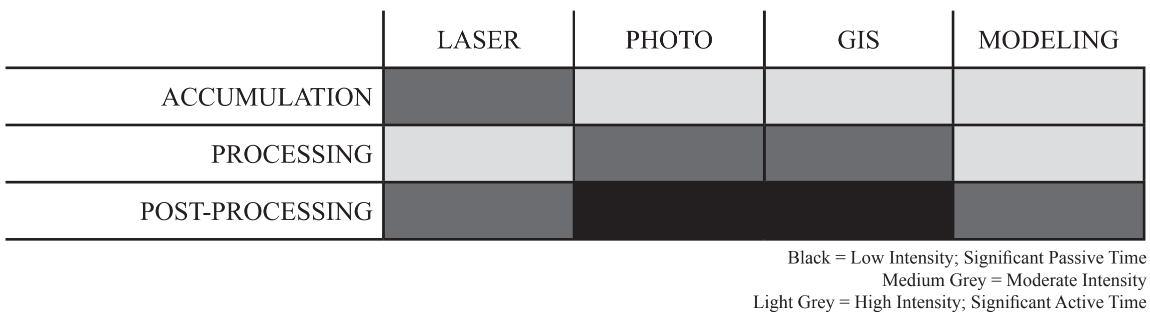

Table 6.7 *- Labor Intensity.*
The table above communicates the level of labor intensity, as well as the relative passive and active time for the digital documentation technologies.

For the trial investigation, a time limitation of ten hours was established for each of the four digital documentation technologies. This ensured that a parallel comparison for the labor intensity of each technique could be possible. This limitation was primarily established for the multimedia GIS technique; this documentation technology can be an ongoing preservation endeavor, and data accumulation alone can take infinite time as more and more historic documents and related content is discovered in research mode. For analytical purposes, the labor intensity is evaluated as the relative percentage of active versus passive time, and the ratio of time spent on the three phases – accumulation, processing and post-processing.[361] Data accumulation for the laser scanning technology transitioned between active and passive time resulting in a moderate level of labor intensity.[362] Active time involves minimal labor as much of the fieldwork stage is spent positioning the scanner. This phase results in a significant amount of passive time while the scanner automatically collected data. Approximately one-fifth of the laser scanning trial was spent collecting the raw data.[363] The data accumulation phases for the photogrammetry, multimedia GIS and three-dimensional modeling technologies are all composed entirely of active time and result in higher labor intensity. Although characterized by active time, the photogrammetry technique typically entails efficient fieldwork. For the data accumulation phase, only one hour was spent capturing photographs for the trial. Approximately five hours were amassed collecting historic images, maps and documents for the multimedia GIS technique. One-fifth of the three-dimensional modeling trial was spent converting and scaling the base plan, as well as gathering onsite reference measurements prior to modeling the structures.

The laser scanning and three-dimensional modeling technologies are the most labor intensive for the data processing phase. Both of these technologies require primarily active time to processing the data. Processing the data for the laser scanning technology involves registering the scans, creating point clouds, colorizing the data and editing the project point cloud. Approximately two-thirds of the laser scanning trial was spent processing

[361] The degree of labor intensity for each technology and phase is specific to this thesis and the ten-hour trials undertaken. However, the general comparison of active to passive time can be compared to documentation campaigns undertaken by cities. Passive time is correlated with a smaller level of labor intensity and active time is associated with greater labor intensity.

[362] Although the data accumulation phase of the laser scanning process has a medium ranking for labor intensity, this stage of the documentation process is relatively fast and involves a quick collection of X, Y and Z points to form the point cloud.

[363] Data accumulation began by systematically placing reference spheres along both the east and west sides of the trial block. With the reference spheres in position, the fieldwork team placed the laser scanner on a tripod and initial preparation for the scan began. After leveling the scanner to an acceptable position, identifiers and parameters within the FARO equipment were established. Following initial setup, labor was only required to systematically reposition the laser scanner along the trial block between scans and push the start button. To achieve ample overlap, the fieldwork team alternated the scanner between the west side and the east side of the trial block for a total of seven scans.

and refining the data. For the three-dimensional modeling technology, extracting the building footprints and modeling the massing of the documented structures constitutes the processing phase. This was a labor intensive phase that consumed nearly three-fourths of the allocated time for the trial. The processing phases for the three-dimensional modeling and laser scanning technologies differ significantly in the ratio of active to passive time involved in the photogrammetry and multimedia GIS technologies. The photogrammetry technology involves a set methodology of initiated commands and a large amount of passive time. In contrast, the three-dimensional modeling technology requires an immense allocation of active time from the operator. Processing the data for the photogrammetry and multimedia GIS technologies is less labor intensive than with the laser scanning and modeling techniques. For photogrammetry, one-half of the trial time was spent working within the processing platform to create a photogrammetric model. This time alternated between passive and active as the software automatically aligned and processed the images. Active time was required to edit and crop the data. Similarly, one-half of the multimedia GIS trial was consumed by the processing stage. This was both passive and active time. Time expended to upload the photographs and maps to the multimedia GIS platform was considered passive, while active time involved arranging the archival documents, base maps and textual information. The photogrammetry and multimedia GIS technologies have a moderate level of labor intensity.

Post-processing and publishing the documentation products is not labor intensive. It took less than one-half hour each to post-process the model produced from the photogrammetry technology and the interactive platform generated through the multimedia GIS technology. These procedures were the least labor demanding. For the photogrammetry technique, the operator simply saved rectified images of the photogrammetric model. The multimedia GIS platform proved simpler to publish, as the operator merely had to share a URL to the generated project. Post-processing the deliverables produced through the laser scanning and three-dimensional modeling technologies was slightly more labor concentrated, although neither of these methods were highly exhausting. Both technologies required the operator to manipulate the generated models to capture desired and effective perspectives of the documented structures. For each of these technologies, the operator spent just over one hour post-processing the data.

Institutional Capacity

	LASER	PHOTO	GIS	MODELING
COST	Light Grey	Medium Grey	Medium Grey	Black
EQUIPMENT ACCESS	Light Grey	Black	Black	Black
SOFTWARE ACCESS	Light Grey	Medium Grey	Medium Grey	Black
ACCESS TO TRAINING	Light Grey	Black	Medium Grey	Black
HARDWARE REQUIREMENTS	Light Grey	Black	Black	Black

Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking

Table 6.8 *- Institutional Capacity.*
The table above communicates the institutional capacity required for the digital documentation technologies.

The capacity, or feasibility for an institution or organization to undertake one of the digital documentation technologies internally is evaluated by analyzing the cost of the technology, availability of necessary equipment and software, computer hardware requirements for the processing and post-processing of the data and the extent of access to software and equipment training programs. Of the four technologies analyzed, laser scanning requires the greatest institutional capacity for successful documentation. The cost of employing laser scanning technology varies and is dependent on the quality of the equipment and software. Generally, laser scanning is not an economically feasible undertaking for many organizations. According to CyArk, a nonprofit recognized for their heritage scanning initiatives, the laser scanning equipment can cost between $15,000 and $300,000.[364] This number does not include the cost of the processing software, a component necessary to read, display and visualize the information. For perspective, the FARO Focus[3D] X 330 laser scanner costs nearly $60,000. FARO SCENE, the processing software specifically designed for use with FARO's large volume laser scanners costs approximately $15,000 for one software license.[365] Less expensive software options are available through companies such as Autodesk, however, many institutions chose to utilize the proprietary software of the scanning company. Due to the complexity of the technology, there is not an open-source option for the processing of scan data.

Access to laser scanning equipment is directly correlated to the cost of the technology. As a result of the high costs, access and availability of the equipment is difficult for small institutions and organizations. Many companies are deterred from employing the equipment due to both economics and expertise. While access to the scanner may be feasible, the technology requires a specialized position and an immense measure of training. However, there are companies that offer rentals of laser scanning equipment; this may be a more feasible option for cities.[366] There are a variety of point cloud processing software packages available for the laser scanning technology. These include both proprietary systems – those owned and developed for a specific company – and open source platforms. Examples of laser scanning software are: PolyWorks by InnovMetric; Cyclone, a proprietary software of Leica Geosystems; SCENE, the proprietary software of FARO; Trimble PointScape;

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[364] Ferguson, CyArk's Laser Scan of New Orleans.

[365] This excludes maintenance costs. "FARO Focus3D Overview," *FARO*, accessed October 20, 2015, http://www.faro.com/en-us/products/3d-surveying/faro-focus3d/overview; "SCENE, FARO's 3D Documentation Software," *FARO*, accessed October 20, 2015, http://www.faro.com/en-us/products/faro-software/scene/overview.

[366] Companies that advertise laser scanner rentals typically offer rental agreements for necessary accessories as well. In addition, these companies provide training if requested.

Autodesk ReCap; and Geomagic.[367] While still expensive, the processing platforms for laser scanning are available from a larger variety of sources. Access to the software is still limited due to its price and relative exclusivity to its brand name.

To undertake a photogrammetry documentation campaign requires a moderate level of capacity, funds and management on the part of the sponsoring organization. The photogrammetry technology provides a significantly more feasible option when compared directly to laser scanning technologies. The only required pieces of equipment necessary to create a photogrammetric model are a digital camera and a computer workstation. As the principal equipment, digital cameras are incredibly accessible and can be available at low costs. The price range of a digital camera varies significantly and is dependent on the brand, quality of the camera, functions of the camera, size of the camera, lens type and degree of resolution. Arguably though, a digital camera is likely a piece of equipment already owned by the institution sponsoring the heritage documentation campaign. The software required to process the photogrammetric data is not as accessible as the required equipment – a digital camera - but is considerably more available than the software necessary for laser scan processing. The price of photogrammetry software can range from free, an open-source option to nearly $10,000. Popular platforms include: Agisoft PhotoScan, which has a $200 educational license or a $3,500 professional license; Pix4D, available for $8,700; and Autodesk ReCap, offered for an annual fee of $500.[368] An additional option is Autodesk 123D Catch. This is a free, open-source processing application; however, the

[367] Naif Adel Haddad, "From Ground Surveying to 3D Laser Scanner: A Review of Techniques Used for Spatial Documentation of Historic Sites," *Journal of King Saud University - Engineering Sciences* 23, no. 2 (June 2011): 109–18, doi:10.1016/j.jksues.2011.03.001; Mostafa Ebrahi, "3D Laser Scanners: History, Applications, and Future" (Assiut University, October 2011).

[368] "Autodesk ReCap: Design in-Context with Accurate Dimensions," *Autodesk ReCap*, accessed October 21, 2015, https://recap.autodesk.com; "Pix4D, UAV Mapping Software," *Pix4D*, accessed October 22, 2015, https://pix4d.com/; "Agisoft PhotoScan."

results of the platform are less accurate and of observably lower quality.[369]

Similar to the photogrammetry technology, multimedia GIS technologies generally require a moderate level of capacity and funds on the part of the sponsoring institution. The multimedia GIS technology is unique because a specific piece of equipment is not necessary for data accumulation. Data accumulation is more reliant on the availability and accessibility of local archives and historic documents.[370] An organization undertaking multimedia GIS documentation would need access to a digital camera or scanner in order to create digitized versions of the archival documents. Additionally, the institution would need access to a computer to upload and publish the historic images and narratives. Both of these prerequisites are likely available at an organization documenting heritage. The most recognized platforms for creating a multimedia GIS documentation project are through ESRI and Arches. ESRI is an international supplier of GIS software. The Arches project was formed through collaboration between the Getty Conservation Institute and World Monuments Fund, and is an open source, web-based system that was purpose-built to inventory cultural heritage.[371] When compared to photogrammetry and three-dimensional modeling, there are less multimedia GIS processing platforms available, making the technology less accessible in terms of software access. However, although restricted in available platforms, the economics of the technology are feasible for cities. Arches is a free, open-source platform for multimedia GIS documentation.[372] ESRI products vary in price.

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[369] C. Santagati and L. Inzerillo, "123D Catch: Efficiency, Accuracy, Constraints and Limitations in Architectural Heritage Field," *International Journal of Heritage in the Digital Era* 2, no. 2 (2013): 263–89; "Autodesk 123D Catch | Generate 3D Model from Photos," *Autodesk 123D*, accessed February 6, 2016, http://www.123dapp.com/catch.

[370] The multimedia GIS technique may not be a strong application for newer cities without expansive archival records. A city or town lacking historic documents might only have contemporary photographs to display within the multimedia GIS platform and may encounter an issue of a lack of content. Charleston, South Carolina, and its expansive local archives is a best-case scenario for the multimedia GIS technique.

[371] "Arches Project," *The Getty Conservation Institute*, accessed September 12, 2015, http://www.getty.edu/conservation/our_projects/field_projects/arches/arches_overview.html.

[372] "What Is Arches?," *Arches*, accessed September 12, 2015, http://archesproject.org/what-is-arches/.

A subscription to ArcGIS Online costs between $2,500 and $17,500 per year depending on the number of users for the organization's subscription.[373] ArcGIS for Desktop includes a subscription to ArcGIS Online and ranges from $1,500 to $7,000 for a single license.[374]

The three-dimensional modeling technology provides cities with the most cost effective technique requiring the least institutional capacity. Three-dimensional modeling programs fluctuate in price from free to several thousand dollars depending on the proprietary brand. The equipment necessary for three-dimensional modeling is commonly accessible; GIS data displaying building footprints can be obtained from local planning departments. Additionally, organizations undertaking a three-dimensional modeling campaign may choose to collect data by physically measuring building footprints or by modeling from Google Earth perspectives. These options are easily accessible at a low cost. Software platforms for creating three-dimensional models are also widely accessible with some open-source options available. Popular platforms for modeling include Trimble SketchUp, Autodesk Revit, Autodesk 3ds Max and CityEngine by ESRI.[375] SketchUp offers two versions of their program; SketchUp Make is a free platform with basic modeling capabilities and SketchUp Professional is a more comprehensive version that costs approximately $700.[376] Autodesk Revit costs $500 per year, while its more elaborate counterpart, Autodesk 3ds Max costs $1,500 per year.[377] CityEngine costs between $500

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373 "Put Your Maps to Work," *ArcGIS*, accessed October 7, 2015, https://www.arcgis.com/features/.

374 "GIS Mapping Software, Solutions, Services, Map Apps, and Data," *ESRI*, accessed November 8, 2015, http://www.esri.com.

375 Moulay Larbi Chalal and Riccardo Balbo, "Framing Digital Tools and Techniques in Built Heritage 3D Modelling: The Problem of Level of Detail in a Simplified Environment," *The International Journal of the Constructed Environment* 4 (2014): 40–52; "3d Modeling & Rendering Software | 3ds Max | Autodesk," accessed February 6, 2016, http://www.autodesk.com/products/3ds-max/overview-dts; Surendra Pal Singh, Kamal Jain, and V. Ravibabu Mandla, "Image Based 3D City Modeling: Comparative Study," vol. XL– 5 (ISPRS Technical Commission V Symposium, Riva del Garda, Italy: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2014), 537–46.

376 "The Easiest Way to Draw in 3D," *SketchUp*, accessed September 23, 2015, www.sketchup.com.

377 "3d Modeling & Rendering Software | 3ds Max | Autodesk"; "Building Design Software | Revit Family | Autodesk," accessed February 6, 2016, http://www.autodesk.com/products/revit-family/overview.

and $4,000 depending on the license version.[378]

The hardware requirements and random-access memory (RAM), which is a unit for measuring computer processing capacity, necessary for an organization to internally generate one of the evaluated digital documentation techniques may significantly influence a city's choice to employ a specific recordation technology. Laser scanning technologies entail a major hard drive constraint. To process the scan data requires a significant amount of RAM that is not likely to be available at a standard workstation or laptop. For the trial, the processing phase for the laser scanning technology was completed on a computer with eight gigabytes of RAM. In contrast, the photogrammetry, multimedia GIS and three-dimensional modeling techniques were successful on a workstation with only four gigabytes of RAM. Although achievable with minimal hardware requirements, depending on the area of structures to be modeled and the data amassed, a stronger workstation may become necessary for the photogrammetry and three-dimensional modeling technologies. The multimedia GIS technique, however, is feasible with an even smaller amount of RAM. The documentation technique could likely be achieved with a portable tablet; the data is saved externally and the platform does not require high volume commands.

Access to training seminars, video tutorials or online resource forums can enhance an operator's level of technical expertise for a digital documentation technology. The amount of instruction available to operators and users is generally influenced by and correlated with the economics and complexities of the documentation equipment and software. Laser scanning technologies have the least accessible training. Limited training videos and webinars are available, however, these are specific to the manufacture's equipment product and software. The online tutorials are marginally informative; the technology is so advanced that physical demonstrations and interactions may prove more effective.

[378] "Esri CityEngine | 3D Modeling Software for Urban Environments," *ESRI*, accessed February 6, 2016, http://www.esri.com/software/cityengine.

Additionally, when compared to Adobe and Autodesk brands, there are insufficient publications instructing effective laser scanning methodology as the technology is still emerging.

Education and training for photogrammetry is both accessible and constructive. Resources available online include both a user manual and a condensed, step-by-step methodology for processing photogrammetric models. Published tutorials address both beginner and intermediate levels. User forums and online resources demonstrate optimal techniques for data accumulation, and are often accompanied by methodical videos modeling the steps to process the data. The multimedia GIS technology, and ESRI specifically, possess a considerable array of online resources. These instructive sources are categorized by forum topics including training for creating maps and GIS projects, sharing projects and performing analysis. Additionally, GIS organizations frequently sponsor training courses, and users can find video tutorials and lessons published online. The three-dimensional modeling technology is also accompanied by a significant amount of easily accessible and informative online forums, video tutorials and local training workshops. Three-dimensional modeling platform can typically be linked to extension warehouses, or secondary external sites that house supplementary open-source models and geometry. The extensive number of published books on three-dimensional modeling is a strong incentive for use of this technology. These publications address a variety of applications for the modeling technology.

Potential Obstacles and Areas of Failure

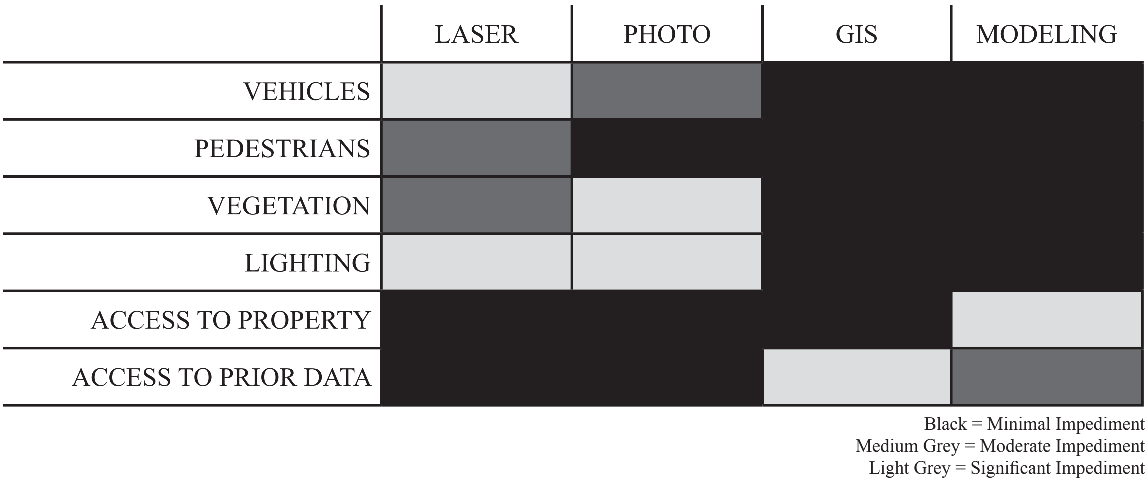


Table 6.9 *- Potential Obstacles and Areas of Failure.*
The table above communicates potential obstacles and areas of failure for the digital documentation technologies.

The potential to encounter specific obstacles or areas of failure during a digital documentation campaign is an inevitable occurrence for a city. This analysis looks at six specific challenges that were present during the investigative trials in Charleston, and would likely be present for other cities. Depending on the architecture to be documented, the topographic characteristics of the area and size of the city or town, these obstacles may or may not be present, or additional challenges not discussed may arise. The obstacles and potential areas of failure evaluated do not present an issue for every digital documentation technology. The method in which data is collected significantly influences how an obstacle affects a digital documentation campaign.

Of the four technologies analyzed, vehicles, both moving and parked, have the most negative effect on the laser scanning technology. Without closing a street to traffic, the presence of vehicles in the point cloud model is inevitable. Unlike photogrammetry where the operator controls the specific moment at which data is captured, it is impossible to modify the data capture rate for the laser scanner. Once the scan is initiated, point cloud data is automatically captured. Moving traffic poses less of an obstacle than vehicles that arrive and park as the scan is in progress. Vehicles traveling down the street appeared as areas of noise within the point cloud project; the operator is able to remove and crop this data. Vehicles arriving and parking in front of the structures became a greater obstacle because the vehicle is captured as both scan points and through the overlaid photographs used to colorize the point cloud.[379] It is simpler to remove vehicles captured as point data, than to remove images captured within the photographic data. Removing data in this form tends to leave larger voids in the point cloud. Vehicles parked in front of the structures for the entirety of the scan process can be left or cropped from the point cloud.[380]

With photogrammetry, vehicles are only a minor obstacle to the documentation technology. Since the operator controls the rate at which the data – the photographs – is captured, moving vehicles can be excluded. The fieldwork team has the opportunity to wait until vehicles pass the documentation area before continuing to collect data.[381] Parked vehicles pose a greater challenge to the documentation technology for both the data accumulation and data processing phases. Vehicles parked directly in front of the architecture being documented will be captured as well; this is an unavoidable obstacle unless the street were to be closed and cleared of vehicles. Cropping these vehicles from the rectified photogrammetric model is a complicated undertaking. Unlike the laser

[379] Vehicles in constant motion – traveling down the street in front of the structures – typically did not pose a significant obstacle to the scan data because they were not positioned in front of the scanner for an extended amount of time. Larger challenges occurred in the processing phase when the vehicles had arrived near the end of the scan process and were captured in the overlaid photographs, as well as the scan data. When the scanner captured a vehicle photographically, the object tended to be warped and the colorized data was stretched across the face of the street. Vehicles parking moved slower than the vehicles simply passing down the street, and their imagery was captured through a large area of the point cloud.

[380] Parked vehicles are less of an obstacle, because the complete vehicle is captured by the scanner. Since the vehicle is not moving, there is not noise present around the object. This is a more straightforward task of cropping the data from the rendering. Since noise is not present, the vehicle can also be left in the point cloud as part of the streetscape.

[381] Waiting for vehicles to pass the architecture to be documented may elongate the data accumulation phase; however, this is arguably an insignificant dilemma in order to achieve an uncluttered documentation deliverable.

scanning technology, photogrammetry has a more difficult time deciphering and isolating planes of data between the fieldwork team and the architecture being documented. Parked vehicles obscure the geometry directly behind them. Cropping these vehicles from the rectified image results in areas devoid of geometry or holes.[382] Vehicles parked on the side of the street from which the photographs are being taken present an additional challenge. Depending on the width of the street, it is likely that the fieldwork team will be required to stand on the sidewalk to capture the full height of the structures being documented. With this methodology, the upper portions of the cars directly in front of the operator may be captured in the data.[383] This issue could be remedied by taking the photographs while standing on a small step-ladder; additional height would position the operator above the parked vehicles.

Neither parked nor moving vehicles are an obstacle for the multimedia GIS and the three-dimensional modeling technologies. Data for the multimedia GIS technology evolves primarily from archival documents and historic photographs. If the sponsoring institution chooses to incorporate contemporary photographs, like the photogrammetry technology, the operator has the opportunity to photograph the structures from angles excluding vehicles. Since the building outlines are derived from previously acquired GIS data, vehicles do not present a challenge for the three-dimensional modeling technique. As with the proximity of vehicles, neither the presence of pedestrians nor vegetation generates an obstacle for the multimedia GIS or three-dimensional modeling technologies. However, pedestrians do present a minor challenge for the laser scanning technology. The presence of pedestrians

[382] To amend the holes seen on the façade of the architecture as a result of parked cars, photographic data could be captured at different angles and at positions closer to the structures. This data would need to be captured during the initial accumulation campaign, otherwise the model must be realigned and rebuilt within the processing software.

[383] Sedans and shorter vehicles do not present a significant obstacle. It is likely possible for the fieldwork team to position the camera above the tops of the vehicles as to ensure that they are not included within the captured data. Trucks, vans and larger SUV's may become a greater challenge during the data accumulate phase.

produces a trivial amount of noise in the point cloud; these areas are not as noticeable as the areas of noise produce by vehicular traffic. Pedestrians and curious onlookers captured by the scanner can be cropped from the point cloud during the processing phase. On rare occasions, the pedestrians are inaccurately documented through the photographic overlay; this may result in images of the pedestrians spread across the ground plane.[384] Pedestrians do not present an apparent challenge for the photogrammetry technology; the fieldwork team has the opportunity to wait until pedestrians pass the documentation area before continuing to collect data.

Areas of vegetation and tree coverage create a minor challenge for the laser scanning technology and a more significant obstruction for the photogrammetric model. Since the scan equipment is repositioned to several locations by the fieldwork team during data accumulation, the laser scanner is able to capture architectural features that may otherwise be blocked from view by areas of vegetation.[385] The point cloud data behind trees is not as complete or clear as the remainder of the scans, but these areas of the structures are still present and decipherable. Vegetation captured by the laser scanner is rendered as areas of noise. Arguably, these areas could be cropped from the point cloud. However their inclusion provides context to the rendering and is not a significant hindrance; the audience is still able to decipher architectural elements and derive information from the documentation product. The rendered photogrammetric model is more significantly affected by the presence of vegetation, specifically trees with lush foliage. Areas of architecture directly behind or in the proximity of the trees are missing a significant amount of data; these areas are rendered as gray voids. Additionally, areas of the facades within the direct proximity

[384] Similar to the vehicles captured through the colorized data, these areas can be cropped from the point cloud.

[385] For the trials undertaken for this thesis, is was important to position the scanner on both sides of the trial block at several different intervals to ensure that the trees planted along the sidewalk would not obstruct large areas of the architecture from being modeled. A larger number of scanner positions assures that obstacles present in the scan – vehicles and vegetation – do not compromise the quality of the deliverable.

of the trees have an inclination to become distorted. What should be straight lines in the rectified images – clapboard siding, mortar joints, window mullions, shutters, lintels and roof edges – become bowed and deformed.[386] These areas are sagging and have a bubble-like appearance to them. The photogrammetric technology is less successful rendering data around vegetation when compared to the laser scanning technique.

The level of lighting, or the potential for washout in the rendered deliverable is a significant challenge for both the laser scanning and photogrammetry techniques. In contrast, lighting is not an obstacle for documentation undertaken through the multimedia GIS or three-dimensional modeling methods. Data for the multimedia GIS technology stems primarily from archival documents, and therefore would not be affected by lighting conditions. Raw data for the three-dimensional modeling technology is comprised from building footprints, GIS data and reference measurements; none of these sources would be a candidate for washout. However, the success of both the laser scan renderings and photogrammetric model is dependent on the lighting conditions present during data accumulation.[387] For both technologies, literature recommends that data is captured during overcast weather. This guideline reduces the chances of washout – or areas of low color, low saturation and limited contrast – near the edges of structures and on building facades with light hues. Even though data was captured during overcast weather, areas of washout were still present in both the laser scan and photogrammetry products. This limitation is primarily observable on light-colored buildings and near the roofs of the structures.

Cities undertaking a digital documentation campaign may also encounter two

[386] It is surmised that this deformation is a result of the processing platform attempting to distinguish the vertical plane in which the tree is located, from the plane in which the façade of the structure is present.

[387] Laser scanning does not actually have the photographic limitations present with photogrammetry. For laser scanning, lighting is only an obstacle if the client requests the scans to be colorized. The scanning technology uses a laser beam to capture data and therefore can be undertaken in complete darkness if the color overlay is not necessary to the documentation project. This method still results in highly accurate and detailed scans, however, the material textures are devoid of color and appear as a black and white point cloud. This technique has a successful application indoors where daylight may be absent.

additional obstacles: access to private property and access to prior data. These obstacles are specific to the multimedia GIS and three-dimensional modeling technologies. The laser scanning and photogrammetry techniques would not be hindered by these restrictions because data can be captured from the public right-of-way and the technologies do not rely on previously accumulated data for success.[388] The multimedia GIS documentation method does not require access to the property being documented. Instead, the documentation method is dependent on local archives. If the sponsoring organization chooses to incorporate a contemporary images, they can likely document the structures from the public right-of-way. With the three-dimensional modeling technology, the level of access to private property needed is dependent on the method of data accumulation the organization elects to assume. Access to the property is necessary to capture reference measurements for the rectified and scaled images used to determine the structures' height. This is minimally intrusive; this method requires only one measurement for each structure, such as the height of a window.[389] However, the fieldwork team may decide they want more accurate measurements of the building outlines than what may be presented with the GIS data or Google Earth imagery. This method of data accumulation would require a more intrusive level of access onto private property.

The success of the multimedia GIS documentation technology is highly reliant on the existence of and access to prior data. Cities without local archives or large collections of historic documents will have a challenging time creating an effective and compelling documentation product. Small cities, or newer cities may realize they lack historic data for this endeavor. Without access to previously archived data, the multimedia GIS deliverable

[388] Access to property may become an obstacle for the laser scanning technology if the fieldwork team decides to document the roof forms of the structures by capturing scans on the roofs of adjacent buildings.

[389] This method of data accumulation in regards to access to private property proved to be an uncomplicated task in Charleston, because the main facades of the structures are typically street-fronting and in plane with the sidewalk. Permission was not needed to take these measurements since the process did not require entry onto the property.

would simply display contemporary photographs of the structures. While not as dependent on access to prior data as the multimedia GIS technology, three-dimensional modeling does necessitate minimal assistance from previously recorded data. This data may be in the form of previously compiled GIS data or aerial perspectives taken from sources such as Google Earth.[390] Access to prior data would not be necessary for the multimedia GIS technology if the sponsoring institution chose to measure building outlines rather than relying on another party's data for the modeling procedure.

The investigative trials resulted in four considerably different preservation products and deliverables. Generally the findings were specific to the digital documentation technology. However, while the multimedia GIS and three-dimensional modeling techniques produced contrasting conclusions, it is interesting to note that the laser scanning and photogrammetry techniques did result in similar findings for many of the finer headings and subdivisions of the parameters. While some technologies produced correlated results, the data communicates that the digital documentation technologies have different strengths for different scenarios. The analysis and matrices discussed above illustrate strengths and weaknesses for each technology in the areas of economics, accuracy, refinement, expertise and manpower. Each technology is more suitable to address certain parameters and applications, contingent on the objectives of the documentation endeavor.

Big picture patterns observed from the data correspond with the economics, technical expertise, degree of refinement and general visual of the documentation products. Generally, if a technology was inefficient in terms of economics and expertise, the documentation technique was highly successful in regards to accuracy and refinement. In contrast, the technologies that required less expertise and investment lacked in refinement and demonstrated a lower level of accuracy, but were still effective and successful as

[390] For the three-dimensional modeling trial undertaken for this thesis, the fieldwork team relied on prior data in the form of the City of Charleston's GIS data layers.

documentation methods. These products typically contained an interactive element and were aligned with the audiences and applications of academics, tourism and interpretation. Documentation generated from the more sophisticated technologies had a superior level of detail and were more applicable to preservation, conservation and restoration objectives. However, these documentation technologies produced photorealistic quality and textural detail unnecessary for the massing models required for urban planning and development purposes. Patterns in the data are further discussed in the concluding chapter.

CHAPTER SEVEN

CONCLUSION

The process of documenting cultural heritage has entered the Digital Era, a time recognized for a cultural outlook framed by machines. With technological advances, the preservation discipline is now equipped with a wide range of sophisticated technologies for recording and preserving architectural heritage. The axiom of a heritage documentation project is to retrieve maximum information through recording.[391] Digital technologies such as laser scanning, photogrammetry, multimedia geographic information systems (GIS) and three-dimensional modeling foster this principle and are expediting efforts to record and interpret historic places. The acceptance of these tools is due in part to their ability to rapidly capture data, their high level of accuracy and their nonintrusive character.

The concept of digitally documenting architectural heritage at a citywide scale is a growing movement. Digital documentation technologies present preservationists with a viable opportunity for undertaking large-scale documentation of the historic urban landscape, measured in blocks and districts. These techniques allow city-scaled documentation, presenting and recording urban architectural patterns, rather than the commonly seen explicit concentration on single historic structures. By employing digital documentation tools, institutions have begun to record a greater magnitude of urban fabric to achieve a range of preservation-related objectives including conservation, city planning, education and heritage tourism applications.

While practitioners assert that digital tools have a home in historic preservation, documentation technologies are powerful and sophisticated, requiring significant investments in hardware, software and training for users and historic preservation

[391] Akboy, "The Mediated Environment of Heritage Recording and Documentation," 7.

organizations. Only after the advantages and shortcomings of digital documentation tools have been identified and discussed can a successful selection of appropriate technology be evaluated for a group undertaking architectural heritage documentation. Much of the discussion comprising digital documentation technologies addresses the strengths of the tools. However, as communicated through this thesis's matrices, the limitations of the documentation technologies offer as much insight as the strengths. It is imperative that both the capacities and limitations of a documentation technology are established and understood before a method is selected for implementation in a city.

Through literature and published case studies, it is understood that practitioners seldom employ just one digital documentation technique for recordation. Academic discussions demonstrate, and often argue for, the overlap and integration of the documentation methods. Few case studies represent a "pure" application of the technology. Prior to this thesis literature did not provide an "apples to apples" assessment of the four techniques. To address this deficiency, this thesis generated a parallel comparison of the major types of digital documentation – laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling – answering the question of how a detailed understanding of the efficacy of the documentation techniques could inform the selection of a specific method for a large-scale digital architectural heritage documentation campaign. Through the analysis and trial investigation of the four digital documentation techniques – laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling – the thesis dissected the effectiveness of the digital documentation platforms available and their applicability to the Charleston Historic District and other cities, forming a parallel comparison of the technologies' strengthens and restrictions.

The analysis of the parameters and the parallel comparison of the technologies' efficacy are ranked according to the specific method undertaken through this thesis for each technology. This ranking takes into consideration all phases of the data accumulation, data processing and data post-processing stages, as well as the equipment, software and hardware employed. This is to say that only one type of three-dimensional modeling, for example using SketchUp, is considered in this analysis. For the laser scanning and photogrammetry technologies, this disclaimer is less pertinent since the range of software and equipment is limited. For these two technologies, the procedure used to capture data will not be drastically altered if a city does not use the same data collection methodology and equipment used in this thesis. Likewise, although there is variety of software available to process laser scan and photogrammetric data, the procedures undertaken through these platforms are similar to how the process was completed for the investigative trials. However, for the multimedia GIS and the three-dimensional modeling techniques, there are many different software programs with different strengths. The analysis presented in the preceding chapter is specific to the software platforms used in this thesis. The analysis of the parameters in regards to these two technologies would likely be incredibly different if an alternate technique or technological platform was used of the same documentation category.

The investigative trials of the documentation technologies explored through this thesis resulted in four considerably different preservation products and deliverables. Arguably, each of the techniques analyzed could successfully document historic architecture if implemented by a city. The results of the trials presented through the matrices indicate that there is not one documentation technology that is recognizably stronger than the three others. Rather, each technology is more suitable to address certain parameters and applications, contingent on the objectives of the documentation endeavor. For example, the three-dimensional modeling technology generated a product most aligned with a massing model, devoid of fenestration and surface texture. This documentation product is more apt to address preservation objectives regarding urban design and city planning. In contrast, laser scanning produced a photorealistic, time capsule-like product more appropriate to address parameters concentrating on accuracy, detail and refinement.

The matrix on the following page provides a cross-reference for the target audiences noted in Chapter Six against the parameters and subcategories used to analyze the digital documentation technologies. The target audiences and applicable technologies are listed on the Y-axis. The technique's text box is highlighted respectively to illustrate the technology's level of success. The analytical parameters and a breakdown of their subcategories are listed across the X-axis. For each audience, the documentation techniques that ranked as successful or adequate - black or medium grey - are included. Techniques that ranked as lacking or less preferable - illustrated as a light grey - are not included in this matrix. The matrix provides a comprehensive visual of all of the parameters evaluated, how each parameter fosters success with a documentation technology and the parameters' relationship to a specific target audience or preservation application. The matrix highlights preferable technologies applicable to each audience and allows users to evaluate if their organization has the means to facilitate that specific documentation method.

For example, if a city wanted to create a digital product that facilitated the process of the architectural review board to determine if infill design is compatible, but they are constrained by a small budget and less capacity in terms of equipment and software, yet they have time, a dedicated staff and access to architectural data such as GIS, they might weigh the parameters of technical expertise required, institutional capacity and labor intensity. Additionally, the organization might evaluate the subcategories of file size, cost, hardware requirements, access to equipment and expertise necessary to derive information from the model. By addressing the matrix, the organization would discover that while laser scanning and photogrammetry adequately address their preservation objectives, the three-dimensional modeling method is most promising for an architectural review board application and successfully documents areas of solid versus void, height, scale and mass, and roof form by providing users with a variety of vantage points within the model.

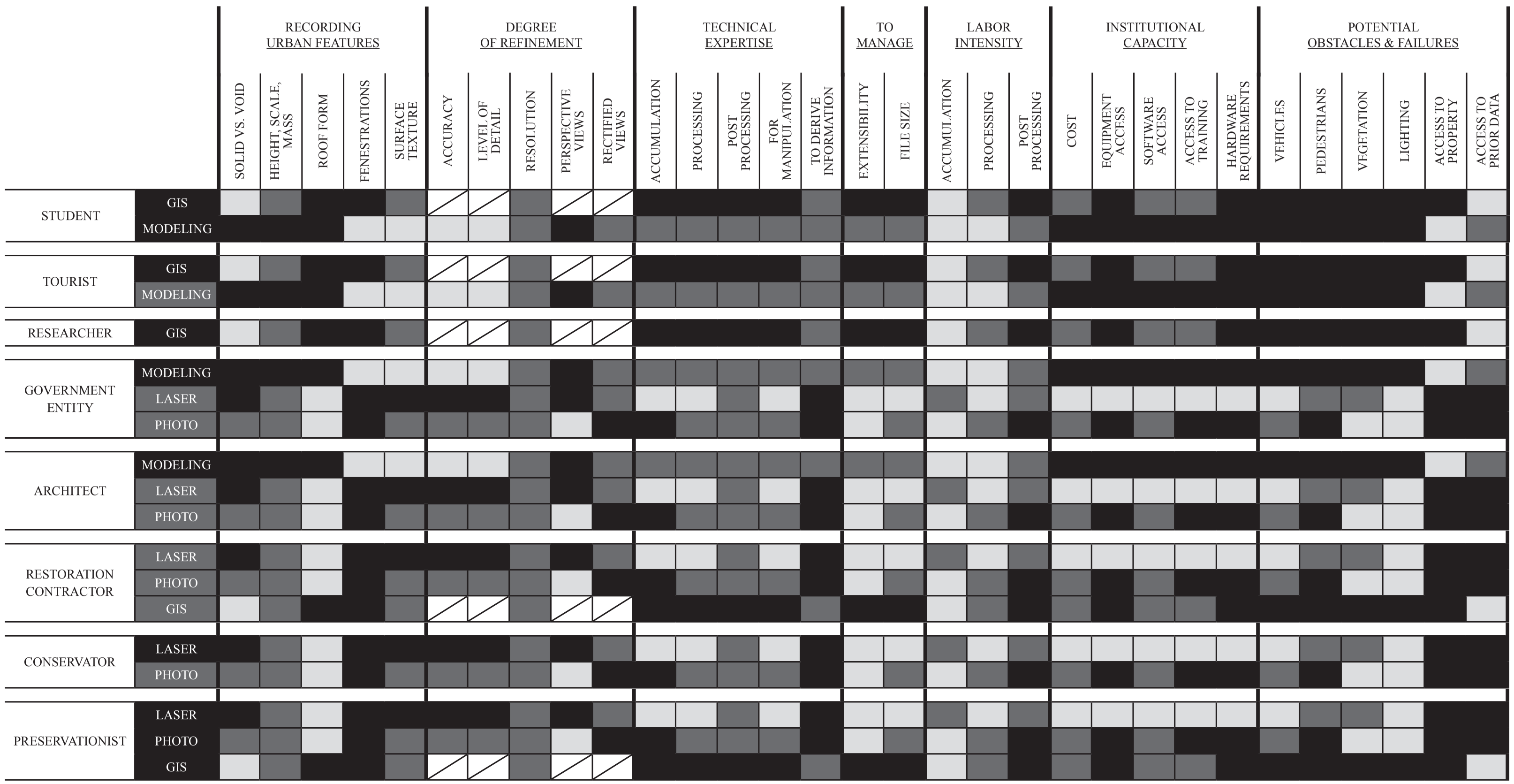


***Table 7.0** - Audience-Parameter Table for Cross-Referencing.*

The table above illustrates the most successful, as well as the adequate documentation technologies for each of the perceived target audiences. The parameters and their subcategories used to evaluate the techniques are included for a comprehensive cross-reference. Technologies that were lacking or less preferable for the audience are eliminated from this chart, but can be found through the analysis chapter.

Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking
Strike Through = Not Applicable

Scope, time and cost are the three most substantial determinants influencing a preservation organization's selection of a digital documentation technology. Scope is further identified as data received, data required and the level of detail desired. Time includes that of training, surveying and interpretation. Cost is subjective to hardware, software and education; however, this factor is often offset by the efficiency of the documentation method. The analysis more narrowly concluded strengths and weaknesses for each of the four technologies in the areas of economics, accuracy, refinement, expertise and manpower. Generally, if a technology was inefficient in terms of economics and expertise, the documentation technique was highly successful in regards to accuracy and refinement. In contrast, the technologies that required less expertise and investment resulted in less preferable – but still effective and successful – refinement and a lower demonstration of accuracy.

In addition to presenting the strengths and limitations of the digital documentation technologies, the analysis of the investigative trials suggested correlated parameters. Interactive platforms are typically associated with documentation products displaying less detail and lower accuracy, unsuitable for the objectives of conservators. Effectively recording areas of solid versus void, as well as height, scale, mass and roof form leads to successful massing interpretation. A successful portrayal of surface texture is correlated with higher levels of accuracy, detail and refinement, and is more suitable for material conservation and restoration. Documenting architectural evolution is correlated with technologies that require less technical expertise, are less labor intensive, present a preferable manageability ranking, and adequately display architectural details and textures. For example, laser scanning is a costly investment in both hardware and personnel, and is therefore less applicable to record architectural evolution. Comparably, although more cost effective, the labor required for three-dimensional modeling also hinders this technology from efficiently presenting the architectural evolution of a city.

Technical expertise required for the data accumulation, data processing and data post-processing phases is directly related to the file size produced from the documentation technology. For example, the laser scanning technology requires a significant level of expertise for all stages of production. In turn, the file produced is heavy – attributed to the large number of data points – and deters facile internal management. In contrast, the multimedia GIS technology requires significantly less technical knowledge and produces a more manageable file. Technical expertise is also correlated with institutional capacity. Generally, a greater amount of expertise on the part of operators requires a more significant commitment from an organization. Specifically within the institutional capacity parameter, the cost of the technology is associated with the accessibility of equipment and software. Higher costs imply less accessible technology and fewer avenues for user training and instruction. Manageability – or more narrowly, extensibility – is partly related to the technical expertise required for manipulation and partly linked to the file size of the generated documentation.

Of the four technologies, photogrammetry presented the most consistent results. In all of the parameters analyzed, photogrammetry had an adequate – not exceptionally preferable, nor deficient – ranking in the areas of economics, manpower, accuracy, refinement and expertise. This demonstrates a technology with a flexible capacity applicable to a variety of historic preservation objectives and relatively successful through the majority of the analysis. In contrast, laser scanning offered juxtaposing findings. While the technology was desirable for its ability to record architectural features and its high degree of refinement, an organization might be deterred due to the considerable level of expertise and labor required, as well as the larger stress on an institution's internal capacity. Laser scanning is a suitable choice for organizations principally concerned with accuracy and capturing detail. However, if an institution were more attentive to economics and the opportunities for internal processing, the organization would likely look to the other documentation tools. Similar to laser scanning, three-dimensional modeling produced contrasting results among the parameters and did not generate a consistent ranking as preferable, adequate or lacking. Internal management was advantageous to the three-dimensional modeling technology; however, the documentation tool lacked refinement and accuracy. Additionally, like laser scanning, three-dimensional modeling is generally an active procedure and therefore more labor intensive, unlike the greater amount of passive time experienced during the processing stage of photogrammetry. The multimedia GIS technology – specifically the web-mapping application employed in this thesis – produced findings similar to photogrammetry. However, in contrast, the multimedia GIS platform was more preferable in the areas of expertise and manageability.

The juxtaposing results and distinct documentation products foster further discussion regarding practitioners' argument for the integration of digital documentation technologies, as seen in published work. There is a strong theme within the literature that to gain adequate knowledge, analysis and preservation of large-scale architectural heritage, many of the methods of documentation discussed are best used in combination. The wide support for integration of the digital methods poses an obstacle for potential users when gauging a parallel comparison of laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling techniques. Although an apples-to-apples comparison of the technologies is essential to form a base understanding of the techniques' capacities, it can be argued that the medium level of effectiveness communicated through the matrices and corresponding discussion in Chapter Six justifies an assimilation of the digital tools. This integration would allow for an institution to reap the strengths of each technique, while making up for the potential limitations of others. This suggestion may include incorporating a point cloud model or a three-dimensional model into a multimedia GIS platform, or combining both laser scan and photogrammetric data for one documentation campaign. The integration of documentation technologies is determined by both the desired recordation type and institutional capacity.

While digital documentation technologies are being accepted and encouraged as a preservation tool, a resurfacing concern for data migration urges further research into the subject. The issue of digital data storage and management is a continuing dilemma for the preservation field as documentation technologies become more prominent. When choosing to document architectural heritage with a digital tool, preservation organizations need to recognize potential limitations with the data files. James W. Shepherd, the director of preservation and facilities at the Washington National Cathedral stresses that organizations must know if their institution has the capacity to store the data and the programs to read the data files. He further states that external influences may have a significant effect on digital data, explaining that the software or hardware utilized may become obsolete, the corporation managing the technology or platform may go out of business resulting in dismantled equipment, and that the operating systems will unquestionably require updating to address technological changes.[392] These issues foster renewed discussion in the debate between two-dimensional and three-dimensional documentation deliverables. Although two-dimensional drawings and line-work can be generated from three-dimensional products, practitioners only have the ability to tap back into data for additional drawings so long as the software is relevant. Additional research into the preservation of digital data will be required with the increasing implementation of documentation technologies.

Although debates on efficacy remain, when asked where the future of preservation was heading, the panel of speakers at the Association for Preservation Technology (APT) 2016 Documentation Technologies Workshop in Philadelphia, Pennsylvania responded with great enthusiasm for the use of digital tools. Annabelle Radcliffe-Trenner, founding principal of Historic Building Architects in Trenton, New Jersey advocated that future

[392] Chris Gray et al., "Association for Preservation Technology Documentation Technologies Workshop" (Philadelphia, PA, March 11, 2016).

preservation endeavors would see a greater reliance on drones and photogrammetry. Chris Gray of the Mollenhauer Group and co-chair of the APT Technical Committee on Documentation supported this belief, also suggesting an increased production in virtual reality projects. Purvi Gandhi Irwin formerly of Quinn Evans Architects and now of CADD Microsystems stated that "drawings are on their way out" with AutoCAD platforms being replaced with three-dimensional models created through systems such as BIM and HBIM. Although enthusiastic about the opportunities possible with a greater integration of documentation technologies into the preservation field, James W. Shepherd, the director of preservation and facilities at the Washington National Cathedral, challenged a reliance on digital means of recording heritage, conveying the opinion that digital documentation technologies are simply tools. He elaborated, stating that documentation tools isolated from education result only in data and preservation practitioners need to be educated in observing conditions in order to derive information from the products of documentation technologies. Shepherd emphasized that while remote sensing technologies present a plethora of benefits, hands-on surveying and an understanding of building construction must be integrated with digital technologies for a successful translation of the data.[393]

Digital documentation will increasingly be fundamental to the understanding, appreciation and management of heritage places. Digital documentation tools and techniques present preservationists with a viable opportunity for undertaking large-scale documentation of historic urban landscapes, fostering a representation of the relationship of architecture and streetscapes. The studies undertaken through this thesis encourage cities to expand their commitment to preservation beyond single historic buildings to a broader documentation of historic neighborhoods and districts. The parallel comparison of laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling formed

[393] *Ibid*.

through this thesis presents a more detailed understanding of the major types of digital documentation and aids cities in apprehending the efficacy of the technologies for citywide architectural heritage documentation.

APPENDICES

Appendix A

Interview with Dr. Robin Williams, Virtual Historic Savannah Project

AB: I emailed a little bit with Professor Johnson and he filled me in and answered some of my questions that I initially sent out to give me an overview about the Virtual Historic Savannah Project; why you guys started it and where it ended up. I would love to hear your side of it as well, being the Director and Chair.

RW: I was the one who conceived the project. I was very early on put in touch with Greg Johnson by colleagues and mutual friends, who was the Chair of the Computer Department at the time. I described to him this vision I had for a project that grew out of a desire to have a comprehensive guide to the city that was not constrained by the limits of a guidebook. That was the genesis of the project: how to document the city, or at least part of a city with what I call the "Guidebook Problem". I created the project as an anti-guide that would overcome the shortcomings of printed guidebooks which are structured and have a linear narrative and are constrained to be organized in one fashion or another, be it chronological, stylistic or more commonly geographic. The idea of the VHSP was that you could explore and investigate Savannah however you wanted to do it; you were not constrained by the editorial preferences of the author. The other constraint of books was inclusion constrains due to how many pages you can include in a guidebook. Guidebooks, or really any kind of study that is printed, inevitably have to make choices. They have to select what is in and what is not in. So for me, the problem with historical analysis, the inventory of historic buildings…it has inherent biases. The idea that the VHSP would be unfettered in a sense, that it would not be constrained as whether something was deemed historic, whether it was grand enough, whether is was big enough. Our criterion for inclusion was that everything counts. So the boundary, we had to set limits. A geographic limit was determined and that was the 1916 Sanborn Atlas of Savannah, a map of downtown called the "Congested District" bounded by the river to the north, Gadsden Street to the south, East Broad to the east and Martin Luther King (now) to the west. That area was defined mostly by the Savannah plan laid out by Oglethorpe and replicated with a few additional areas in the southwest and southeast corners; that is what most people consider downtown Savannah. That was a logical boundary. In fact, when we got Federal funding from the National Endowment for the Humanities, one of the questions that arose in that process was to justify those boundaries. The Sanborn map proved to be very useful, because it served as evidence as historically this is how the city was seen downtown. In terms of the area and basic premises of the project, it grew out of my interest in trying to document the city. I was kind of naïve when conceiving this project. So document every structure in downtown regardless of whether an outhouse or grand civic building, everything counted; like on a Sanborn map, everything is documented. But the other dimension of it was, guidebooks tend to focus on what is standing, not what was on the site previously. "Then and Now Books" create the false impression that sites had a previous building and a current building. Some sites in some cities go through six or eight buildings on the same site. That in older cities is going to happen in certain locations. And the other thing is that buildings change. It raised the issue of what would be an appropriate interface, and I assumed a model. A computer model that is infinitely changeable, it is nimble, it can have as many iterations as it needs to have, it can be navigable. The introduction to Greg Johnson as a game design professor, aware of this online language called VRML (virtual reality modeling language), it turned out to be a fantastic partnership. He was able to help develop the visualization of this vision I had for a model. And he was a real advocate for this technology. He genuinely thought…that there was a legitimate chance that the Internet would become increasingly three-dimensional. We were trying to create something that was way out of left field, which it was; we assumed that the Internet would steer in the direction that we were moving. But it really felt for a long time that we were creating something that was going off into the darkness and into uncharted territory. You hope that others will follow; and in some ways they did, Google Streetview emerged after we were well into this project. I still believe in the merits of the idea, the problem is that we were struggling against a lot of logistical challenges. We were both full time professors; in addition I am a Chair. Once we got funding, it helped pay for us to get course releases. It was a project that to work out to its maximum potential, one thing that would have helped would have been if we could have devoted our full time to this project, rather than 20% of our time. That caused the project to slow down in terms of its development. We eventually partnered with a third team member around 1996-1997. Leon Robichaud is a researcher who had worked on a similar project for Montreal, a much smaller project, not nearly as comprehensive as I had in mind, but had some aspects of it. He was the database programmer for the project. There was funding in a grant that paid for him to come to Savannah and meet with us, and we plotted out the database. Just documenting downtown Savannah buildings that were standing took us years to do it properly and photograph them all. Part of my original vision was also to not only document every building within that geographic parameters, but a naïve goal was also to document every building that had ever stood in that area. Nevertheless, we wanted to document every building that had every stood in downtown Savannah from the present (the late 1990s) back to 1733. That was the goal. And you could access that project through a 3D interface online, for free. Greg Johnson was adamant, an early decision was that we only used off the shelf software, nothing would be proprietary from a technological point of view. That turned out to be huge for getting Federal grant money from the National Endowment for the Humanities. Also, we thought wouldn't it be smart if we had a project that was replicable, so if we used off the shelf software, other people could do the same. The project ended up being so huge, at one point we had 13 people working on it, and the ambition of it was so outrageously large. We only relied on historic sources that treated the district evenly, [such as] Sanborn maps, map, censuses, and city directories, as opposed to a great thesis project done on a single building that could provide all sorts of great information on that building. The beauty of this project is the evenness of it, not this random deep plunge into the information on a single building. Moving forward, we started with one ward; Jasper Ward was our pilot project. Greg and I, working with a handful of students and that was relatively easy. It was maybe about 50 buildings in the Ward… [this was used to] work through the kinks of the model, the database, the procedures for compiling data standards, photography. We ended up getting three different grants. One from the State for $10,000, one from the National Endowment for the Humanities for $50,000 and a third one for $150,000; $210,000 dollars, not bad for funding. On the research side: there was the field research of counting buildings and taking in what we could see about buildings and defining what are buildings…and tabulating that data. And then there is the research of how old the buildings are, when did they change, more deep architectural history research; that was challenging. I was committed to a social history dimension of the project.

{End of Recording 1}

RW: It actually astonishes me that the website is still up and running after 18 years, 17 years. Which, I don't know, I guess that is a testament that we did something right. The number of people that have said to me, they would love to see me revisit the project and somehow adapt it to new technology, but make it strive to achieve its potential. On the research side, challenges: tallying buildings, "big area with what turned out to be 2200 buildings in the existing downtown." Towards the end of the project, as we were running out of gas, we had counted over 6,000 lost buildings going back to 1853. And you think of Savannah, like Charleston, as a well preserved downtown, and to think that for every surviving building in downtown Savannah, there are three lost buildings. And that is where I am sort of sad that it took so long to work through what we did accomplish. At the pace we were working, to do the project to my original vision would have taken thirty years. I was becoming very frustrated with the technology. What is also frustrating is that we have research data compiled that has no real home. I was proposing to do things that were so out of my depth. Looking back, I am shocked that we got any funding at all. I think the advisors saw the ambition in the project, and said well let's see where this goes. We were able to document buildings that have since disappeared. We have some of the only photographs of buildings that are now gone. And then for the models, that was a whole other can of worms. We thought we would use the 3D data layer [of GIS] and extrude out the wire frame footprints of all the buildings. Great! That will help expedite the building model. When people make GIS street plans and footprints, they typically use aerial photographs and trace them. They do not use archaeological precision. The sides of the streets are not necessary parallel, they are not accurate, and they sometimes trace the shadow not the outline of the buildings, they had buildings out in the middle of the road, more buildings than not were trapezoids, they were nowhere near in the right spot, some buildings were missed. The data was useless. We found some old maps, which I gave to an architecture student, to create a base map, a new relatively accurate base map of downtown. Various students worked on building models, but mostly this student named Darren Ostrum (?), who was an architecture major and an architecture history double major, built most of them. We were conceiving a project that would work over the Internet, which at the time was like a very skinny straw. Now it is like a massive trunk line. But back then, we knew that the project was larger than the average bandwidth could handle. But this we did predict actually; Greg said that bandwidth will double every 18 months. And he said let's just build a project that is too big for today's bandwidth, but at the pace we are building this project, the bandwidth will catch up. And he was absolutely right about that. It was such a slow process to see the model load. Every polygon mattered. Greg had to come up with strategies for modeling efficiently. We were very mindful that the more shape you put into a building model, it resembled the building it actually was, the more polygons you had. So we actually sat down and mapped out, we made polygon budgets for how many buildings in a Ward could be modeled as simple cubes and how many needed detail. And in this regard, there is a little bit of privileging of landmark buildings. But the idea is if you are going to navigate through a model, you need some buildings to be recognizable. As time went on, the modeling got better. The early models are really generic. We had to go back out and create the new building footprint map because the city's data was useless. Then from that, the modeler using photographs and field notes and so on, built approximately, as accurate as we could do it. It took us 10 years to model the existing city, develop procedures, do the research on this, the occupation data went through most of the 20th century, compiling lost buildings and entering the data was done to a point, and the modeling and implementing the model. All the while there was this other aspect that I had to help coordinate. That was getting the data base programmer, Greg and my data to all talk to one another. And there were so many hiccups. This was so far beyond my training as an architectural historian, just the learning curve on all these fronts. I was not trained to do practically any of this. And technical challenges just kept rearing their heads. But where it really got frustrating, where buildings have multiple addresses, the database freaked out. If you do not have a specific date for a building, what does the database do with that? It's so different than how we think about buildings when we talk about them in a narrative. Databases are cut and dry.

AB: In your opinion, even if this site has not been used recently, or it ran out of juice, do you think that it adequately documented the city's architectural heritage and architectural evolution? And could it eventually be used again, should it get pumped back up?

RW: I think it is most successful in terms of documenting the city as it stood in the late 20th century and providing perspective on the architectural occupation history of each of those existing buildings. So, I think that is what it is most successful at, is the existing city as it stood at the end of the 20th century. Does it adequately show the evolution? No. I mean the harsh reality is no. But, what it does do though…it is successful telling you information about the existing built environment through time. So the evolution of the existing built environment is also successful. So what I mean by that is, if you queried the year 1850, it would only show those buildings that exist today that existed in 1850. That aspect of the Savannah project, that you can go in and go year-by-year or decade-by-decade true what we did document, and you see the population of downtown of what survives, only based on what survives, that sense of the evolution it does depict very successfully. You can see the sparse 18th century number of buildings. It picks up speed in the early 1800s, but when you get to the 1850s, it's like bam you have got most of downtown; downtown is loaded with 1850s buildings. And then you have got another big bam around 1890 to 1910. And then it really does not change a lot after that. Through that perspective of documenting the city's evolution, the project provides you a tool that is unique. I have been able to use the data, not as presented on the site, and this is where I am sort of sad, my dream was there would be a really robust search engine, you could query the project and say show me and you would have these search terms, …and it would illustrate or highlight or make glow. The before and after effect; that you have a vantage point and then if you could, like Google has a slider where you could change the year and the model would refresh and change without you changing your vantage point, that was a dream. And that never happened, because every time you changed the year, the model defaulted to this aerial view and reloaded, slowly. There were things like that that were immensely frustrating and killed the operability that I had in my mind.

{End of Recording 2}

Appendix B

Interview with Brinker Ferguson, CyArk

AB: Why the project was initiated? What was the objective?

BF: New Orleans was chosen, as it is a historic city with rich history expressed through the architecture. Like the other sites and structures we have documented, the city is vulnerable to naturals disasters like we saw with Katrina. New Orleans is part of a larger narrative that is going on in the history of world culture. We partnered with HERE, part of Nokia to undertake the Historic Cities Project. The goal is document four to five historic cities, including New Orleans, Philadelphia, Chicago, San Francisco and Boston.

AB: Who are/have been the key people involved from CyArk?

BF: Yes, I mean what we do here, Ross Davidson, he is on our website, he is our field manager right now, and he creates a site map. He works with technology companies. He is really the one that creates the site, either around a monument, or in this case around a city and documents where exactly the best and most strategic places to capture, to get as much information from the city as possible are.

AB: Who are the primary users/viewers of the program?

BF: Our goal is actually to do a 360-degree video of the city; when you are telling the story of the city, but telling it through the architecture, you can do a 360-degree view and go all throughout. Our goal with that, and all of our online content, is education. We always work very closely with K-12 to create lesson plans that feed into curriculum. There is an online component that is for the general public, but there is also very much a K-12 component with the material and then with universities we work with more technology.

AB: Where have you seen the successes and benefits of this digital documentation method?

BF: We use a lot of different types of technology. We use photogrammetry; laser scanning; structured-light, which is sort of the hand scanner for detailed work. There are a lot of pros and cons to both. I would say with photogrammetry, starting there, the pro of course is that it is low-cost. It is much more accessible. I think the biggest problem with photogrammetry is users need to be educated on how to use it so there isn't any user error. But once they understand the 50% overlap and how you should circle a monument and the right kind of lighting, things like that, then it becomes very easy for people to do and very mobile. We are developing an emergency kit that is for emergency documentations in the Middle East. It is a photogrammetry kit with some tutorials and software to train people on how to take it, but once they take it, it's great. You can really calculate the depths in photogrammetry, get really wonderful detailed shots and of course for model reconstruction, the actual color and actual details. Which is pretty awesome. Laser scanning is a little more costly to do, especially if you are someone starting up rather than a tech company. It is a lot faster and you get more detailed work for engineering-grade conservation documents. Photogrammetry is certainly improving a lot, and I could see us moving towards photogrammetry in the future.

AB: What have been the obstacles or failures involved with this digital documentation method?

BF: In terms of getting tops of buildings and aerial shots, the best thing to use for that are drones and photogrammetry. So I would say that it is very much terrestrial. Building the mesh from the ground, even though you can do a camera pass wherever you want, you are having data loss when you are restricted just to terrestrial scanning. So I would say that is the biggest downfall.

AB: In terms of efficacy, how did the digital documentation method rank in your opinion; has this method adequately documented the city's architectural heritage, and do you think for posterity it will be successful displaying the city's architectural evolution?

BF: What we do is digital preservation. The light definition of conservation is basically tracking the rate of change over time and trying to slow down that change as much as you can, slow down the process of it as much as you can. Preservation, in contrast, is about taking a snapshot in history. It is about a frozen moment in history that you are trying to get a site or monument back to, or to stay at. So what we do is digital preservation. It is not so much about the evolution of the city, unless we were going to go back in five years and document again, and then in another five years and document again. Right now it is just about creating a time capsule, basically, of what New Orleans looks like in February 2015.

AB: In terms of cost, was this a feasible undertaking, or would you describe it as feasible for a mid-sized city?

BF: We partner with tech companies and that is how we are funded, generally not through the site, unless it is a national park. Economically, in terms mid-sized cities wanting to document architectural heritage through laser scanning, whether or not they partner with a large corporation depends on the size of the institution; a private university, probably not, but if it is a small historic center, then probably yes. The scanners themselves can range in cost from $15,000 to $300,000. I think the most expensive thing though is the software to be able to read, display and visualize that information.

AB: How did ease-of-use rank specifically during the data accumulate phase; specifically the data processing phase?

BF: What we do at CyArk is pretty specialized. We have a full time 3D modeler and a full time production specialist. They use everything from Maya to Recap to ZBrush, so a lot of different software. I would say with photogrammetry it is much more user-friendly, because depending on the software you use, like 123D Catch which is free, or you can use Agisoft which costs money, but it is a lot better. I mean it is relatively user-friendly.

AB: What brand of laser scanning equipment was used?

BF: I don't know off the top of my head, I believe FARO.

AB: Generally, was the digital documentation method successful? Would you employ the same method again?

BF: I would say that it is certainly better than like Google Streetview, because you can actually calculate depths and textures of the buildings. I don't know about in the future using photogrammetry, that is certainly an option.

Appendix C

Additional Images from Investigative Trials

Laser Scanning

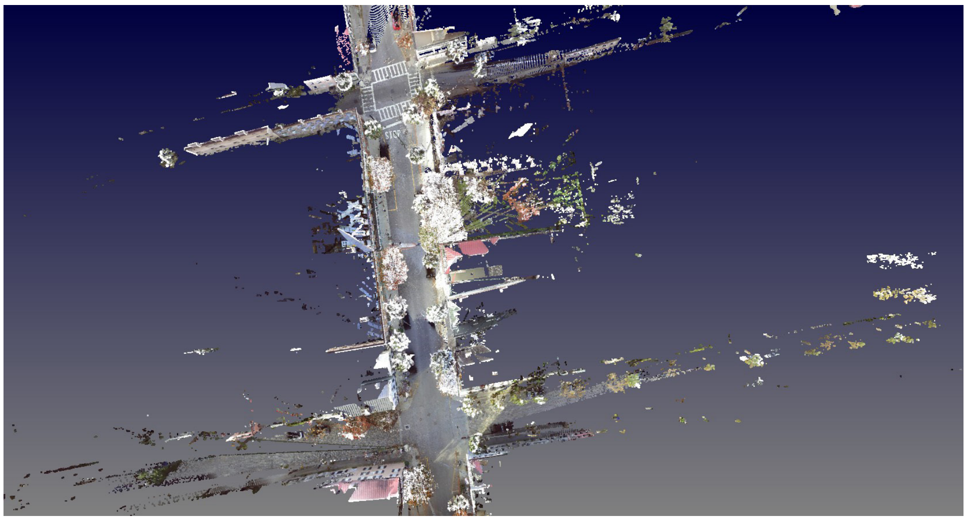


Figure C.1 - *Plan of the Trial Block from the Scan Data.*
The image above portrays an aerial plan of the trial block on Church Street captured in the processing platform's workspace.
Screen-capture in the FARO SCENE software by author

Figure C.2 - *Ortho-Rectified Image of the East Side of the Trial Block with Trees.*
The image above is a rectified view from the rendered laser scan portraying the east side of the trial block. The French Huguenot Church can be seen on the left.
Screen-capture in the FARO SCENE software by author

Figure C.3 - *Rendered Laser Scan Looking North.*
The image above is a street-level perspective of the trial block looking north up Church Street. The steeple of St. Philip's Church can be seen in the distance.
Screen-capture in the FARO SCENE software by author

Figure C.4 - *128 - 134 Church Street.*
The image above depicts a rendered scan standing at the corner of Church and Chalmers street, looking at the structures at 128, 130, 132 and 134 Church Street.
Screen-capture in the FARO SCENE software by author

Figure C.5 - *Rendered Scan Looking South.*
The image above was captured from the final laser scan rendering. 131 Church Street can be seen at the right side of the image and 132 Church Street is on the left.
Screen-capture in the FARO SCENE software by author

Figure C.6 - *Laser Scan Detail of the Dock Street Theatre Portico.*
The image above portrays a street-level perspective detail captured of the Dock Street Theatre portico and the building's brownstone columns.
Screen-capture in the FARO SCENE software by author

Photogrammetry

Figure C.7 - *Photogrammetric Detail of the West Side of the Trial Block.*
The image above portrays a detail captured in the photogrammetry software and depicts the structures at 127, 129 and 131 Church Street. Areas of data loss and washout are visible near the palmetto trees.
Screen-capture in the Agisoft PhotoScan software by author

Figure C.8 - *Photogrammetric Detail of the French Huguenot Church.*
The image above is a detail captured of the French Huguenot Church. The spires and buttresses are successfully rendered, however, similar to the image above, there is moderate data loss near the palmetto trees.
Screen-capture in the Agisoft PhotoScan software by author

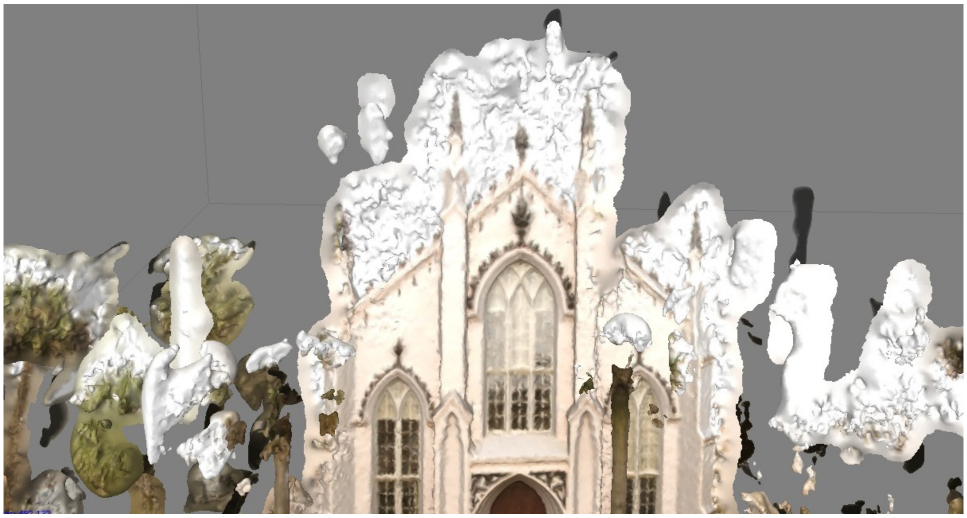


***Figure C.9 -** Detail of the French Huguenot Church Before Editing.*
The image above portrays an enlarged detail of the French Huguenot Church prior to editing and cropping. There is a significant amount of washout surrounding the Church's roof and in the proximity of the palmetto trees.
Screen-capture in the Agisoft PhotoScan software by author

Figure C.10 - *Detail of the French Huguenot Church GIS Data.*
The image above shows some of the historic documents uploaded to the multimedia GIS project for the French Huguenot Church. This view includes both a HABS photograph from the early 1900s and a Sanborn Fire Insurance map.
Screen-capture in the interactive ArcGIS platform by author

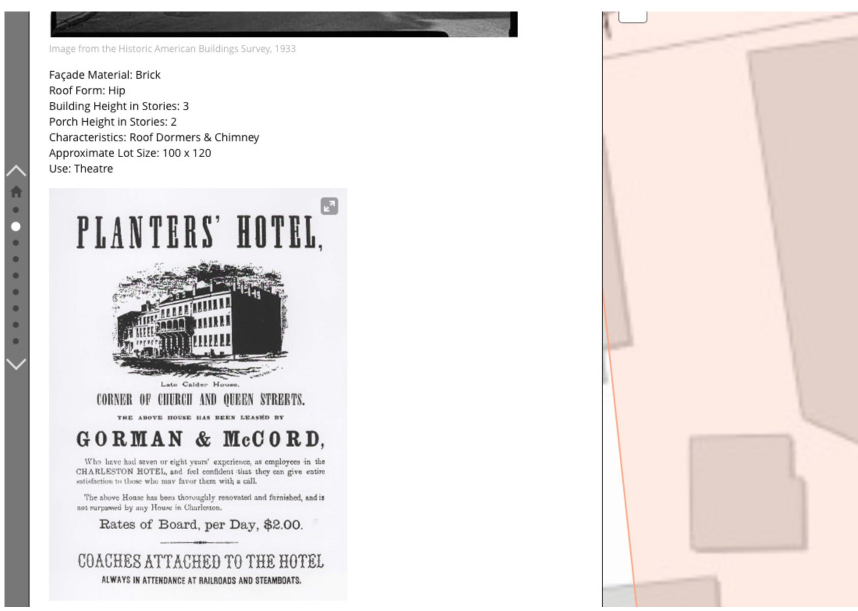


Figure C.11 - *Historic Pamphlet for the Planters' Hotel.*
The image above portrays a historic pamphlet advertising the Planters' Hotel, which formerly occupied the current Dock Street Theatre building. This document, as well as others discovered in the archives was uploaded to the GIS platform.
Screen-capture in the interactive ArcGIS platform by author

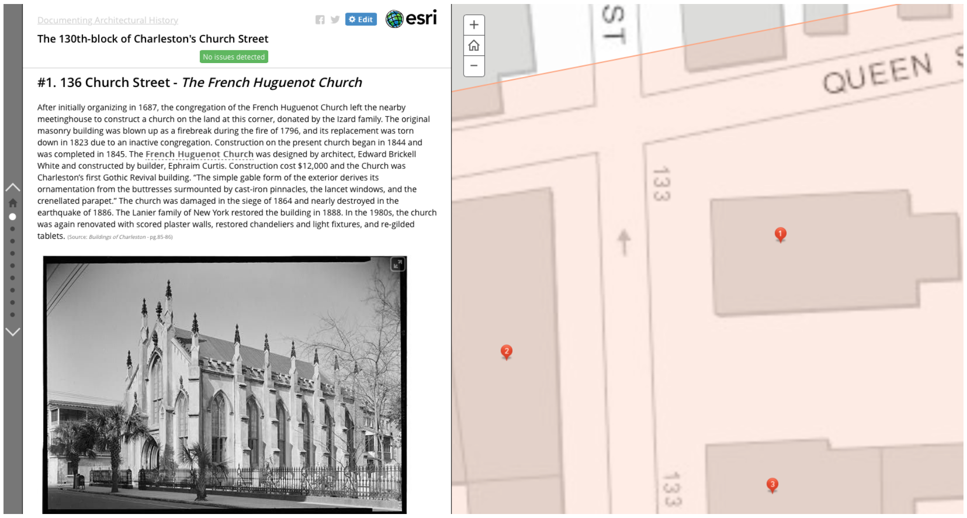


Figure C.12 - *Detail of the French Huguenot Church Archival Data.*

The image above was captured in the multimedia GIS platform and shows the narrative for the French Huguenot Church and a HABS photograph from the 1920s. The building is indicated on the right side of the base map.

Screen-capture in the interactive ArcGIS platform by author

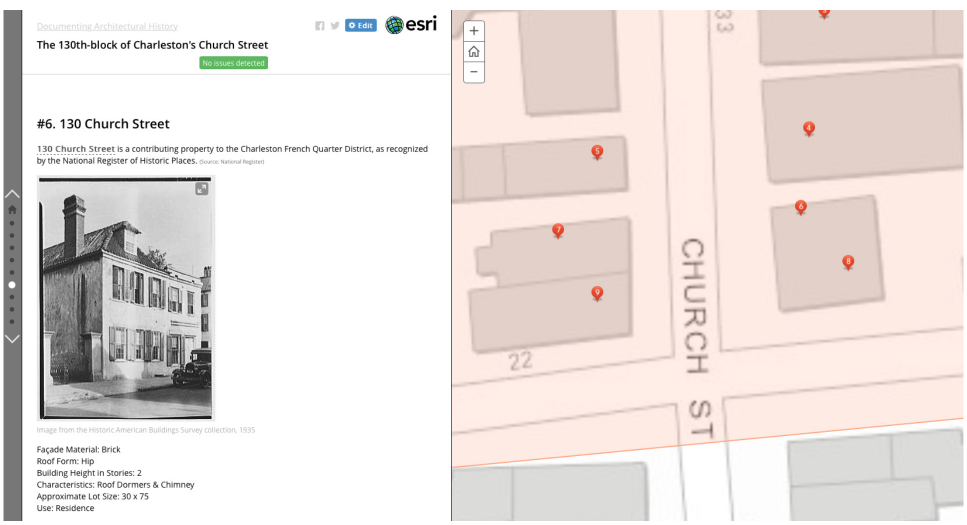


Figure C.13 - *130 Church Street GIS Section.*

The image above shows the data uploaded to the interactive platform for 130 Church Street. This data includes a short narrative about the structure, as well as an architectural description and historic photograph.

Screen-capture in the interactive ArcGIS platform by author

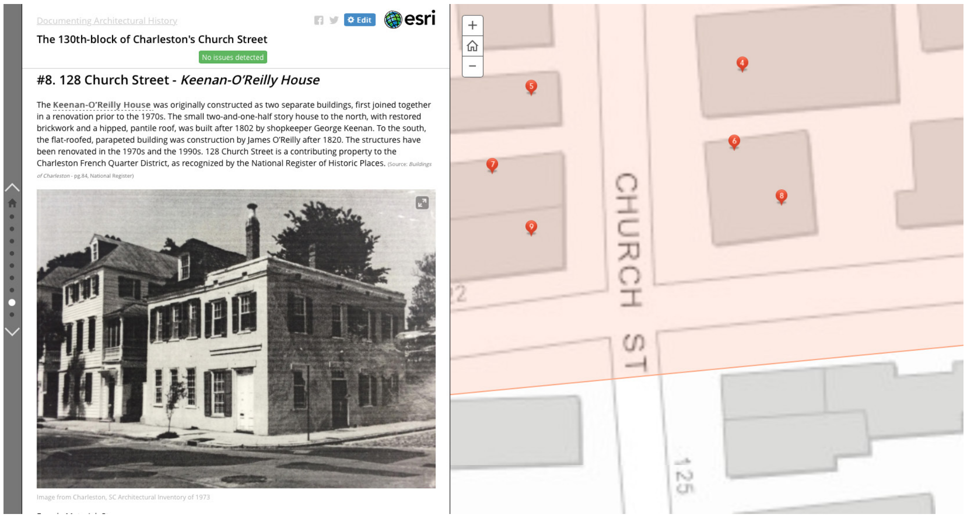


Figure C.14 - *128 Church Street GIS Section.*

The image above portrays the relationship between the base map and the historic data uploaded to the multimedia GIS platform. An early-1900s photograph of the house at 128 Church Street can be seen at the left side of the screen.

Screen-capture in the interactive ArcGIS platform by author

Three-Dimensional Modeling

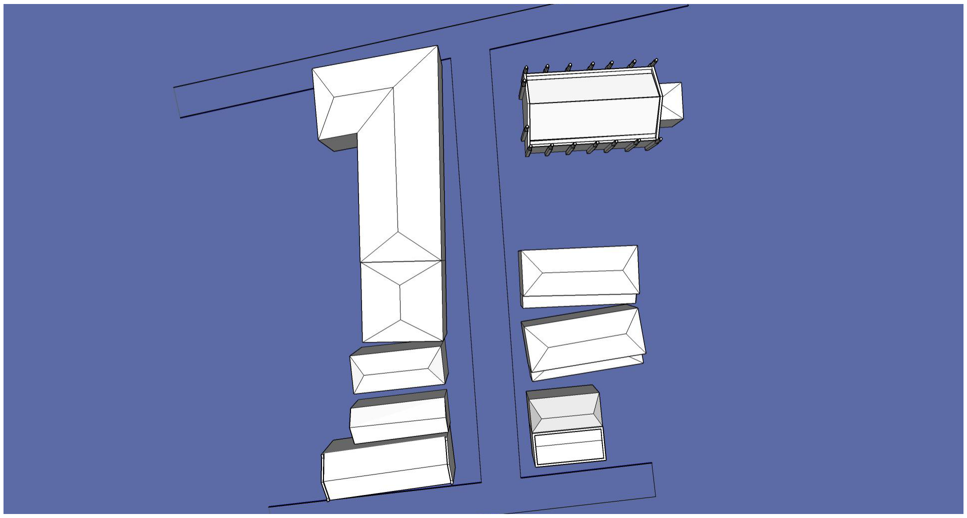


Figure C.15 - *Aerial Perspective of the 3D Model.*
The image above portrays an aerial plan of the 3D model created for the trial block in Trimble SketchUp.
Screen-capture in SketchUp by author

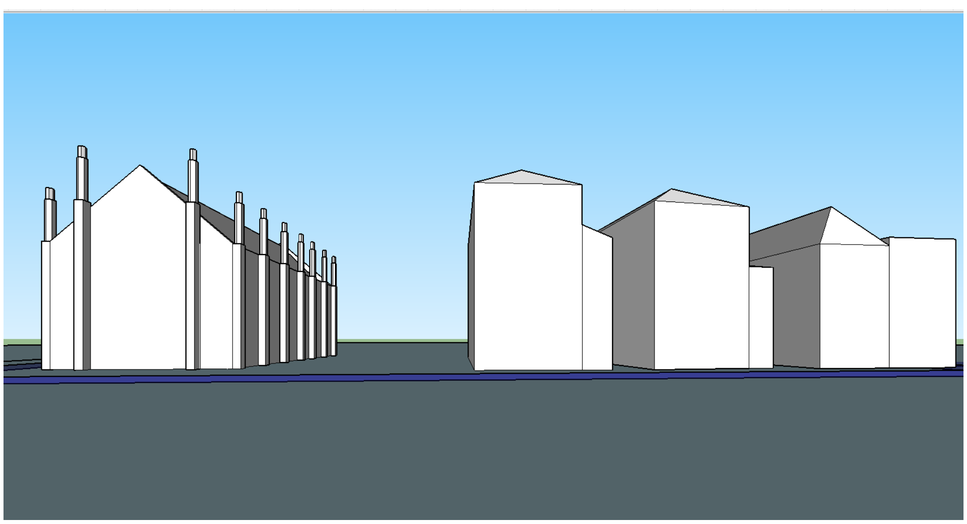


Figure C.16 - *Rectified View of the East Side of the Trial Block.*
The image above is a rectified street-level perspective of the east side of the trial block. The French Huguenot Church is at the far left side of the perspective.
Screen-capture in SketchUp by author

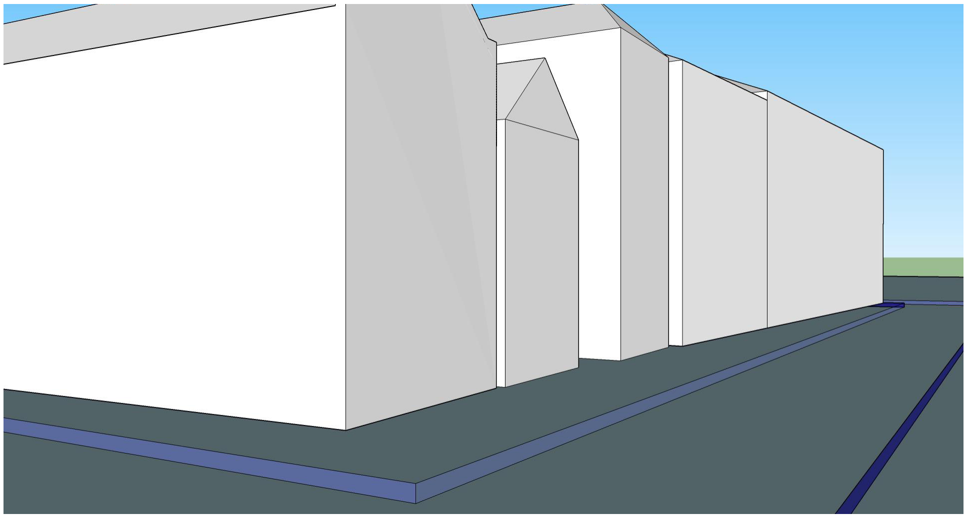


Figure C.17 - *3D Model Perspective Looking North.*
The image above is a perspective captured within the modeling platform looking north towards Queen Street. The perspective shows the massing on the west side of the trial block.
Screen-capture in SketchUp by author

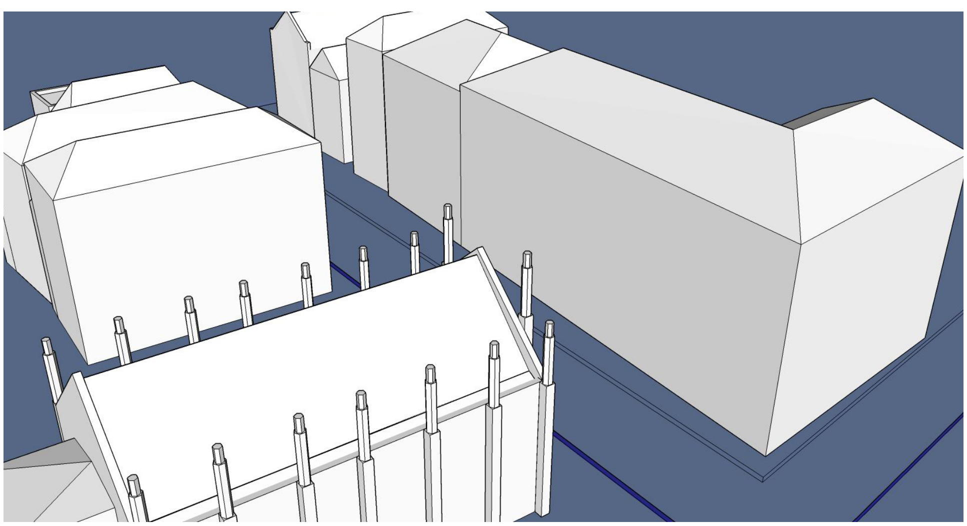


Figure C.18 - *Isometric View of the 3D Model.*
The image above is an aerial perspective taken from above the French Huguenot Church looking south down the trial block.
Screen-capture in SketchUp by author

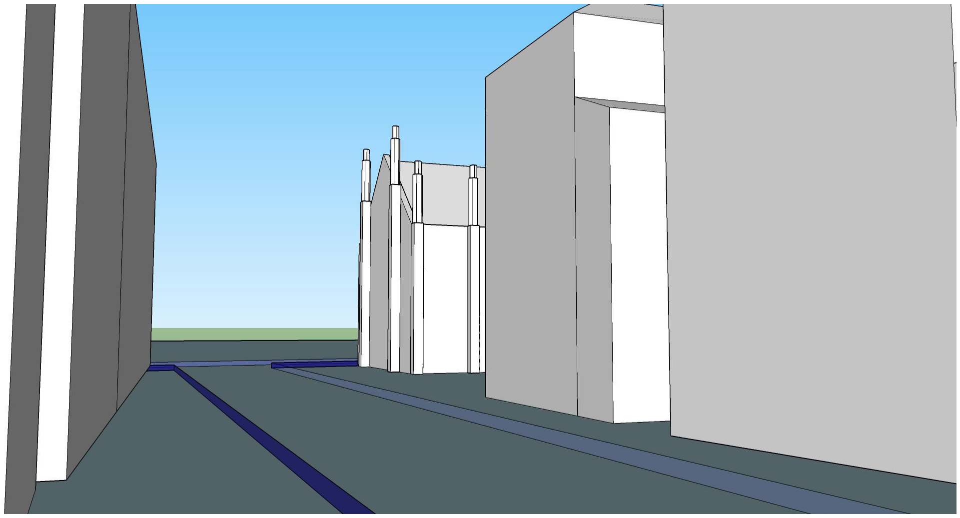


Figure C.19 - *Street-Level Perspective of the French Huguenot Church.*
The image above was captured at "eye-height" and looks north towards the French Huguenot Church. The massing of the Dock Street Theatre can be seen at the left side of the perspective.
Screen-capture in SketchUp by author

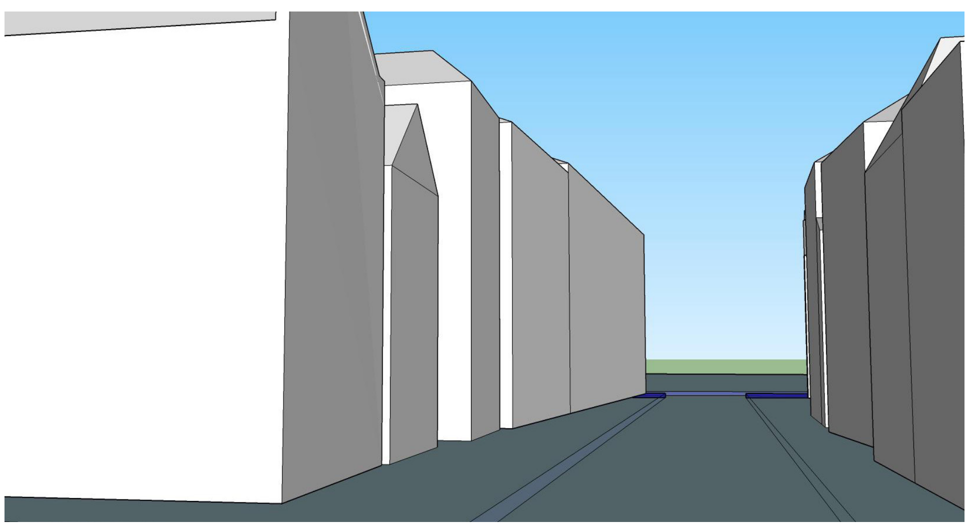


Figure C.20 - *3D Model Streetscape Perspective.*
The image above was captured at the intersection of Chalmers and Church streets and looks north. The general massing of the block can be understood from this perspective.
Screen-capture in SketchUp by author

Appendix D

Matrices from Concluding Analysis of Digital Documentation Technologies

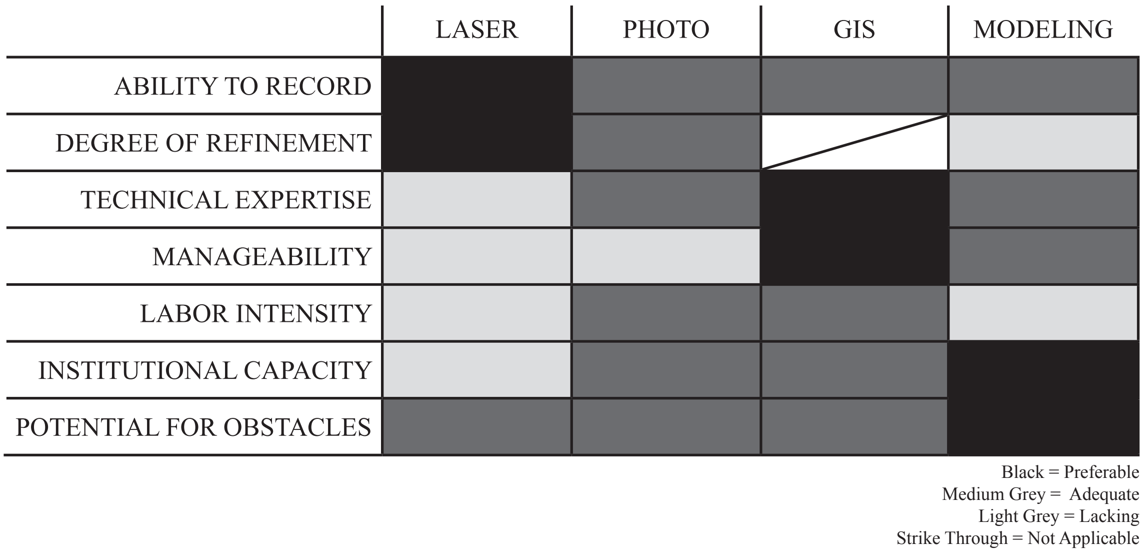


Table D.0 *- Analytical Parameters.*
The table above represents the accumulation and average of the finer headings to be discussed later in the chapter for the digital documentation technologies - laser scanning, photogrammetry, multimedia GIS and three-dimensional modeling.

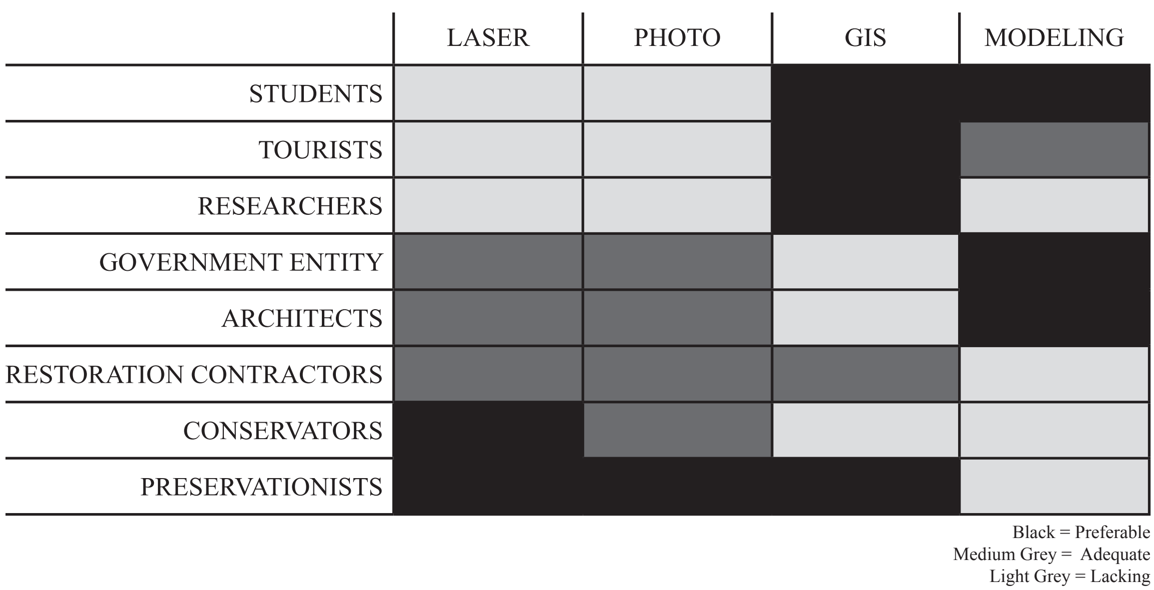


Table D.1 *- Perceived Target Audience.*
The table above communicates the perceived target audiences and intended users for the digital documentation technologies.

	LASER	PHOTO	GIS	MODELING
EDUCATION	Medium Grey	Medium Grey	Black	Medium Grey
HERITAGE TOURISM	Light Grey	Light Grey	Black	Light Grey
RESEARCH	Light Grey	Light Grey	Black	Light Grey
INTERPRETATION	Light Grey	Light Grey	Black	Light Grey
URBAN PLANNING	Medium Grey	Medium Grey	Light Grey	Black
PRESERVATION	Black	Black	Medium Grey	Light Grey
CONSERVATION	Medium Grey	Medium Grey	Light Grey	Light Grey
RECONSTRUCTION	Black	Medium Grey	Light Grey	Medium Grey
TRACKING EVOLUTION	Light Grey	Medium Grey	Medium Grey	Light Grey

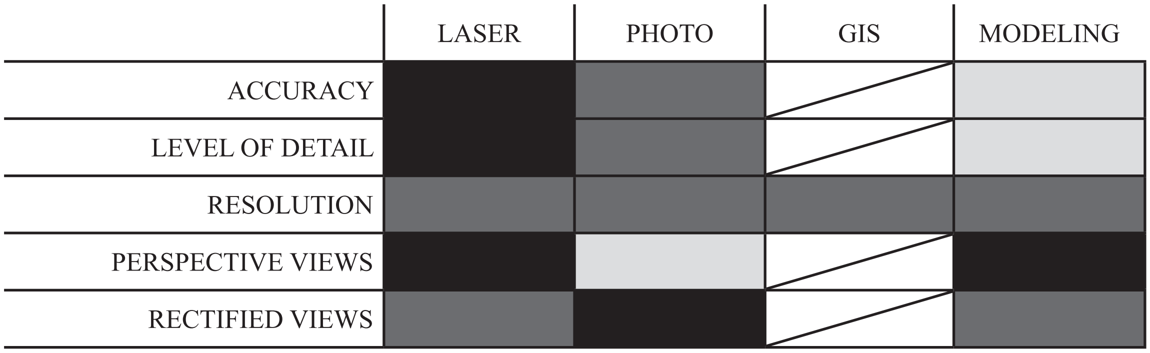
Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking

Table D.2 *- Effective Application.*
The table above communicates the most effective applications for the digital documentation technologies.

	LASER	PHOTO	GIS	MODELING
SOLID VS. VOID	Black	Medium Grey	Light Grey	Black
HEIGHT, SCALE, MASS	Medium Grey	Medium Grey	Medium Grey	Black
ROOF FORM	Light Grey	Light Grey	Black	Black
FENESTRATIONS	Black	Black	Black	Light Grey
SURFACE TEXTURE	Black	Medium Grey	Medium Grey	Light Grey

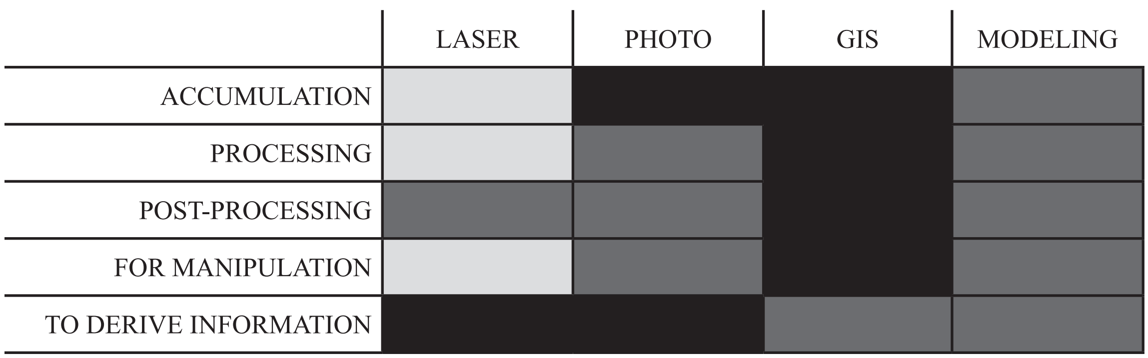
Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking

Table D.3 *- Ability to Record Urban and Architectural Features.*
The table above communicates the ability for the digital documentation technologies to record urban and architectural features.



Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking
Strike Through = Not Applicable

Table D.4 *- Degree of Refinement.*
The table above communicates the degree of refinement achieved by each digital documentation technology.

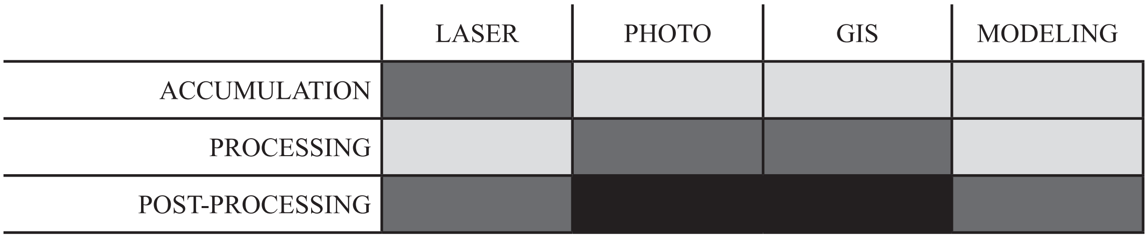


Black = Minimal Expertise Required
Medium Grey = Moderate Expertise Required
Light Grey = Significant Expertise Required

Table D.5 *- Technical Expertise Required.*
The table above communicates the level of technical expertise required for the digital documentation technologies.

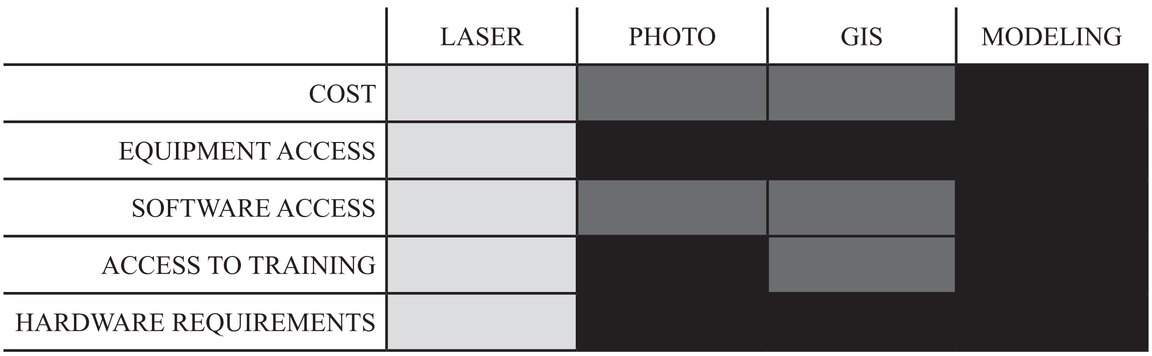
Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking

Table D.6 *- Manageability.*
The table above communicates the degree of internal manageability for the digital documentation technologies.



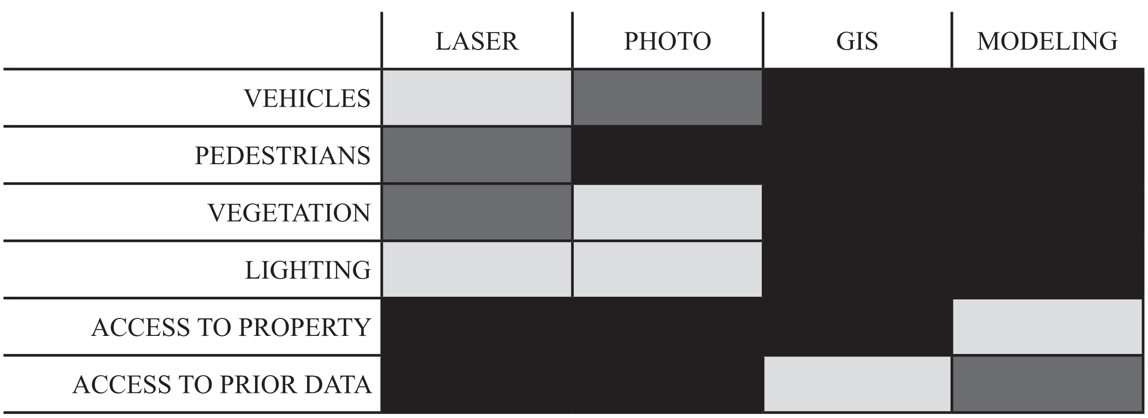
Black = Low Intensity; Significant Passive Time
Medium Grey = Moderate Intensity
Light Grey = High Intensity; Significant Active Time

Table D.7 *- Labor Intensity.*
The table above communicates the level of labor intensity, as well as the relative passive and active time for the digital documentation technologies.



Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking

Table D.8 *- Institutional Capacity.*
The table above communicates the institutional capacity required for the digital documentation technologies.



Black = Minimal Impediment
Medium Grey = Moderate Impediment
Light Grey = Significant Impediment

Table D.9 *- Potential Obstacles and Areas of Failure.*
The table above communicates potential obstacles and areas of failure for the digital documentation technologies.

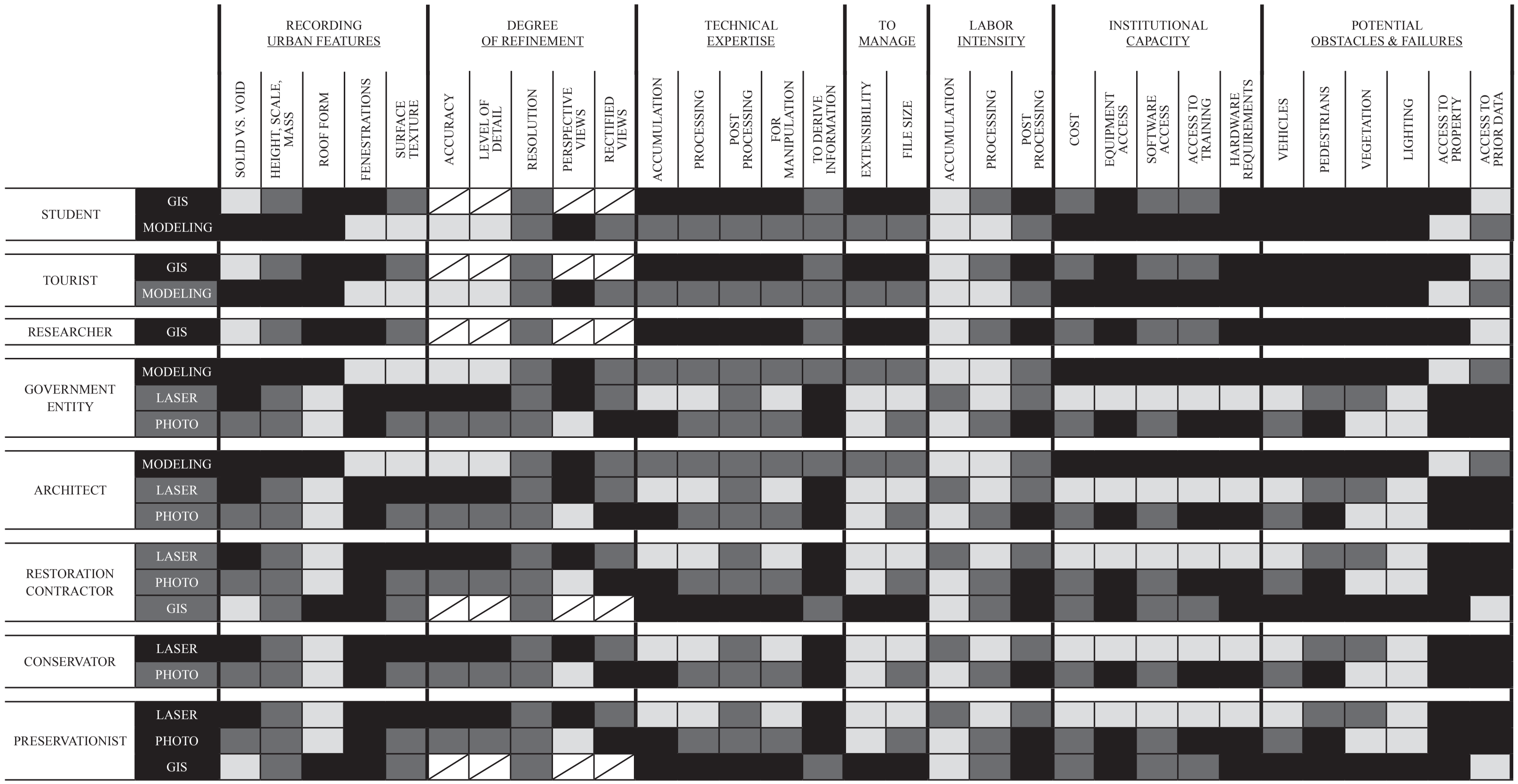


Table D.10 - *Audience-Parameter Table for Cross-Referencing.*
The table above illustrates the most successful, as well as the adequate documentation technologies for each of the perceived target audiences. The parameters and their subcategories used to evaluate the techniques are included for a comprehensive cross-reference. Technologies that were lacking or less preferable for the audience are eliminated from this chart, but can be found throughout the analysis chapter.

Black = Preferable
Medium Grey = Adequate
Light Grey = Lacking
Strike Through = Not Applicable

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