DOCUMENTATION AND DATA MANAGEMENT STRATEGIES FOR FRANK LLOYD WRIGHT'S TALIESIN WEST

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A THESIS

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### Abbreviations

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<th>Description</th>
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<tbody>
<tr>
<td>AIA</td>
<td>American Institute of Architects</td>
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<tr>
<td>AEC</td>
<td>Architectural, Engineering and Construction</td>
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<tr>
<td>BIM</td>
<td>Building Information Modeling</td>
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<tr>
<td>CAD</td>
<td>Computer-Aided Design</td>
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<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<tr>
<td>HABS</td>
<td>Historic American Building Survey</td>
</tr>
<tr>
<td>IFC</td>
<td>Industry Foundation Classes</td>
</tr>
<tr>
<td>LoC</td>
<td>Library of Congress</td>
</tr>
<tr>
<td>LOD</td>
<td>Level of Development</td>
</tr>
<tr>
<td>MEP</td>
<td>Mechanical, Electrical and Plumbing Engineering</td>
</tr>
<tr>
<td>NHL</td>
<td>National Historic Landmark</td>
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<tr>
<td>NIBS</td>
<td>National Institute of Building Sciences</td>
</tr>
<tr>
<td>NBIMSPC</td>
<td>The National Building Information Model Standard Project Committee</td>
</tr>
<tr>
<td>PMI</td>
<td>Project Management Institute</td>
</tr>
<tr>
<td>RFP</td>
<td>Request for Proposal</td>
</tr>
<tr>
<td>SHPO</td>
<td>State Historic Preservation officer</td>
</tr>
<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
</tr>
<tr>
<td>UTSA</td>
<td>University of Texas San Antonio</td>
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1. Introduction

“One Ring to rule them all, One Ring to find them,
One Ring to bring them all and in the darkness bind them.”

J. R. R. Tolkien, The Lord of the Rings

Historic sites connect us to our heritage so that we can better understand our past by building a sense of identity.\(^1\) This thesis will address the constant search for an approach to organizing historical information in the digital age, as well as the need for a tool that can work with that historic information for both management, as well as educational purposes, that echoes the technological advances of the moment. This search for solutions needs to be tempered by finding realistic long-term methods employing common file types which have reached critical mass and have a good track record. Every historic site, on a daily basis, has to deal with issues related to its conservation, documentation, recording and educational programs, all of which are directly connected to the management of the site. This means that preservationists, or site managers, are left with vast amounts of data that they need to organize and communicate to others, but it is not always an easy task to find out which formats and software are most useful and cost effective for the site’s specific needs. Across the United States historic sites are placing more dependence on modern digital tools and techniques to better understand and maintain their resources. These modern systems capitalize on the benefits of

the technological revolution by offering better integration of data, helping to reduce costs and increase productivity, but also by providing analysis, visualization and interpretation in ways that would not have been possible a decade ago.

This thesis has several areas of inquiry focusing on traditional, as well as modern digital recording and data management approaches, in an effort to identify a package that can meet the preservation and conservation management needs of a site, but also serve outside researchers. The term package is used here because the expectations of a single software that meets all a site’s needs is overly optimistic and, in many regards, unrealistic. Professionals in the field may be misled to think that one software or method can manage all of the issues or tasks that they are going to encounter while managing their site, which is why this thesis explores those needs, and explores the software that are used for those tasks.

Architect and Builders, as well as property and construction managers, are using Building Information Modeling (BIM) on a daily basis for design and recording of the building fabric, a technique that’s growing in popularity with heritage management. This thesis will address what BIM as a concept is and look to answer questions such as:

- What is BIM?
- How does BIM impact Heritage Sites?
- How can BIM be applied to sites like Taliesin?
- What benefits does BIM offer?
- Is BIM a single software solution?

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Dozens of different digital tools and techniques are currently available to record and maintain historic site data, many of which are worthy investments, and all of which may find justification. The approach taken in this thesis is not intended to suggest a single solution to the problem, nor is it intended to be a perfect solution, but instead is intended to help a specific site attempt to identify ways to make good choices based on the extremely complex needs and limitations of that site. To meet these goals, the study will focus on the office of Frank Lloyd Wright at Taliesin West as a case study, but in the process of identifying solutions it will discuss issues that are common in many historic sites including maintenance, recording, and digital data management.

In the context of this thesis, understanding site management, and specifically preservation site management, is important for understanding why the use of BIM. Management is key for the survival and preservation of historic sites. Sites like Taliesin West need to be monitored daily to address typical maintenance issues, but they also need to be viewed with a longer lens when addressing issues related to long term care, to ensure these sites can be saved for future generations. Management is the way of stewardship for these sites.

This thesis explores questions like:

- What does project management at Taliesin West entail?
- Who are the professionals involved with addressing management issues at sites?
- What software options are there for the professionals at Taliesin West to care of for the site and buildings?

The answers to these questions will inform the final package.

And finally, this thesis will focus on the benefits and significance of physically “recording” historic sites and structures both for the purposes of site management, but also for the purposes of the long-term knowledge and understanding of design and cultural traditions.
associated with architecture in the United States. Unfortunately, there is conflict in the fact that
the collected data for one group may not have universal value to all. While it can be difficult to
place any clearly defined monetary value on the historic and cultural benefits associated with
recording, it has always been one of the most important foundation blocks for proper historic
preservation in this country. To this day, the Historic American Building Survey (HABS) stands as
the most important repository for documentation of the built world in the United States
creating a lasting record for future generations.³ The organization was tasked with creating and
maintaining a “complete resume of the builder’s art” from the “smallest utilitarian structures to
the largest most monumental”.⁴ By creating this public archive of America’s architectural
heritage, HABS has provided a “database” of primary source material. HABS currently provides
several guidelines that remain the foundation on which many techniques of recording historic
buildings in the United States have been based. HABS recording, which is one of the foundations
of the preservation field, serves the greater national good by providing a permanent record of
the nation’s most important historic sites and large-scale objects, including Taliesin West. But it
is not a stated goal of HABS, that the teams recording and submitting to HABS produce useful
resources for a site itself. The HABS drawings that have been created at Taliesin West have not
been useful to the site as a management tool for either daily maintenance and preservation
needs, or the more didactic aspects of site evolution. The debate remains of how these types of
drawings are of use for the management needs of historic sites.

In order to better understand the complexities of the discussion, certain terms need to
be defined. While the Secretary of the Interior Standards and Guidelines defines

³ American Place: The Historic American Buildings Survey at Seventy-Five Years. [Washington, D.C.]:
⁴ Ibid., 1.
“documentation” in a general sense as providing important information related to the significance of a property for use by historians, researchers, preservationists, architects, and historical archeologists, it doesn’t identify the nuanced difference between the more text based work of architectural historians, and the graphic work typically associated with the efforts of architects or “recorders”. For clarity in this thesis, the term “documentation” will be used for reference to the text based process typically associated with the written part of the Historic American Buildings Survey (HABS) work, while the term “recording” will be used for work associated with the more graphical documents typically found in the drawings and photography of HABS.

Site management, project management, maintenance and conservation/preservation can all find common ground; however, each one has a unique role in the overall functioning of an historic site like Taliesin West. While a section of the thesis will go into greater depth on the meaning and function of some of these roles, it is important here to create a basic definition of each of these terms in order to provide clarity. Site management encompasses the work of project management, maintenance and conservation/preservation where a site manager will generally have authority over the work of project managers, the maintenance staff as well as the conservators. The job of a site manager is to ensure that the work of all parties is in the best interest of all stakeholders. The site manager has a long-term investment in the site and is often a full-time employee of a site. A project manager is typically hired for the duration of a specific project. While both are vital to the site and the completion of any project, the site manager has the entire site in his purview while the project manager is dealing with the specific completion on a contracted project. Maintenance refers to the general day to day aspects of maintaining the function of a site. This might include, but not be limited to, janitorial services, grounds keeping, as well as basic construction and painting. Conservation/Preservation refers
specifically to people trained in the nuanced complexities of historic sites. This might include, but not be limited to, the conservation of identified historic fabric as well as the identification of proper methods for replacing and repairing, based on principles governing the preservation field such as the Secretary of Interior Standards for the Treatment of Historic Properties.

Frank Lloyd Wright was an American architect, writer and educator whose career lasted more than 70 years. He is internationally recognized for projects such as Fallingwater in Western Pennsylvania and The Guggenheim Museum in New York City, but may be best known for designing in both the Prairie and Usonian styles. When Frank Lloyd Wright was seventy, he arrived with his wife Olgivanna and his apprentices to Arizona, where they created a camp of improvised shelters at the Mcdowell Mountains, the current location of Taliesin West. Taliesin West, officially located in Scottsdale, Arizona, was intended to serve as Frank Lloyd Wright’s and his apprentices’ winter home. Unlike other designs by Wright, this complex was created using the principles of Organic Architecture which is a philosophy that promotes harmony between human habitation and the natural world. Achieved through design approaches that aim to be sympathetic and well-integrated with a site, the buildings, furnishings, and surroundings of the Taliesin campus become part of a unified, interrelated composition. Wright believed that materials should be used honestly. Taliesin West was known as a place of constant change and experimentation where trades people were not hired, but instead the apprentices built the structures and learned the crafts associated with making architecture a reality.

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comfortable with this approach since it was his home and he was the only one accountable.9

Today, Taliesin West serves as the home of the Frank Lloyd Wright Foundation. The site also possesses an “outstanding universal value” attracting international visitors and being designated a UNESCO World Heritage Site.10 Nationally it has been recognized as a National Historic Landmark (NHL) and included in the National Register of Historic Places.

The Frank Lloyd Wright Foundation is committed to the preservation and stewardship of both Taliesin in Wisconsin and Taliesin West in Arizona.11 They are committed to continued research, in an effort to articulate how these sites and their accompanying structures were developed and how to best care for them for future generations.12 The tradition of change at Taliesin West, even today, creates challenges for preservationists and outside researchers alike, to preserve the structures.13 There is no clearly defined period of significance and the philosophy of the architect was always to have a continued evolution whenever it was necessary. While Wright died in 1959, building construction on site ranges from the late 1930’s until 1980 and beyond. It would seem, however, that this notion of change, which was so vital to the philosophy and existence of Taliesin West, is what preservation can often prevent. While

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9 Taliesin West typically underwent annual changes any time Wright saw a better way to alter or improve an element, or when the natural materials were so deteriorated that they needed to be replaced. Ibid., 38.
10 Outstanding Universal Value: “cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. As such, the permanent protection of this heritage is of the highest importance to the international community as a whole.” “Operational Guidelines for the Implementation of the World Heritage Convention.” UNESCO World Heritage Centre, n.d.; “Frank Lloyd Wright Foundation Unveils UNESCO Plaque at Taliesin West.” Frank Lloyd Wright Foundation, January 15, 2020. https://franklloydwright.org/frank-lloyd-wright-foundation-unveils-unesco-plaque-at-taliesin-west/.
12 Ibid.
examples of this dilemma can be found across time throughout the site, an active example is the famous canvas roofs found in several locations on the site. Originally constructed of canvas and wood, through the years Wright changed their design to increase longevity and to allow them to provide better shelter from the harsh Arizona environment. Even after his death, changes continued to occur, but most experts of the site would agree that none of the realized designs were ever an ideal solution. The site is currently looking for a better solution for these roofs that are both sympathetic to the original intent of the architect, but can also solve the problem of leaking, as well as the difficulties and expense associated with constant replacement. The question of what is appropriate always lingers because preservation is now one of the most important priorities at Taliesin West, but should Wright’s philosophy of continued change be cast aside or followed?
2. Recording and Site/Project Management

While entropy is primarily defined as a property of Thermodynamics, it is also described in the dictionary as a process of degradation, running down or a trend to disorder. Most active building sites, historic or otherwise, require some form of active management in order to avoid this fate. Without proper management, both physical and administrative characteristics of sites will degrade. The Project Management Institute (PMI) defines project management as the “art of directing and coordinating human and material resources throughout the life of a [site or] project by using modern management techniques to achieve pre-determined objectives.”

Project management, or site management, helps sites address issues related to the deterioration and growth of a site. This is important because the managers will not only work planning and executing the projects, but also addressing all the risk factors of the site to better achieve the goals of the site for the physical fabric, as well as for educational purposes.

Managers need to have knowledge of the values and significance of the site in order to make decisions about all the different projects affecting the site for both the short and long term. The PMI Guide to Projects Management Body of Knowledge describes the job of a project manager or site manager as “The conductor who provides the orchestra with leadership, planning, and coordination through communications. The conductor provides written communication in the form of musical scores and practice schedules. The conductor also communicates in real time with the team by using a baton and other body movements.” Site Managers are expected to communicate well with all the consultants so it’s important for them to have knowledge about

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the different tasks involved with a project. In addition, they need to have basic understanding of fields such as architecture, construction, design, and engineering.

All well executed building projects, both new and historic, typically depend on some form of site management. In the building and construction industry, which typically addresses the construction and management of new buildings, site managers, also referred to as project managers, construction managers, site agents or building managers, are responsible for the day-to-day running of projects on a site. Project managers are required to keep within the timescale and budget of a project, and manage any delays or problems encountered on-site during the project. Also involved in the role is the managing of quality control, health and safety checks and the inspection of work carried out. In addition, project managers are responsible for managing communications between all parties involved in the on-site development of the project.

Typically, a project manager is employed by a construction company, contractor or civil engineering firm, however; project managers can also be hired by the company or organization where the work is being carried out. This type of project manager, typically referred to as an owner’s rep, is someone hired by an owner to manage and execute a design and construction project on their behalf – particularly when they don’t have the industry knowledge, time or resources to carry out the work themselves. An owner’s rep acts as the owner’s eyes and ears throughout the entire process with the sole purpose of executing the owner’s goals and mission.

As far as site management is concerned, historic sites can differ from their more contemporary counterparts when addressing values of significance and character defining features more commonly associated with historic preservation. Unlike new construction, or projects in non-historic buildings, historic sites often need to follow additional guidelines and

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may require extra permits from entities that look after the integrity of community heritage. In addition, section 106 guidelines may need to be addressed if the site is owned by, or in any way is financed by the government. Although some people might suggest historic sites differ greatly from their contemporary counterparts, as far as their management needs are concerned, in reality, both require similar planning standards. The following explains the PMI’s 5 phases of project management which are called Process groups:

- Phase one, or the initial process, focuses on project definition and authorization.
- Phase two, the planning process, focuses on goals, scope and course of action.
- Phase three, the executing process, addresses the processes necessary to complete the work defined in the management plan.
- Phase four, the monitoring and controlling process is the tracking, reviewing and regulation phase of the project; if changes are going to be made to the plan they are applied in this stage.
- Phase five, the closing process, is where the project is formally closed.

2.1 Recording and Documentation as a Management Issue

From a site management perspective, the “history” or “evolution” of a site and its structures is not always seen the same as the long-term character defining changes identified by historians. And at historic sites, the marriage of these two types of evolution can sometimes be rocky. Site maintenance and site preservation can often be at odds with each other because many of the efforts, typically viewed as maintenance, can also be viewed as destructive to historic fabric. The addition of new fixtures, or the replacement of broken ones, which are critical to the day to day functions of a building, can often be seen as detrimental to the historic character of a site, and in some cases can directly conflict with specific city guidelines, especially
if it is a modification to the exterior. A document such as the Code of Ordinances for the
Development of Historic Resources in Scottsdale, Arizona, the community in which Taliesin
stands, states:

No building, permanent sign, or other structure in an HP District shall be
erected, demolished, moved, restored, rehabilitated, reconstructed, altered, or
changed in exterior appearance, nor shall any historic resource be altered,
moved, remodeled, demolished, enlarged or extended contrary to the Historic
Preservation Plan for the HP District or historic resource until plans for such
activities have been submitted to and approved by the Historic Preservation
Officer or the Historic Preservation Commission, and the City has issued a
Certificate of No Effect, a Certificate of Appropriateness, or a Certificate of
Demolition Approval for the subject property. This requirement is in addition to
any other permit or approval required by law.17

In addition, some communities make even clearer definition of what is deemed
unacceptable. Doing just a cursory search on the internet displays the guidelines from a wide
range of different communities throughout the country including Cartersville, Georgia which
states that “[I]t is not appropriate to introduce contemporary equipment to include satellite
dishes, solar collectors, playground equipment, heating and air units, storage units, swimming
pools in locations that comprise the historic character of the building site”.18 The simple act of

17 Sec. 6.120. - Development of Historic Resources. (Ord. No. 3242, § 7, 7-13-99; Ord. No. 4143, § 1(Res.
No. 9678, Exh. A, § 128), 5-6-14)
https://library.municode.com/az/scottsdale/codes/code_of_ordinances?nodeId=VOLII_APXBBAZOOR_AR
TVISUDI_S6.121ALHIREAPRE

18 Cartersville Historic Preservation Commission. “Guidelines for Structures Contributing to the Historic
Residential-Guidelines?bidId=
adding an air conditioning unit to a site like Taliesin West can be in conflict with acceptable preservation practices, even though it is seen as vital to the long-term success of the site and its visitorship.

2.2 The Management Structure of Taliesin West

Taliesin West, like all sites, encounters unique management challenges involving maintenance, funding, visitation, education, etc. The site management team at Taliesin consists of two employees of the Frank Lloyd Wright Foundation, Vice President of Preservation, Fred Prozillo and Director of Preservation, Emily Butler. In almost every building related project at Taliesin West, both Prozillo and Butler are involved from start to finish, and while their roles differ, they complement each other. As site managers they both are responsible for assessing and addressing the physical fabric of the full Taliesin West campus. Prozillo oversees and sets priorities for the preservation and collections department, both at Taliesin and Taliesin West. He is focused on developing the big picture planning for preservation on both sites.\(^{19}\) Butler’s tasks are focused specifically on Taliesin West and range from doing visual inspections, planning project phases, going through local SHPO or local government permit processes, developing Request for Proposals (RFP), hiring staff and scheduling for projects, managing budgets and training facilities staff as well as working on conservation plans for the site.\(^{20}\) Both staff members will go through all the steps a typical project manager needs to follow to achieve their goal. They will be the primary people monitoring the budget, contractors and other professionals that are involved, and as the owner’s reps, it is their responsibility to communicate their intent to the leadership of the foundation.

\(^{19}\) Emily Butler (Director of Preservation at Taliesin West) in discussion with author, February 2020.  
\(^{20}\) Ibid.
2.3 The Historic American Building Survey and the goal of the HABS Collection

In order for site managers to do their jobs effectively they need to have proper baseline recording information. For a contemporary project, this typically consists of what the American Institute of Architects (AIA) describes as the construction documents. These documents include the written and graphic instructions used for construction of the project. In the AIA *Emerging Professionals Companion*, it describes construction documents as “The unique combination of words and drawings that is the last iteration of the virtual building—and the first that most nearly approximates its final shape.”21 These documents must be accurate, consistent, complete, and understandable. Without question, the most important part of those construction documents is the architectural drawings, which have been completed to a level that allows a builder to be able to fully construct the project in question. All details, no matter how small, or how buried in a wall, need to somehow be included in these documents.

For historic sites, this level of recording can be difficult to either find or achieve. In many cases, original construction documents for the site have been lost, and what is available is often not complete or lacks full detail. In many cases, the actual constructed building did not, in every case, follow the drawings to full completion, making the available material inaccurate. This is particularly the case for Taliesin West where no construction drawings were ever created. Due to the unique way in which Wright designed his buildings at Taliesin West, available drawings consist mostly of conceptual sketches on butcher paper. And since Wright and his apprentices were constantly modifying the site through time, what drawings are available, often do not reflect the current design.

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For historic sites, drawings from the collection of HABS are often seen as critical to this baseline documentation, and for some sites they are seen as a replacement for the missing original records. In the introduction of the *HABS Guidelines for Recording Structures and Sites* it states that “A significant role for HABS drawings is that of base architectural drawings for facilities management purposes, as well as for renovation and restoration projects. And where an important historic resource is faced with an adverse impact, such demolition or substantial alteration, HABS documentation can serve a mitigative role.” It is important to point out, though, that while HABS drawings can be used for management purposes, they are not specifically created for management purposes. In the 1930’s the Historic American Building Survey (HABS) was created to document America’s heritage in order to mitigate vanishing architectural resources. The mandate stated “to document for posterity America’s architectural heritage through the production of measured drawings, historical reports, and large format, black and white photographs for inclusion in a centrally located, publicly accessible repository.” Nowhere in the HABS mission does it state that the drawings produced for HABS need to serve the site which is being recorded, nor does it state that the drawings should be a complete record of all features of a building and in most cases, the ability to create detailed drawings that meet the standards of the AIA for construction documents is just not realistic, due to time and budget constraints, as well as an inability to actually see everything that is contained within the walls of an existing structure.

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The Historic American Buildings Survey, however, identifies two distinctly unique efforts associated with the recording process. This consists of the written history containing the historical context in which the structure was built and subsequently evolved, as well as the drawings and photography component which generally includes the features as they exist at the time of recording, meant to convey floor plans, elevations, architectural details, and construction elements. While this process is sometimes expanded to include sectional or axonometric drawings to convey the interrelationship of the building parts, the drawings themselves, are not seen as the key to conveying changes, both large and small.\(^{25}\) The HABS drawing guidelines directly state that:

HABS drawings are considered “as-built” drawings. As such, they illustrate the existing condition of a building at the time of documentation, including additions, alterations, and demolitions which have occurred since the building was first constructed. Where enough knowledge exists concerning the sequence of changes to a building over time, it may be useful to provide appropriate notation on the drawings. Alternatively, delineators may wish to produce additional interpretive drawings illustrating the building at an earlier date, in order to more fully explain its historic significance.\(^{26}\)

The tone of the statement above marginalizes the act of showing building evolution and changes within the drawings themselves. This is not to suggest that HABS does not support the


recording of changes over time, but it does draw attention to the decision by HABS to have the written component be the primary source for this type of information.

It is well understood though, by people in the preservation field, that building, and site evolution can often be presented very effectively through photography and drawing, and the didactic qualities of three-dimensional drawing can offer an added benefit. Historic England has created a series of documents which address the recording of historic buildings, and their document titled *Drawing for Understanding* states that “Three-dimensional drawings can be useful for showing relationships between numerous floor levels and relating interior spaces to exterior features. These types of drawing, like reconstruction drawings, are a useful aid to interpreting the evolution of a building.”

Harley McKee, in the introduction to his 1970 book entitled *Recording Historic Buildings*, stated the following “In this era of accelerating change, accurate and thorough records of historic American architecture are among the essential tools for scholarly study and historic preservation. It is highly important that records be made of these historical links between past and future generations.”

Having detailed documentation and recording is already viewed as a requisite for being a World Heritage site, but nowhere in the available treatises on recording from around the world does it clearly state a common level of detail or the type and format of the product needed. There are many historic sites around the nation which vary in size, resources and management needs, and most have an established set of objectives to help define how they are interpreted and managed. In the current market though, most have

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developed plans which follow current trends in digital recording, often overlooking the importance of long-term data flow. Proprietary file types are common, and the software being used often cost more than a typical annual budget can afford or require specialized training. Additionally, available resources from other organizations, such as HABS, are often not in an ideal format for current management trends. This typically results in tools and resources that are outdated or unusable and files formats which are obsolete. It is important to remember that HABS recording is not intended to become a record of the typical small-scale day to day modifications of a structure which typically fall under the purview of maintenance and are so vital to active site management. This disconnect between the available data and the needs of a site are not the fault of HABS, and nowhere in the available documentation from HABS is there a specific set of guidelines that tell recorders the type of software required, or the file type needed to produce HABS drawings. The guidelines focus more on the product and not the process, leaving the burden of responsibility for file types and formats in the hands of the recording team.

2.4 Taliesin West Current Recording Needs

When dealing with site management at a historic site such as Taliesin West, all changes need to be considered as a vital part of the overall evolution, with maintenance informing preservation and preservation informing maintenance. To achieve these goals a single integrated “site management” system should be maintained where all parties can find their data. As a site, Taliesin West provides an ideal set of factors for assessing long-term site management tools related to preservation. One of the most pressing considerations of any historic site is the need to maintain existing historic fabric, however; During Wright’s lifetime Taliesin West has maintained continuous alteration of its materials as part of its core mission.
The National Register nomination, which was written in 1984, draws attention to the preservation challenges of the site in the following statement:

Frank Lloyd Wright altered details and added to Taliesin West, from the time of the construction of its principal components, in 1937-38, until his death in 1959. Since that time, alterations of form to the existing structures have, in general, been minor, although later additions have been made to some of the structures, and a few buildings have been added in areas remote from the main grouping. In the interest of durability, however, materials in the early portions have been modified. These changes began during Wright’s lifetime. The major modification in materials involves the canvas originally used for roofing and windows. Wright had intended the canvas to be stored each year, during the Fellowship’s absence at Taliesin in Wisconsin. Although the canvas provided the intended light and spaciousness, seasonal use proved untenable, because the Fellowship’s stays at Taliesin West grew longer and longer. The canvas wore out quickly, being prone to leaks and decay when in constant use. Thus, beginning in 1945, after Mrs. Wright’s urging, the canvas was replaced with translucent plastic and glass. Wright had come to view this change in a positive light. 29

Fred Prozzillo, current Vice-president for Preservation of the Frank Lloyd Wright Foundation states that “Taliesin West was Wright’s living laboratory, a place where he explored form, materials, and concepts for living in the desert. Each year, upon returning from summers in Wisconsin, Wright would build and re-build his winter camp. It was a place of learning and

continual change, like most camps there was a sense of impermanence in its very creation”.30 Wright’s original vision of replaceable materials, however, is inconsistent with some of the standard views of preservation, which generally frown upon replacement of materials unless necessary. On page 27 of the *Secretary of Interior Standards for the Treatment of Historic Properties*, preservation is defined as “the act or process of applying measures necessary to sustain the existing form, integrity, and materials of an historic property. Work, including preliminary measures to protect and stabilize the property, generally focuses upon the ongoing maintenance and repair of historic materials and features rather than extensive replacement and new construction.”31

As a site of National Register and UNESCO status, Taliesin West consists of over 620 acres containing buildings, underground infrastructure, both man-made and natural landscape features, as well as student-built structures which are all vital to the overall quality which defines Taliesin West. With this complexity, five principle issues are worth considering.

- The site has expressed a need and a desire for a digital data management package.
- Existing digital HABS documentation is available, furthermore a program established with the University of Texas San Antonio will increase the amount of available data as students document different structures at the site every year.
- The site is complex enough to justify using BIM and can be seen as on par with other historic sites in the nation.

• There is a pressing need for a full set of accurate “as-builts” of all structures on site, ideally in three-dimensions.

• An ideal system would be able to integrate or communicate with other digital platforms such as ArcGIS.32

Preservation Director Emily Butler states that good recording helps them make better and more informed decisions regarding where and how best to make interventions in the historic building fabric when necessary.33 High quality two-dimensional drawing, using the traditional HABS approach, has been an ongoing pursuit at Taliesin West through work being done by the students of the University of Texas in San Antonio. But while the management team at Taliesin West unequivocally states that they appreciate the drawings of Taliesin West being produced for the HABS collection, they do admit that the drawings themselves often don’t provide the necessary level of detailed information, and that the format of the available drawings is not ideal for addressing the day to day needs of their site based on current management trends.34

In order for Taliesin West to better manage their preservation into the future, members of the in house management team have identified a set of management needs that are vital for long term care, but at present are difficult to achieve, due to the complexity of this level of recording, and the time needed to achieve it. This includes more comprehensive recording on both a two-dimensional, and more importantly, a three-dimensional level, as well as a digital platform to manage that collected data. In addition to what the Taliesin team identified, T. Gunny Harboe, of Harboe Architects, who was given the responsibility of writing the Taliesin

32 Ibid.
33 Emily Butler (Director of Preservation at Taliesin West) in discussion with author, November 2019.
34 Emily Butler (Director of Preservation at Taliesin West) in discussion with author, February 2020.
West Master Plan in 2015, stated that it is vital that a thorough and clear interpretive program be developed to fully explain the history of Taliesin West. This should include an explanation of the changes over time that have occurred in the past and those that will likely occur in the future. What are the options for being able to create a connection between the type of work being commonly produced for HABS and the type of data necessary for daily project management by a management team at a site like Taliesin West? Both comprehensive drawings, and building evolution are uniquely challenging propositions at Taliesin West, due to the experimental nature so central to Wright’s vision for the site. The HABS guidelines outline the two-pronged approach which has been traditionally used to accomplish these goals. But by following the guidelines of HABS, the drawings themselves, generally do not convey building evolution and are not being produced as a platform on which Taliesin West can begin to incorporate their own data, such as day to day maintenance work. In addition, the drawings are strictly two-dimensional, which eliminates the benefits of the more didactic potential found in three-dimensional drawings. This leads to a critical question of what can be done from a site management perspective to ensure a symbiotic relationship between the type of documents that are required to satisfy HABS and the types of resources that can serve the long-term needs of historic sites like Taliesin West?

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3. A Three-Dimensional BIM-based Platform for Taliesin West

Historic sites, like Taliesin West, can find added benefit from a three-dimensional digital platform rather than the more traditional two-dimensional approach, since the models can recreate a more realistic virtual representation of the physical and spatial characteristics. In addition, the three-dimensional model can function as a single source for all the drawings and can also serve as a platform for a database of information typically addressed in site management. With the added benefit of BIM additional data can be linked to each of the building components. Two-dimensional records of structures have always been important and useful as a way to inform users of the original intent of the designers, and the current two-dimensional work being produced for HABS at Taliesin West offers many of those benefits. The highly unique architecture of Taliesin West is complex to comprehend, though, where the organic design of the slanted masonry walls is difficult to fully visualize in a two-dimensional drawing. Two-dimensional documentation will always be useful to have at hand and make available to contractors and other professionals, to complement a three-dimensional model, as well as for submittal to repositories like the Library of Congress (LoC).36 Three-dimensional model allow anyone to quickly produce highly specific two-dimensional drawings from any location within a structure at the moment they are necessary, unlike regular two-dimensional documentation, where traditionally only a few sections are pre-determined and then produced.37 The benefits are not just limited to the production of these specialized two-dimensional drawings, but include the ability for a site to produce renderings and animations from the same model, which can offer educational benefits without the added financial burden

of having to create a new source for the information. Additionally, more comprehensive
descriptive data can be organized and linked to parts of the structure that could provide for
contractors and other professionals working at the site.38

3.1 What is BIM

BIM, which is most commonly used as a noun, is an acronym from Building Information
Modeling. It is commonly defined as a reliable, digital, three-dimensional, virtual representation
of the project to be built for use in design decision-making, construction scheduling and
planning, cost estimates and maintenance of construction projects.39 The National Building
Information Model Standard Project Committee (NBIMSPC) which provides consensus based
standards for BIM nationally, provides a more comprehensive definition. NBIMSPC is a sub-
group of the National Institute of Building Sciences (NIBS) which was established by the U.S.
Congress in the Housing and Community Development Act of 1974, and is an authoritative voice
that supports advances in building science and technology to improve the built environment.40
NBIMSPC defines BIM as a “digital representation of physical and functional characteristics of a
facility. It serves as a knowledge source for information about a facility forming a reliable basis
for decisions during its lifecycle from inception onward”.

A BIM is a digital representation of what will be in new construction; or, in the case of
historic structures and sites, what is already there. Its use has grown quickly in popularity for
Architecture, Engineering and Construction (AEC) as a way to digitally execute projects,

providing open communication between different members of a project team who can all be working from a single common model. A BIM model serves as a base for all associative plans (facades, sections, perspectives, etc.) Each correction on the model is automatically reflected on all plans and also on dimensions, hatches and annotations. Mass and room calculations are made automatically too. Plans can be shown in different scales and any necessary changes are automatic (text size, hatch density, drawing detail).\footnote{What Is BIM - Building Information Modeling? AutoCAD – Tricks, CAD Standards, Block Libraries. Accessed May 21, 2020. https://www.cadtobim.com/what-is-bim.html.} In addition to opening lines of communication, BIM has been shown to help reduce costs, time and mistakes. Referencing the NBIMSPC definition that states from “… inception onwards”, the resulting model produced for new construction is commonly passed to the facility managers of a site to use as a long-term management tool. The model will serve as an expandable database that can allow managers to input information for specific components, resulting in a growing record of work over time.\footnote{Paul Teicholz and IFMA, \textit{BIM for Facility Managers} (New York, UNITED STATES: John Wiley & Sons, Incorporated, 2013). 17. http://ebookcentral.proquest.com/lib/upenn-ebooks/detail.action?docID=1158414.} This information can then facilitate the analysis of costs, quantity, space management, etc.\footnote{Ibid. 18.}

Depending on your definition of BIM, almost any design software can be defined as offering BIM capabilities. Cadaddict.com provides the following list of 10 software which it identifies as BIM, and these are just the ones it defines as architecture based.

- Autodesk Revit Architecture
- Graphisoft ArchiCAD
- Nemetschek Allplan Architecture
- Gehry Technologies - Digital Project Designer
- Nemetschek Vectorworks Architect
• Bentley Architecture
• 4MSA IDEA Architectural Design (IntelliCAD)
• CADSoft Envisioneer
• Softtech Spirit
• RhinoBIM (BETA)\textsuperscript{44}

3.2 Challenges of BIM

Although BIM is useful and provides many benefits to the different phases of design, users can run into challenges if a plan of objectives or “BIM Execution Plan” is not determined before the modelling process begins. A BIM execution plan is a comprehensive document that helps the project team identify and execute the role BIM plays in the various phases of construction management. People can become side-tracked as a result of focusing too much on micro-details. As a result, the entire process can come to a grinding halt. Additionally, if each professional uses different modeling tools, or if the level of development is not appropriate for the creation of construction documents, time efficiency will be lost.\textsuperscript{45} This issue may challenge contractors if migrating models to different software, adding potential errors and time to the project.\textsuperscript{46} When it comes to implementation, it must be understood that BIM is an entire process and cannot be simplified for the sake of time and money. To avoid running into said challenges the user must understand what BIM is and what benefits are brought to a project.\textsuperscript{47}

\textsuperscript{46} Ibid.
\textsuperscript{47} Ibid.
When new construction projects are being designed as a BIM, guidance is critical to maintain the common language of the model components. Many professional practices have created their own standards for deliverables and design phases for clients, but these standards can differ from office to office and are adjusted depending on a project’s need. In response, the AIA, in conjunction with BIMForum, a team of experienced professionals focused on harnessing Building Information Modeling (BIM), and emerging issues in the industry, brought together a group of AEC professionals to define standards that bring language commonality to the field. Two terms commonly associated with these defined standards, are level of detail and level of development, each of which can be confused for the other. Level of detail refers to how much detail is included in a given model element, while level of development, or LOD, is the degree to which that element’s geometry, and attached information, has been developed, or the degree in which team members may depend on the information when using that model. The AIA has defined 5 Levels of Development. The lowest number representing the most primitive model and the highest number representing the most developed. The levels are defined by the 2019 Specifications as:

- Level 100: The Model Element may be graphically represented in the model with a symbol or their generic representation but does not satisfy the requirements for

49 While conducting this research it was apparent that level of detail and level of development are used by the field interchangeably. Even though they work together, they refer to different things, and in this section, both will be referenced. Although, this project is principally working on a historic structure that does not involve new construction development, understanding the needs of level of development and level of detail is key to come to an understanding of what is the most adequate approach for the Taliesin West model.
LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.\(^{51}\)

- **BIMForum Interpretation:** LOD 100 elements are not geometric representations. Examples are information attached to other model elements or symbols showing the existence of a component but not its shape, size, or precise location. Any information derived from LOD 100 elements must be considered approximate.\(^{52}\)

- **Level 200:** The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.\(^{53}\)

  - **BIMForum interpretation:** At this LOD elements are generic placeholders. They may be recognizable as the components they represent, or they may be volumes for space reservation. Any information derived from LOD 200 elements must be considered approximate.\(^{54}\)

- **Level 300:** The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.\(^{55}\)

  - **BIMForum interpretation:** The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to

\(^{51}\) Ibid. 245.
\(^{52}\) Ibid. 245
\(^{53}\) Ibid. 245.
\(^{54}\) Ibid. 245.
\(^{55}\) Ibid. 245.
non-modeled information such as notes or dimension callouts. The project origin is defined, and the element is located accurately with respect to the project origin.\textsuperscript{56}

- Level 350: The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.\textsuperscript{57}

- BIMForum interpretation. Parts necessary for coordination of the element with nearby or attached elements are modeled. These parts will include such items as supports and connections. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information such as notes or dimension callouts.\textsuperscript{58}

- Level 400: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.\textsuperscript{59}

- BIMForum interpretation. An LOD 400 element is modeled at sufficient detail and accuracy for fabrication of the represented component. The quantity, size, shape, location, and orientation of the element as designed can be measured directly from the model without referring to non-modeled information such as notes or dimension callouts.\textsuperscript{60}

\textsuperscript{56} Ibid. 245.
\textsuperscript{57} Ibid. 246.
\textsuperscript{58} Ibid. 246.
\textsuperscript{59} Ibid. 246.
\textsuperscript{60} Ibid. 246.
Since the specifications have excluded Level 500 from this reference the U.S. General Services Administration (GSA) definition will be used:

- **Level 500**: is the post construction as-built stage of a project. This is the final first cost stage of any project. At the conclusion of the 500 level, the model is handed over to the building's Facility Manager. The process of creating a 500-level model will often involve the integration of the 400 level fabrication model data into the 300-level model.61

The model will contain all building elements. They will be geometrically accurate while not showing excessive fabrication level detailing. For example, duct work will be sized correctly as installed but will not have flanges modeled. Objects will contain their actual record costs (data), purchase documentation (link), commissioning data (link), maintenance requirements (link or data), object specific data (e.g. fan CFM) as well as any other data relevant to the life cycle management of the building.62

The numbering system may seem a bit confusing since five levels would best be represented by five evenly distributed values (figure 1). The LOD Specifications exclude Level 500 because it relates to information that must be field verified and not the development of project components. These specifications also add an extra level, Level 350, which gives extra detail to 300 but is not as complete as 400. Level of development is not a design phase but the completion of a phase. Complete models, themselves, should not be defined by the LOD since different components of the model develop in different rates. Therefore, the user may have some components being level 100 as well as some other components reaching level 400. For

62 Ibid.
historic sites, some objects may not need as much accuracy as others, it is dependent on the management or maintenance needs.

3.3 Historic BIM: A case study at Mount Vernon

The same BIM approach commonly employed for new construction, can be applied for historic site management as well. Although BIM models for historic buildings are very uncommon, existing documentation and field survey can be used to create a three-dimensional model. The added cost of converting existing two-dimensional data into a three-dimensional model, however, can be a large enough burden to a site that it will typically eliminate model development. But the products associated with historic building recording and documentation are critical to successful site management on a wide range of levels.

At the 2015 ESRI Federal GIS Conference held in Washington D.C., Mount Vernon presented the results of a BIM project they referred to as HBIM due to the historic component. This three-dimensional BIM model, developed by Mount Vernon and Quinn Evans Architects using Revit and ArcGIS, resulted in a digital tool on which the buildings of Mount Vernon were placed in their landscape. Embedded information for each building component resulted in a digital database of the site’s history and evolution, providing a range of different digital benefits. One of these was the ability to provide staff and researchers a tool to analyze data contained within the system virtually. Eric Benson, GIS and view shed manager for Mount Vernon, whose role is to monitor development happening across the Potomac River from the site, was able to use the tool in a way that showed the benefits of the system. Mount Vernon's view shed is primarily composed of trees, and the three-dimensional model, which contained a LiDAR
sourced tree canopy, could be used to analyze this canopy data. With this tool the site was able to determine how much development was visible from above the tree line and what trees could be used to provide screening. This type of analysis helps managers like Benson work with the necessary partners to place easements on areas where existing trees that screen the development, protect the view shed.

Another benefit from the Mount Vernon project is the three-dimensional model and its accompanying database. Information was attached to building features, such as the plasterwork. Original plasterwork could be differentiated from replacement, helping management make better and more informed decisions regarding where to make an intervention to the historic building fabric when necessary. Thomas Reinhart, Deputy Director for Architecture at Mount Vernon, discussed how having the representation of different plasterwork campaigns and repairs in a model helped inform them where to locate sprinkler heads while upgrading their fire suppression system, reducing the overall impact on original material. Having sprinkler heads penetrating 1950 plasterwork was viewed as more acceptable than having it penetrate 1787 plasterwork, the model being able to convey information about significance to both site management as well as the consultant.

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63 LIDAR - Light Detection and Ranging—is a remote sensing method used to examine the surface of the Earth. These light pulses—combined with other data recorded by the airborne system—generate precise, three-dimensional information about the shape of the Earth and its surface characteristics. A LIDAR instrument principally consists of a laser, a scanner, and a specialized GPS receiver. Airplanes and helicopters are the most commonly used platforms for acquiring LIDAR data over broad areas. US Department of Commerce, and National Oceanic and Atmospheric Administration. “What Is LIDAR.” NOAA’s National Ocean Service, October 1, 2012. https://oceanservice.noaa.gov/facts/lidar.html.


One of the potentially widest reaching benefits from this BIM is that which resulted from its remote capabilities, providing a three-dimensional view to stakeholders through a web browser. This is beneficial since it provides direct access of the spaces and landscapes without being in the physical site. The spaces also provide the data regarding evolution and changes through time to the audience exploring the model converting it into an extended educational tool of the site. While the benefits of this tool for the purposes of education are quite clear, the overall costs of creating the system would most likely preclude it from happening if only being used for this purpose. This project showcases how an historic site can benefit from BIM. Mount Vernon has gained a resource that will provide a means of maintaining a digital “as-built” record of the structures that includes history, date of repairs, manufacturers, etc. It also resulted in a three-dimensional model that is developed to a high enough level so as to easily produce two-dimensional drawings that could meet the HABS requirements. And the three-dimensional model can function both as a project collaboration tool to inform consultants of the space and its significant features, as well as an educational tool for visitors, both at the site and remotely.

Mount Vernon made a decision about what software package to use based on their needs. All sites have specific needs when it comes to management and education, but there are a large number of options for software with BIM capabilities, including the ones discussed in greater depth below. How to select the right tool though always depends on the current and foreseeable future goals, needs, and resources of the site, as well as the tasks the facility managers and preservation staff have assigned.
4. Choosing the right Methodology for Taliesin West

BIM is not a single proprietary software, but instead is a concept. While BIM is often misunderstood to be a software, it is no more a single software than is a GIS, which has become so ubiquitous in society that the maps produced are often taken for granted. In fact, while there are software packages, such as Autodesk’s Revit, which attempt to offer a single BIM platform, BIM utility can often be more powerful when executed using interoperability, taking advantage of the built-in strengths associated with other software packages. Interoperability is the ability of computer systems or pieces of software to exchange and subsequently make use of data. Architect Matt Morgan, registered architect at A&E Architects in Montana feels that synergy is gained by working with a suite of software, taking advantage of the strengths of each software to serve the unique needs of the site in question. Matt states the following:

Each project requires a multi-software problem-solving approach and I have yet to find a single “black-box” solution. Each project presents unique and specific challenges. The key to success, in my experience, is understanding those challenges upfront and allowing them to guide me in determining my software toolkit. One of the biggest barriers is often cost. As uncomfortable as it may be to admit, money will have a significant impact on how one approaches a project. We have grand notions that budget might not be a factor and that the client will see the value in our approach, but in reality, there must be significant savings or efficiencies reflected in the ways we conduct our work. This ultimately requires us to do more with cheaper solutions. This does not mean

that these “cheaper” solutions are less accurate or less valuable. This is a fundamental item I run into in my job daily. In terms of BIM software such as Revit, there are those that feel it is the best software for architecture/preservation and those that think you cannot do preservation in BIM. I use Revit as a project repository and database to begin with, and then later as a means to graphically represent the project data. AutoCAD is a drawing software, and Revit is a database software. Revit can then link the two together and create a more robust and data filled drawing set that is more easily mined and read by contractors, project managers, and others involved in the project. Both opinions about BIM miss fundamental questions: What do we need, and why do we need it? Do we need to model every component and detail? If so, why? Technology is always evolving, the cutting-edge software of today will be tomorrow’s old news. Without proper training and upfront planning, the choice of software can be detrimental to the long-term preservation goals of a project, and perhaps create inaccurate and unusable final products.

Revit, AutoCAD, and Excel to a lesser degree, are all softwares that continue to be used extensively in the architecture and building trades, both for the purposes of drafting, as well as for building information management. Websites such as The Balance.com, which focuses on careers and career definitions unequivocally states that “The actual drawing up of plans is done on computers these days, as are simulations, artistic renderings, and much of the rest of the visual output of this field. You will need to develop agility with various architectural drafting software including”:
• Architectural Rendering
• AutoCAD
• Computer-Aided Design (CAD)
• Computer Processing
• Model Making
• Revit

Although not viewed as an architectural software per se, Excel has been available for 35 years and most AEC professionals have had experience with it. Excel is a powerful tool for organizing and presenting data; and considering it has over 300 million users it can be assumed that site managers and architects include it in their toolkit. In addition, because of its ubiquity, it is a software which most companies already own, then it does not increase overall costs when applied as part of a methodology. For Taliesin, this software is already included in the site’s budget and the facility managers use it regularly for projects and information management. But Excel can’t be limited to those tasks apart from being considered for calculating and accounting it can be used to organize schedules, plan projects and track material inventory and budgets, task list and more. To better understand the chosen methodology and its associated software, it is important to understand the chosen software and what they offer to the process.

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68 Here is an example list of the software’s Yale’s Architecture school has for their students. “Yale University.” Software List | School of Architecture Advanced Technology. Accessed April 3, 2020. https://digitalmedia.architecture.yale.edu/inforesources/software-list.
4.1 Autodesk

In architecture construction and site management, Autodesk as a company is viewed as the dominant player in the AEC fields. And while other software companies have made advances on Autodesk’s market, it maintains a strong presence in the two-dimensional and three-dimensional CAD and BIM market. Although the numbers are difficult to identify due to conflicting data, some estimates place Autodesk’s Revit as high as 46% with Autodesk’s AutoCAD adding an additional 24%, accounting for Autodesk’s 70% share of the BIM and CAD markets (figure 2).71 Because of its ubiquity and durability, it is an almost foregone conclusion that any organization that deals with architectural drawing, either for drafting or management purposes, will own at least one license of the AutoCAD software.72

4.1.1 Revit

Revit is a BIM Software for architectural design as well as mechanical, electrical and plumbing engineering (MEP) professionals. In 1997 this new product was launched to the market offering data-base capabilities, a parametric component-based design system, history management and change propagation capability. In 2002, Autodesk bought Revit and since then it has become one of the top 10 BIM platforms in the AEC industry.73 The application offers many of the benefits of a BIM all in one software, allowing the user to create a three-dimensional model to which attribute data can be attached for different components within the model. From the model, construction document quality drawings can be produced. With this software team members can collaborate in the same model space, export or import drawings

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and references, as well as managing schedules and materials.\textsuperscript{74} Revit also interfaces with other platforms that provide extra management and scheduling tools.\textsuperscript{75} The base of a Revit document is a three-dimensional model composed of components. With the icon's available walls, doors, roofs structures, and windows can be created, and for each component, parameters are adjusted to the characteristics the designer needs. When a project is shared with different users, a principal file is created, with the master copy being stored on a server. Each user works from a copy and when that copy is saved, the master is updated to reflect the changes. This then results in updates to the current files of each user.\textsuperscript{76} Revit has a feature that checks with the main file when users start drawing, preventing users from making the same changes and creating conflicts.

4.1.1.1 Benefits and Challenges

Benefits

- Multidisciplinary Tools: Revit has tools that encompass the varied group of professionals that use the software.\textsuperscript{77}
- Collaboration: Multiple users can work on the same document improving the workflow of a project.

\textsuperscript{74} Ibid.
• Parametric Components: The model produced can be shared with other professionals giving spatial visualization and rendering products, but the software includes 2-D drawings associated to the model.78

• Interface with other Software for extended usability: Revit interfaces with software like AutoCAD three-dimensional to further the functionalities of site analysis and Autodesk Inventor for manufacturing components. For Cost Estimation it interfaces with platforms like Sage Timberline and US Cost.79

• Analysis of Environmental Impact: This software integrates tools that allows analysis of energy efficiency.

• Visualization: with a three-dimensional digital model it allows immediate virtual visualization of the designed structure.

Challenges

• High Cost: Revit is a subscription-based software. Autodesk offers different subscriptions including a $305 monthly; a $2,425 annual; or a $6,550 for the duration of three years.80 These costs cover one full license and don’t include any sort of training. Training costs can vary but raise the total cost of the software use.

• Limited people are trained in the program.81

• Difficult Data Extraction and limitations for permissions for data accessibility.82

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82 Ibid.
No backward compatibility. The files cannot be downgraded to an older version.\textsuperscript{83}

4.1.1.2 As a Tool for Taliesin West

Overall, looking at Revit’s features it seems that this software will be adequate to implement in a site like Taliesin West. Revit is an excellent example of the benefits of a BIM software. It is one of the most popular and known programs in the field, and most professionals would suggest that this is the solution. Factors like being multidisciplinary and having direct connections to AutoCAD and cost estimation platforms is beneficial for management and maintenance needs. It also includes the collaboration feature that Taliesin West needs for the several users interacting with the model database. But when the needs of the site are evaluated this software goes over-budget in the cost of holding a license and, the level of ease of use and training needed for the new users is also exceeded.

4.1.2 AutoCAD

Automatic Computer Aided Design or AutoCAD is a two-dimensional and three-dimensional drafting software from Autodesk. Since 1982, when the first version of AutoCAD was introduced, Autodesk has launched more than 30 updated versions for both Windows and Mac making AutoCAD one of the top 3 drafting software in the world.\textsuperscript{84} Autodesk offers two versions of the software, AutoCAD LT and AutoCAD. Although both offer similar capabilities, AutoCAD LT has lesser capabilities than AutoCAD to appeal to clients in a lower price range. The following is the comparison of capabilities of each software:

AutoCAD LT


• Create and edit 2D geometry
• Annotate drawings with text, dimensions, leaders, and tables
• Customize the ribbon and tool palettes
• Attach and import data from PDF files
• Share and use data from DGN files and Bing Maps

AutoCAD

• Create and edit 2D geometry
• Create and edit three-dimensional models with solids, surfaces, and mesh objects
• Annotate drawings with text, dimensions, leaders, and tables
• Customize with add-on apps and APIs
• Customize the ribbon and tool palettes
• Customize with add-on apps and APIs
• Extract object data to tables
• Attach and import data from PDF files
• Share and use data from DGN files, Navisworks, and Bing Maps
• Apply and monitor CAD standards

AutoCAD, as the name implies, is a CAD software and CAD and BIM are defined as fundamentally different. When using CAD for building design, the focus is on creating a drawing,

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85 “Buy Autodesk Software: Get Prices & Buy Online: Official Autodesk Store.” Buy Autodesk Software | Get Prices & Buy Online | Official Autodesk Store. Accessed May 8, 2020. https://www.autodesk.com/products?mktvar002=afc_us_deeplink&AIID=11343162&PID=8206971&SID=jkpcJgKQQw7v0BRDOARIsAGh37irzg9sD3AbjqqkYEYudbCgR49vMi8iphK-3kaLdrrQ8L8v6PLIZMaAhNVEALw_wCB&term=1-YEAR&click_id=Cj0KCQw7v0BRDOARIsAGh37irzg9sD3AbjqqkYEYudbCgR49vMi8iphK-3kaLdrrQ8L8v6PLIZMaAhNVEALw_wCB&quantity=1&cjevent=c667a7147a6511ea817100b50a240612&gclid=Cj0KCQw7v0BRDOARIsAGh37irzg9sD3AbjqqkYEYudbCgR49vMi8iphK-3kaLdrrQ8L8v6PLIZMaAhNVEALw_wCB&gclsrc=aw.ds&support=ADVANCED&affname=8206971_11343162&compare=acdlt#.
but when using BIM, the focus is on creating a building model from which the drawings can be generated from that model.

As for the database options typically found in a BIM, AutoCAD does offer the ability to attach attributes to blocks, which can function as a primitive component, and the data from these blocks can easily be exported as table data. Unlike with BIM modeling, though, CAD drawings have no connections to each other. Each new plan must be drawn fresh and any change on one plan must be applied manually to all other referenced plans. The data for inventories is measured from the drawings, recalculated and manually entered into tables. Procedures such as dimensioning, hatching, annotations, room data creation are time-consuming and any modeling for visualizations is executed separately. While not typically viewed as a BIM software, there are several versions of AutoCAD such as AutoCAD MEP (previously known as Autodesk Building Systems) which provide workflows that support BIM processes such as data-rich intelligent objects. And the AutoCAD .dwg is also a natural choice when having to deal with issues in actual BIM software, such as clash detection of features, which may require exporting into alternative software. The AutoCAD .dwg format tends to still be the most compatible with external applications. Although Revit can export straight to some external software, most deliverables also require a companion .dwg so that different trades can reference one another’s work during coordination efforts.

In review, AutoCAD offers many tools that benefit AEC professionals. It offers architectural planning tools, including templates specifically design for architecture and building

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construction as well as analytical tools for stress and load levels. With the three-dimensional capabilities, the software provides engineers a means to design their mechanical components or parts and analyze systems. It also includes features to do mapping and rendering of designs while used simultaneously with other Autodesk software like Maya and 3D Max. Many industries, such as the fashion industry and the industrial design industry, also make use of the features discussed above like three-dimensional printing.

4.1.2.1 Benefits and Challenges

Benefits

- Highly ubiquitous: The longevity of this software makes it still one of the most common software used for architectural design throughout the world.
- User friendly Interface and Workspace: it offers quick tool sets to increase productivity and streamline designs.
- Import and Export of files: AutoCAD supports referencing and importing files to increase productivity.
- Point clouds: Many historic sites use point clouds to scan and document their sites, with AutoCAD the point clouds can be imported and manipulated to trace drawings.

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89 Ibid.
90 Ibid.
92 Ibid.
93 Ibid.
• Layering: The layering system allows for users to organize more adequately the different components of a document and turning those components on and off when needed.94

• Measuring Features: The software includes tools to calculate area, volume and distances.95

**Challenges**

• High Cost: AutoCAD is a subscription-based software like Revit offering three types of subscriptions for a single license. $210 a month; $1,690 a year; and $4,565 every 3 years.96 For AutoCAD LT, since it has less features, the cost is less: $55 a month; $420 a year; and $1,135 every three years.97

• Training is required to fully learn all the features of the software.

• CAD drawings have no connections to each other.

**4.1.2.2 As a Tool for Taliesin West**

To this day, Taliesin West “As-Builts” have been produced with AutoCAD. This is the software used by the preservation managers and the students who record the buildings each year. The drawings include the typical plans, sections and elevation as well as a site wide plan used for wayfinding and reference for management and maintenance decisions. This tool will continue to be used by the site because it is the industry standard but also, because already recorded data has been produced with it. AutoCAD is not a BIM software and for this thesis it

94 Ibid.
97 Ibid.
works as a complement to the main software of the approach to create a synergy and a more useful product. This process will allow for refinement of drawings that are extracted from the three-dimensional model and customized for maintenance, conservation and educational purposes.

4.2 SketchUp

SketchUp is now owned and distributed by Trimble Inc. Founded in November 1978, Trimble is an international corporation that services global industries in agriculture, building & construction, geospatial, natural resources and utilities, government, transportation and others. Trimble also does hardware development of Global Navigation Satellite System receivers, laser rangefinders, unmanned aerial vehicles (UAVs), inertial navigation systems and software processing tools, making it one of the lead players in the massively expanding fields of spatial data collection and geomatics. This application is used for a wide range of drawing applications including architecture and engineering and is available in different forms including a free web-based application and a paid version called SketchUp Pro which currently comes in either a seat-based license or as a subscription that costs $300 a year.99

SketchUp is an easy to use two-dimensional and three-dimensional modeling program that is used in the architecture, interior design, engineering, film and video game industry. SketchUp was first introduced in 2000 by @Last Software with the purpose of creating three-dimensional models, giving users drawing flexibility in a digital software.100 In 2006 Google acquired SketchUp as a way to add models to their Google Earth software, making the software

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100 “History of SketchUp.” SEE-IT-3D, August 23, 2017. https://www.see-it-3d.co.uk/history-sketchup/.
available to everyone for free. In 2012 Trimble acquired SketchUp and with their version 13 release, features like the Extension Warehouse and more plug-ins were implemented. Today Trimble offers different versions of SketchUp. For personal use, there is SketchUp Free and SketchUp Shop, while for professionals there is SketchUp Pro and SketchUp Studio, all of which are available at educational discounts.

The SketchUp School, an online resource which offers tutorials, states the following as important to understand before any user with no previous experience of SketchUp begins.

- The Mouse: To better navigate the software a 3-button mouse with a scroll wheel is essential. This will allow for quick "orbiting" and "Panning" around the modeling space of the software.

- How Geometry Works: SketchUp geometry is composed of three different elements: End Points, Edges and Faces. The software allows the user to edit those geometries for example, by erasing edges and faces and moving points.

- The “Stickiness” of Shapes: The geometries created in SketchUp overlap other geometries and they stick to each other. This process will allow to create customized shapes by erasing edges and faces of the geometries. This “stickiness” can create problems further along if the user doesn’t understand the next point,

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102 Ibid.
• Groups and Components: After geometries are created the users should “group” them or create a component. By grouping the geometry gets isolated and protected from sticking to other geometries. It will essentially become an object and be easier to edit further along. Components are similar but give the users extra capabilities by allowing to create copies, editing all the copies at the same time and attaching specific data to them. 106

• Extensions: also known as Plug-ins, are a third-party tool that makes SketchUp more powerful. These tools make tasks easier and the main software customizable. A wide variety are available in the Extension warehouse and in other sites like SketchUcation to be downloaded and installed in the SketchUp software.

Once the software is installed and opened, and the user understand the basics, they will be able to select from a range of templates. These templates have preselected units and workspace environments that suit the modeling goals of the user. For example, in “each template has a title consisting of: Simple, Architecture, Interiors, Urban planning, Landscape, Woodworking, three-dimensional Printing and Plan View (figure 3). What makes each of these different is the units in which the user will be working. SketchUp already comes with predefined tool bars (figure 4). The Toolbars can be customized by going to “view” and selecting “view tab” and choosing toolbars. Here the user is able to select which tools to show on the toolbar.

Other capabilities from just two-dimensional drawing and three-dimensional modeling include:

• Adding data to the three-dimensional Model: With Dynamic Components users can add attributes and data to the objects they are modeling in SketchUp.

• Importing and Exporting: SketchUp can import DXF and DWG documents from CAD software as well as export in these file formats including but not limited to PDF, HD Animation.

• Present and Document: Once the model is complete, Trimble has made available Layout which works exclusively with SketchUp to produce hard copy and digital presentations as well as construction documents.  

SketchUp offers resources like the 3D Warehouse and Extension Warehouse which are useful to integrate previously modeled objects and capabilities when needed. The Extension Warehouse is a library of custom third-party extensions created to optimize the user's workflow. Developers create tools that can be integrated to the software that now are not included in the main software. These extensions range, and are not limited to Architectural rendering, Scheduling, Planning, and modeling. The three-dimensional warehouse is a space where all types of models can be shared. Users, developers and manufacturers can share and promote their designs including buildings, hardware, furniture, vegetation, construction materials, etc. For example, a user may need a fire extinguisher and that is available in the extension warehouse (figure 5).

4.2.1 Benefits and Challenges

Benefits

• Cost effective: Trimble offers an annual subscription-based license that changes depending on the version of software. For personal use SketchUp Free is free, as the

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name implies. SketchUp Shop is available for $119.00, SketchUp Pro starts at $299.00 and SketchUp Studio is priced at $1,199. For students, educators and nonprofits a yearly license of $55 is available. Trimble also allows a one-time purchase of a classic license for $695. This license includes all the features SketchUp pro provides. If the classic license holder wants to upgrade to the latest version of Sketchup they will have to pay $120 for it.

- Online there are many tutorials and resources available for free to understand how to use SketchUp. SketchUp offers many more features than what can be discussed in this thesis. The features discussed offer benefits to users and sites like Taliesin West that can be incorporated into their sites.

- Ease of use: Its intuitive interface offers ease of use to users and a very basic training.

- Customization: The ability to customize the toolbars and add extensions gives the user a most personalized workflow to that the site may need. Tools like the three-dimensional warehouse gives the users ways to customize the models with objects and materiality.

- Geo-Location: With SketchUp, models can be geo-located and uploaded in Google earth.

- Extensions: This tool adds extra capabilities to the software giving the software more uses and making it customizable for the users needs.

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111 Ibid.

• Layering System: SketchUp, just like AutoCAD, offers a layering system to organize model components.

Challenges:

• A main challenge of SketchUp is not having the basic knowledge of how the software works. An example is when geometries stick together if they are not grouped or have been made into a component creating future editing problems and frustration.

• Extensions: Although this tool allows the software to have extra capabilities if the developers do not maintain or upgrade the plug-ins they may become unfunctional in newer versions of SketchUp, becoming unreliable in a long-term basis.

4.2.2 As a Tool for Taliesin West

SketchUp is a software that represents simplicity but does not disregard complexity. This program is a drawing and modeling software that integrates BIM capabilities to its components. Like Revit, this software can work as a model database where drawings and data can be produced and managed. Although features like collaboration are not directly inherent to SketchUp like Revit, external references and extensions can integrate the feature. In its simple interface and straightforward tools, complex geometries can still be produced. SketchUp benefits surpass the challenges that it would bring Taliesin West. This software, although not part of the site’s toolkit, provides an option that is affordable and can be included in the sites budget, as well as the ease of use for training the preservation managers. SketchUp is a software that is common in the field, so students like the ones from UTSA can record and produce a three-dimensional model where drawings for HABS submission can be extracted and refined in AutoCAD. This software will be an advantage to the site, and the student’s product will be useful
both for repositories like HABS and sites like Taliesin West. SketchUp features allow for users like Taliesin West to use other software like ArcGIS, AutoCAD, Excel, etc. to supplement the data on the main software.

4.3 Spreadsheet Software

Excel was introduced in 1987 by Microsoft, and its available in both desktop and digital versions. This software is part of a suite called Microsoft Office which brings essential tools for writing, presenting, planning, communicating and collaborating. Excel is one of the most popular spreadsheet software used by more than 750 million people worldwide.\(^{113}\) Excel has become the preferred spreadsheet software and industry standard because of its features and options.\(^{114}\) Excel has many features that can be applied to any type of businesses like automatic arithmetic operations, charting data, planning for goals and inventory, creating schedules, project management, creating forms and more.\(^{115}\) Once the user opens a workbook, they can enter the data to the cells and the toolbars offer options of formulas that can format the cells to a given action. The toolbars also have options for different types of charts, graphs and pivot tables to show and analyze the data. It allows the users to perform work which can relate to decision making in business and economic functions. This work can be statistical operations, drawing

\(^{113}\) Cocking, Simon, and Anne Walsh. “SEVEN REASONS WHY EXCEL IS STILL USED BY HALF A BILLION PEOPLE WORLDWIDE.” Irish tech News, December 13, 2017. https://irishtechnews.ie/seven-reasons-why-excel-is-still-used-by-half-a-billion-people-worldwide/?__cf_chl_jschl_tk__=3e76de98e07956bf0e6305eb56103a105d2c0782-1586641566-0-AdLdm9xs0K-SCM7QIKLyGOSx7EKQWnExnZzO72KkSwNVtvty4rzOEHeY7t049IAZWmsFjijf6tPpBzloosj7x0dK0xT-kissyn6VOUh4bI3y3jtC2FI58LA2o0c988LBcoceWXqHLLF-Oks3AzIKnCbihjaLaGvKHE6XN_N-DmMT7Ee0cCYF0we0C_RXS1XrgYnuQ3phFdlLZxPjsfMTQANTCpL1kjo1ukkyCFmlNy3r-8BuJnkFDF2_tMpdrJHz4cmYunTxB1MaIi_508BrAv7GvFvQbLRRfuNHGU5s4lUR82liX1WV6c4MfW7xNIN_s7-92UnGIRc6_MpauU6m6utyj-FoiPOYJedQRI_kBlMjHkgg2VrTd8lePtNow.


graphs and charts based on the given data and generating professional reports for internal and external use, automatic arithmetic operations, charting data, planning for goals and inventory, creating schedules, project management, creating forms and more.\textsuperscript{85} Excel can be divided in three main parts:

- **Worksheets:** It allows the user to enter, calculate, manipulate and analyze data of both numerical and alphanumerical.

- **Charts and graphs:** Charts and Graphs are a visual representation of the users collected and analyzed data. Excel helps the user present data to in two-dimensional and three-dimensional column charts, pie-charts and many other types of charts and graphs.

- **Databases:** The third important function of Excel is data management. For instance, once the user entered its data in the excel worksheet, the uses has the tools to sort and organize the data, if required, can search specific data, and can select that specific data needed by the user.

### 4.3.1 Benefits and Challenges

**Benefits**

- Excel is the selected spreadsheet software because it’s already included in Taliesin West’s toolkit.

- Highly ubiquitous: this is the most commonly used spreadsheet software in the world. Since the software has become the industry standard a great amount of management offices has access to it, and it’s an economic with costs being low.
• It is easy to use and create new data workbooks. It is easy to add information to the cells and create titles as well as adding formulas without having to learn about programming.

• It is simple to create charts from existing table data. A user selects the data that is needed to create a chart and a wizard guides the user through options to customize the form of the output.

• Data Analysis and Visualization: Overall, this software allows the user complete control over the data. Excel receives data and allows the user to find specific data needed and access, organize and present it. Excel provides tools like graph, charts and tables to present data more efficiently.\(^\text{116}\)

• Multidisciplinary: Because the software does not have a specific field of use, excel can have an unlimited pool of users. Small businesses as well as individuals can track finances, stock, bank accounts and payroll, but also site managers can use it to organize and analyze data regarding collections, materials and historic evolution.

• Collaboration: Excel web versions allow users to work on the same document and data.

Challenges

• The software is limited by how proficient the user is with it. Someone who does not know anything about Excel cannot benefit from it in the same way a more experienced user can.

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Large amounts of data can make the software slow since the compiler needs to go through each column and row to process information.\textsuperscript{117}

4.3.2 As a Tool for Taliesin West

Excel is in no way considered a BIM software, it is a software primarily for data management and analysis, but it does complement and give extra capability to SketchUp in the application discussed. Although Excel does not directly connect to SketchUp, with extensions and other tools, data can be extracted, opened and manipulated in Excel. This benefits sites like Taliesin that need to manage data regarding the site’s maintenance, conservation and history. Excel complements the model database and maintains the data organized and “on-hand” when the managers need it. The collaboration feature will permit site managers and contractors to have in-site and remote access to the data in the model components without the need of opening the three-dimensional model file. This way data is available in two places where one is spatially visible and the other is organized in a spreadsheet.

\textsuperscript{117} Ibid.
5. Identifying the Parameters for Taliesin West

To create the right software package for a site, different factors need to be considered. The most logical approach is to identify software that fall within a price range that a site can afford. The software package being identified in this thesis corresponds to the specific management needs of Taliesin West and was selected based on the following criteria:

- Integrated BIM
- Low-Cost
- Commonality in field
- Life expectancy of software
- Level of knowledge retention needed to maintain the use of the software

A decision was made that the software package should consist of a single primary software, as well as a set of secondary software. While a single software might provide an all-in-one solution, most of the software that provide an all-in-one approach, which are currently available, fail to meet the basic criteria mentioned above. Open systems, such as OpenBIM\textsuperscript{118}, are being developed but have by no means reached critical mass. As mentioned earlier, identifying a set of tools which, when combined, could provide a system for better overall site management through a digital platform was seen as vital for success. Site managers wear many hats which involve knowledge of a wide range of disparate topics including architecture, maintenance, finance, management and communications to name a few. But site managers are often not architects, contractors or CPA’s and, as such, it is important to find software which work for people who function as a “jack of all trades”. Highly specialized software, requiring

\textsuperscript{118} OpenBIM is format that allows each and every project member to access the information model without hampering the native design. It is a universal approach to collaborate with design, realize and operate buildings based on open standards like IFC, BCF and others.
extensive training and high levels of knowledge retention, can be problematic, where as ubiquitous software which have reached critical mass make better choices since they typically require less training. Simpler modeling software were identified as the most appropriate because of the value Taliesin West places on both three-dimensional models and two-dimensional drawings ready to export from the same document, as well as a lack of funding available to provide team members the necessary training to learn highly complex modeling software. If the software could offer some form of BIM capabilities, it could provide a richer model, with organized information regarding the maintenance and history of the site. Having the primary software offer a means of creating cost effective HABS type drawings, like those created by the students from University of Texas, would allow others to assist in the overall data development, reducing the burden on the management team. In addition, a modeling software would allow current site managers to incorporate future changes directly into an existing model. And finally, it would provide a model that could be used for vital didactic educational purposes.

Based on the considerations mentioned above, the goal for the Taliesin West project was to identify a package of software which consisted of a single easy to use, cost effective “primary” software that could allow for the creation of three-dimensional models. Goals of the methodology included some form of BIM capabilities, as well as identifying common “secondary” software that could easily work in unison with the model and associated data. The “primary” software, like with most BIM approaches, would ideally be the program in which the model was created. Obvious choices for the full package of software included modeling programs like AutoCAD or Revit, as well as spreadsheet software like Excel and databasing tools like Access. Additionally, software such as Primavera and Microsoft Project, which deal with CPM scheduling, were seen as potential candidates because they can be of great value for overall site and project management. With such a big pool of software options available, on-site
goals and needs must first be clearly defined and this is where a proper BIM executive plan would serve the site well.

One of the fundamental concepts behind BIM is that each component within a drawing has the ability to contain additional information about that object, such as dimensions, manufacturer and type. This allows users of the data to be able to calculate quantities, create schedules, do construction takeoffs or estimate costs based on tabular information. Software such as Revit have the ability to do this type of work from within the software itself, but other external software can do this type of calculation as well, assuming the data exists within a drawing and can be extracted. While the use of Revit was considered, its high price, complexity, steep learning curve and level of knowledge retention needed to maintain the software as a tool in the office was what negated it as a viable option. AutoCAD was also considered, even though it is more a CAD software than a BIM software. While it is an expensive software, it is often considered a “ubiquitous” program, apparent in the number of “copy-cat” software that are available on the market, including Draftsight, NanoCAD and the open source LibreCAD. In addition, AutoCAD was one of the first CAD programs available, and its long shelf life, 35 years, has given it a universally recognized status. Due to the longevity of AutoCAD, most people who have been working in the building and architecture trades during the recent past have had enough experience with the software to retain the requisite knowledge to use it even when out of practice. In addition, AutoCAD has been, and continues to be, a common platform for producing standard drawing sheets for field work, including for organizations such as HABS. AutoCAD was not seen as an ideal tool for the primary software, though, since individual drawings created are not linked to each other, and their two-dimensional nature prevents the software from being able to produce a single source, from which all the data can be extracted, in the way a BIM three-dimensional model does. While AutoCAD does offer a three-dimensional
component, using these options requires an additional level of knowledge, and the learning curve is steep. As such, AutoCAD is retained in the overall “software package” but is considered a secondary software.

5.1 Choosing the Primary Software

Among the widely available three-dimensional modeling applications, SketchUp is considered one of the easiest to use. Within a few hours of launching SketchUp for the first time, almost anyone can get good enough to build something. Ultimately the decision was made to use SketchUp based on the following parameters.

- Cost effectiveness
- Ease of use
- Three-dimensional modeling software
- Ease of exporting two-dimensional drawings
- Able to attach additional information to “components”
- Ease of exporting “component” data
- Compatibility with secondary software such as Excel and AutoCAD
- Graphic quality of output for educational purposes

5.1.1 Working with SketchUp

Before attempting to build a 3D model in SketchUp or in any software, a user should consider the following questions: Is this software the correct tool for the objectives? And do they have a basic understanding of how the software works, as well as an understanding of different tools that it offers? As mentioned earlier, SketchUp comes in a variety of different...
versions, but for this project SketchUp Pro was used. The professional version, unlike the free version allows for the use of Dynamic Components (discussed below).\textsuperscript{121} This does not, however, preclude those involved with the project from being able to use the free version, since models for each version can be interchangeable. As long as there is at least one copy of the professional version available, the project can proceed successfully.

As part of a basic BIM executive plan, different objectives for the model were defined including condition assessment, education programs, digital databasing, and management. In addition to the BIM executive plan, the level of development (LOD) was defined to determine how much data would need to be recorded in the field, as well as included in the model. Based on the numeric values discussed earlier, it was decided that all components within the finished model should try to achieve the value of 400; however, it was clear that not everything in the model could reach this level. For some components the data was not relevant for this proof of concept, and for some features of the structure data was not visible, since no destructive investigation was carried out.

The field collection process was more in depth than would normally be done for a two-dimensional drawing set, since extra data needed to be acquired to understand the full three-dimensionality of objects. If a set of two-dimensional records already exist, as they did for Wright’s office, this can be beneficial, but actual hands on survey was still vital to have a complete set of field data. It was also valuable to have a basic understanding of construction and how objects are built. In many cases historic sites don’t have enough visible information regarding how a building was constructed, but the building, itself, can provide clues which can allow for well-informed extrapolation.

\textsuperscript{121} Ibid.
5.1.1.1 Understanding the Graphic User Interface

The graphic user interface (GUI) of Sketchup should be self-explanatory although a review of its basic composition and methods for use is important to properly use the software. When SketchUp is first opened a “Welcome dialogue box” will appear providing different templates to choose from. These templates define differing measuring systems that are preferred. Some templates open with a two-dimensional view while others open in a three-dimensional view (figure 3). After selecting a template a file will open to SketchUp’s modeling graphic user interface (GUI). The interface consists of seven basic parts including the title bar, the menu bar, the getting started toolbar, the drawing area, the status bar, the measurements box and the default panels (figure 4).

- The title bar contains the standard window controls (close, minimize, and maximize) and the name of the currently open file.
- The menu bar, found at the top of the GUI, includes all of SketchUp’s tools, commands and settings. The menus include File, Edit, View, Camera, Draw, Tools, Window and Help.
- The getting started tool bar is available below the menu bar by default. It contains the basic tools you need to begin creating 3D models.
- The drawing area is where a model is constructed. This space can be identified by the different colored axis, blue, red and green, which also work as the spatial origin of the modeling space.

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122 Ibid.
123 Ibid.
124 Ibid.
• The status bar, available at the bottom of the screen, contains the both the “measurements” box as well as the “tips” box. On the left side of this bar two icons can be selected to “geolocate” or “claim credit”.\textsuperscript{125}

• The measurement box displays dimensions of the geometries created for the model. These dimensions can be manipulated by the user, directly from the box, for more accurate models.

The default panels appear on the right side of the screen and consist of a series of individual panels regarding materials, viewing styles, component library, as well as the “entity info” (discussed below). To customize these panels, from the menu bar at the top of the GUI, a user can select “window” and “default tray” to select other panels for viewing.\textsuperscript{126}

5.1.1.2 Methods of Organizing

Organization of data in any architectural application is important for better overall management, and SketchUp provides several different methods for organization. Layers, groups, components, classifications and attributes are all methods of organizing data within a single model file, and while they have great value as standalone options within Sketchup, they can also provide a way to uniquely identify data when employing one of the extensions discussed below, as well as provide extractable data when creating reports directly from SketchUp.

Layers exist as a panel option in the “default” panel section of the GUI and appear as a list. Each uniquely named layer can be independently turned on or off, as well as locked to

\textsuperscript{125} Ibid. With Geolocate the users can import terrains from Trimble database. For more information regarding this process use the following link https://help.sketchup.com/en/sketchup/importing-preexisting-terrain-sketchup-and-geolocate-model. Claim Credit is a feature for users to associate a model with themselves and see who else has contributed to the model. For more information regarding this feature please use the following link, https://help.sketchup.com/en/sketchup/using-credits-feature.

prevent changes from occurring. This is one method of placing objects together under the same category.

A second means of organizing the geometries of SketchUp is through the use of grouping. This option is available in the “edit” menu from the menu bar at the top of the GUI. By selecting multiple geometries in a model, from within the drawing area, they can be grouped together to create a feature that functions as if it were a single object. As mentioned earlier, one aspect of SketchUp is the “stickiness of geometry” where lines and faces intersect with each other (figures 6 and 7). This stickiness allows for the customization of shapes by overlapping geometries and erasing shared lines that are not required in the fabricated element. While this can be beneficial, it can also create problems when geometries are unintentionally intersected. Any grouped feature will not suffer the difficulties associated with stickiness.

A third means of organizing geometries in SketchUp is through the use of components. Components allow SketchUp to function as a primitive BIM, where descriptive attributes can be embedded, component by component, within the overall model. As with grouping, the option for creating a component is found in the edit menu at the top of the GUI. While on a basic level, groups and components appear to function the same way, components offer some additional benefits. Once a set of geometries have been converted into a single component it can be easily multiplied within the model by copying and pasting. When only a single copy of that component is edited, all copies of that component will display the same edits. This can be highly beneficial when designing new construction where, for example, a set of matching windows needs to be resized. Edit a single copy of that window and all of the copies of that component window will

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change at the same time. More important to the work of the Taliesin West project, though, components can also be given easily understandable names as well as descriptive data like manufacture’s names or conditions.

The “entity info” panel is one of the most important panels in the SketchUp GUI (figure 8). As a 3D model is constructed in SketchUp, an entity is created whenever a line or face is drawn. Combining lines and faces into a group or component creates special groups or component entities mentioned above. Each entity in a model has attributes, such as its measurement, the layer it’s on, and more. Depending on what a user is doing in SketchUp, they may need to know or change an entity’s attributes. All of this information can be found in the “entity info” panel. When creating a component, a window opens that allows the user to enter a set of attributes, including definition (which is also the name of the component) and description (figure 9). This information, when added, is integrated into the model and remains with the component. After creating a component, a user can add additional attributes to that component by way of the “entity info” panel. With the component selected and the “entity info” panel open, click the “show advanced attributes” icon. A list of advanced attributes will appear, as well as options for entering details about the component status or owner, the desired information being typed in the appropriate text box.

Dynamic components are an added option that can be used with any component created and provides the software with most of its BIM capabilities. Dynamic components can be employed in both free and professional versions of SketchUp, but only the professional version is able to actually create and assign the attributes.128 In the professional version, users can customize dynamic components from the component attribute window. These

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customizations add even more value because it allows the users to control the parameters like color, texture, size, etc. as well as embed data to the components. All of this data can then be easily extracted. Dynamic components provide the user with the comfort of not having to depend on the long-term functionality of added extensions. This tool can provide benefit to sites management teams, by giving the software database capabilities that BIM software like Revit offer. The process of assigning dynamic components attributes is simple but can become complex when more attributes and subcomponents are added. In the “Making a Dynamic Component” website created for SketchUp, it describes creating components as being like programming, but simpler. A notice on the website states that it may take several trials before all the behaviors and attributes work together efficiently and “do what they were told to do”.\(^{129}\)

Accessing the “dynamic component” window can be done by selecting a component from the model and left clicking (figure 10). By selecting “component attributes” from the list of options, a new window will open (figure 11). The default attribute data which appears in this window will be the name assigned to the component, as well as the units. In addition, an “add attribute” row is available with an empty space provided to the right. When a user clicks the “add attribute” option, a list of attributes will appear from which the user can chose. These options include information that can be modified in the “entity info” tray, discussed above. In addition are position, size, rotation, behaviors, form design and finally custom, allowing the user to include their own categories (figure 12). Users can select all the attributes appropriate. Once an attribute is selected, the user can do three things (figure 13):

1) Type Information in the space provided.

\(^{129}\) Ibid.
2) Select the blue arrow which is provided to access more options. A new window will open which, depending on the attribute selected, gives several options (figure 14). In the example provided, a custom attribute of “condition” was assigned, and two options are available. The first option is “units” and in this case the choices include decimal number, text, inches, centimeters or default. The second option is “display rule”, which dictates if users can edit, or see the attribute. More customization is available under “select from a list”, which will open a new row where options can be added (figure 14).

3) Remove the Attribute by selecting the “minus” icon on the left side.

A fourth method of organizing data in SketchUp is through classification, using the “classifier” toolbar. When the “classifier toolbar” is used to embed data into groups or components, those groups or components become objects. An object is either a group or a component which has been specifically defined and when objects have names, descriptions, and so on, the user can manage the details about those classified objects. If a user classifies their data in SketchUp using the “classify” toolbar, they can use BIM to create models that not only look realistic, but also contain practical data about all the objects that need to be assembled. SketchUp recognizes Industry Foundation Classes (IFC) which describes a hierarchical structure of building elements, systems, types, properties etc. specifically for BIM application. IFC is a standardized, digital description of the built asset industry. “It is an open, international standard (ISO 16739-1:2018) and promotes vendor-neutral, or agnostic, and usable capabilities across a wide range of hardware devices, software platforms, and interfaces for many different use cases.”130 In a SketchUp model, components can be identified as specific building elements such

as doors, windows, stairs etc. Using IFC, these features may be classified with even more specific, but standardized identifications. A window may be classified as being a skylight with a single panel, top hung with an aluminum frame. In addition there can be multiple standard and custom properties with values describing each window.\textsuperscript{131} While the “classifier” toolbar has great potential for better levels of classifying data in a SketchUp model for the use of BIM, time did not allow for the “classifier” tool to be employed in the Taliesin West project. It should be explored more for its potential regarding greater levels of identifying data at Taliesin West.

For the Taliesin West project layers, groups and components were all used to help with organization; however, components proved to be the most important since descriptive data was attached and later extracted.

5.1.2 Extensions

A plug-in or extension is defined as a computer software add-on that provides new functions to the host program, app or web browser, without altering the program itself. “By sharing plug-in architecture with other companies, software developers create useful synergies between their own products and a variety of related products. Plug-ins, themselves, are not software. Each plug-in enhances the value of the host program, and the success of the host program enhances the value of the plug-ins.”\textsuperscript{132} In SketchUp, plug-ins are known as extensions and they can be found and added by means of the Extensions Warehouse located in the window menu at the top of the GUI. Extensions offer added value to SketchUp by providing the software extra capabilities beyond what is available in the factory version of the software.\textsuperscript{133}


Extensions for SketchUp are built using the Ruby programming language, and prior to the purchase of SketchUp by Trimble in June of 2012, extensions could be easily downloaded from third-party sites such Smustard.com. These extensions are developed specifically for SketchUp using their guidelines; and now developers must apply to create an extension and once submitted, they are reviewed and approved before they can be added to the warehouse.\textsuperscript{134} Although there is no overall assessment information on the types of people developing these extensions, it can be presumed that architects, designers, educators, etc., who are using the software on a day to day basis, are the people responsible. Most of the extensions in the warehouse are free for users to download and deploy, but developers have the option to sell them for a onetime fee or subscription and the price for these extensions vary depending on what services they offer.\textsuperscript{135} Several weaknesses of using extensions do exist though, including the uncertainty of their longevity, and their reliability. Both factors depend on the developers who may or may not continue to update them as the software evolves. This is definitely a concern for the long-term usage of the Taliesin West project data, but in this case the obvious benefits of the available extensions outweighed the drawbacks. Two primary extensions were tested for the Taliesin West project based on defined needs, and both added real benefit to the modeling data.

\section*{5.1.2.1 The SU2XL Extension}

This extension was created by Olivier Lesage, an architect and engineer from Louvain-la-Neuve, Belgium. While created by an individual, and not a large corporation, the benefits of this


\textsuperscript{135}A quick survey of the Extension Warehouse was conducted by the author. Each of the categories that the Extension Warehouse offers were evaluated for the most expensive Extension in 2020. LSS Arch $240, in the categories of: Productivity, Reporting, Text & Labeling. https://extensions.sketchup.com/
plug-in outweigh the drawbacks of a small development budget. This extension can be downloaded, for free, from the Wisext (corporation) website, or the SketchUp Extension Warehouse and be directly installed to SketchUp through the Extensions Manager.\textsuperscript{136} SU2XL provides a means of adding additional text beyond what can be done with dynamic components. Data attached to components using this extension can then be exported to a spreadsheet software such as Excel.

This extension in SketchUp works directly with an active Microsoft Excel workbook, by embedding text-based data from the SketchUp model components into an Excel worksheet. Before any data can be embedded from the model, though, an Excel file needs to be linked to SketchUp. This can be accomplished by first creating a new Excel workbook, and then naming and saving it to a folder specified by the user. With the SU2XL extension installed, a toolbar titled “Wisext SU2XL” will be available in the SketchUp GUI (figure 15). Clicking on the first icon, a new window will open, which will allow the user to select the export file format (figure 16). Once confirmed a second window will open that provides a way to select the previously saved Excel file, linking the file to SketchUp. This process works in real time and will not affect the results of embedding data. In addition, the linking can be done with the Excel file open.

Once the Excel workbook has been linked, new attribute headers within a worksheet will be defined by the SketchUp extension. The following is a list of the default headers in the order they appear in the worksheet and what they represent for each component.

\begin{itemize}
  \item Entity ID: These values, assigned by the extension, represent the unique identifiers for each component within the model. They cannot be changed or removed.
\end{itemize}

• **Wattributes:** Two columns are titled Wattributes, which is the default name that the extension applies for any of the customizable attributes assigned to the component.

• **Parent:** Listed in the table is the name of the “parent” of that component. Since the parent is the SketchUp model itself, the default values will be “Model”.

• **Type:** This will list the type of feature the object is (group or component) within the model.

• **Name/Instance:** This field provides the given title of each of the components as specified by the user at the time the component was created.

• **Length/Area/Volume/Max and Min Areas/ Max and Min lengths/Centers:** The cells within these columns are populated by default values and represent exactly what their titles imply.

• **Layer:** This column will identify the layer that has been assigned to the component in the model.

• **Visibility:** This column will identify if the component is actually visible within the model, and is useful if different iterations of a component are in separate layers (such as variations over time), some of which may be turned off.

For some of the fields within the table, the attribute headers, can be customized by the user. The wattributes fields can be customized and there is no limit to the number of these attributes that can be assigned. To add a new attribute, beyond the two provided, the user selects the second icon in the extension toolbar called “Wisext wattributes” (figure 17). To name these new attributes the user can select the third icon from the extension toolbar to open a small window named “Add Title” (figure 18).
The most important aspects of this extension are how to make the attributes useful and how to add data relevant to selected components. This can be accomplished in two different ways. By selecting the first icon of the extension toolbar a window will open, specifically for the purpose of adding or modifying the attribute data for the component selected. The second method is by left clicking on the actual component in the model and selecting “add/edit Wattributes” from the menu of options (figures 19 and 20). To remove any unwanted attributes the fourth icon in the extension menu provides a dropdown list of all the available attributes, each of which can be selected and removed (figure 21). To rename a “Wattribute” the user will select the second icon of the “Wisext Wattributes” Tool bar, and a window will open to substitute the names (figure 22). The “name” field can also be edited. Changing the name, though, does not require working within the SU2XL extension, since the “name” is actually controlled in the “entity info” palette of SketchUp. With the component selected within the model, left click and choose “entity info” from the list of options. Any changes to the data in SketchUp’s “entity info” will be reflected in the linked Excel worksheet.

The link between Excel and SketchUp, created by this extension, provides a user the option of either working directly in the model, or work directly from the Excel worksheet to adjust information. If edits are made directly in Excel though, the file needs to be backloaded to the model for the changes to be reflected. This can be achieved back in SketchUp, by selecting the fifth icon of the SU2XL extension toolbar (figure 15). Once selected a window will open asking if the user wants to update the information from the external file. The benefits of this export option cannot be stressed enough. In the context of site management, tabular data is vital. Once data is available in Excel, pivot tables can be run, as well as any of the large number of functions that are available by default in Excel. The synergy of combining this two software is obvious.
5.1.2.2 Cross Reference Organizer V2.6 Extension

Taliesin West is a very large site comprised of a huge number of individual structures and features and creating a single three-dimensional file containing all of this data would be difficult. The concept of cross referencing or “externally referencing” drawings allows teams of people to work together on a common product, where each person is able to externally reference other people’s drawings so that the work they are doing individually, is properly registered to that of their team mates. In addition, cross referencing allows files that would otherwise be too big, to exist virtually, though a set of independent drawings that are all spatially referenced to each other. A drawing of a very large city, with all its complex layers of underground, on grade and above ground infrastructure can exist spatially correct, without ever having to worry about all of it being together in the same file unless absolutely necessary. This contributes to the synergy of the software, offering a tool to maintain references updated in an individual workspace.\(^{137}\) It impacts directly the outcome of the workflow of a user making processes quicker and informing the status of the referenced files in an organized manner. It benefits the response of computers, reducing the file size by having several smaller files instead of a single large one which takes more time to process. Additionally, collaboration can reduce production time with several teammates modeling different aspects of a site.\(^{138}\)

The Cross Reference Organizer extension is distributed under the company name of Lasu Apps and was created by George Theodoridis, an architect from LAW Architects who has created several SketchUp plug-ins.\(^{139}\) Theodoridis states that he created these plug-ins to


overcome shortcomings in the software.\textsuperscript{140} The Cross Reference Organizer extension allows team members to work on the same project simultaneously, by allowing each team member to visually reference other team member’s models in their work, similar to the external reference option found in AutoCAD. In addition, each team member’s model can be managed and updated in real time, as long as everyone is saving regularly to a common server.

Unlike the previously discussed plug-in, Cross Reference Organizer only has a single icon toolbar, which will open a window for managing all externally referenced material (figures 23 and 24). Within the window, the first icon allows the user to add a cross-referenced file to their SketchUp document. The second icon informs the user of status, green indicating that the referenced file is up-to date; yellow indicating the referenced file is out of date or has been updated or changed and red indicating the referenced file has been moved and needs to be re-linked. To update each reference individually, this can be accomplished by clicking the colored icon next to the referenced file name. The third icon in the window will update all the references to green status; however, the extension developer does not recommend this action, if the file is large, since it may take longer than expected.

\textbf{5.1.2.3 An External Referencing Alternate}

An alternative option to reference external files to the master SketchUp model can be done without the use of an extension, by importing copies of other SketchUp files. All SketchUp files depend on the same coordinate system to define their location in space and different models can be referential to each other by working with this origin. Models can be independently constructed by sharing a common base plan, where each model is constructed in its assigned location. When multiple models are brought together this common base plan can be

\textsuperscript{140} George Theodoridis (Architect of LAW Architects, Lasu Apps team member) in discussion with author, March 2020.
used for the purposes of registration. While this method is not ideal for working with highly integrated drawings, a site like Taliesin West, with its independent buildings, can create referenced drawings of its buildings by working from a common base plan and then individual models can be imported to a master. If an original file of an imported model is updated, the master file can be updated as well. This can be done by selecting the component, left clicking and selecting “Reload” from the menu that opens (figure 25). The same process as importing the file will repeat, and the user will have to select the file and click OK to load the changes.

5.1.3 Data Extraction

With the “generate report” feature in SketchUp, users can create reports containing component attributes which can then be downloaded as a CSV file and used in software like Excel (figure 26). This option allows site managers to work with their data in tables as well as in models. If the component created is a door and the user add a price, size, and type to the component, a report can be generated that can help estimate how much replacing that door would cost in a project. To see how using a different type of door might impact the cost, the door component can be swapped out for another using SketchUp’s “replace selected component” feature creating an updated report with new cost estimates. SketchUp can generate tabular reports from models, regardless of whether objects in the model have been grouped or component, but the only objects in a model that can have embedded attributes are the components.\(^{141}\) When the “generate report” window opens an empty untitled template appears (figure 27). To select which elements to include the user selects “create new template” in the top left corner of the window (figure 27). Listed below are the different options available:

• Choose Filters: This option allows the user to select from where the data is to be extracted, either the entire contents of the model or a current selection.

• Format Columns: This option has two columns (figure 28). The left column lists all available attributes and the right column lists only those that have been selected. A user can select attributes from the left column and, using the available arrows, assign the chosen attributes to the right. Reversing the process removes chosen attributes.

• Selection Units: This option allows the user to select the format of the units, as well as define the precision of the chosen unit.

Once the template has been formatted a report can be run by selecting the “run report” option in the bottom right corner. In addition, the current template can be saved for use in future reports. The software will display the results of the report showing each unique component from the model as a row (figure 29).

5.2 Secondary Software

Exporting and Importing is a critical part of working with multiple software. For anyone working with data it is always good to know what file formats their software can import as well as export. Secondary software includes programs that have no direct connection to the primary software but serve as tools for producing output, adding the power of multiple software in a single tool package. This includes software such as Excel and AutoCAD. SketchUp Pro, as a stand-alone, does not directly communicate with any of these programs, but there are simple ways of using the data from SketchUp, in conjunction with these other tools, to enhance the collected data. SketchUp allows for the export of models and drawings in other file formats.\(^\text{142}\) The export

option from SketchUp Pro offers both two-dimensional and three-dimensional output. These file formats not only include .dwg or .dxf that can be directly opened in AutoCAD, but also include PDF, EPS, Window Bitmap, JPEG, Tagged Image File, and Portable Network Graphics, CSV that opens in Excel, KMZ for Google Earth, all of which can be processed in other software. Working with a three-dimensional SketchUp model does not eliminate the ability to create drawings that satisfy HABS guidelines since they do not require that drawings be CAD based.¹⁴³ The export option from SketchUp to AutoCAD is incredibly easy and only requires minimal effort. In addition to the AutoCAD option, the SketchUp Pro software suite includes an application called LayOut, where models can be inserted, and construction grade drawings can be created and manipulated.¹⁴⁴ Excel, AutoCAD, and ArcGIS are all software considered as secondary for this approach. This will allow the SketchUp model data to be manipulated and used in a different way that the primary software does not include.

5.2.1 AutoCAD

AutoCAD is a drawing software that has continued to serve the AEC fields for more than 38 years. Taliesin West does use the software to produce architectural drawings or diagrams that can be useful for management of the site. For sites with World Heritage status it is expected that drawings are available, and in the digital age these drawings have been most commonly produced using AutoCAD.¹⁴⁵ Drawings are also produced for inclusion in national collections, like HABS at the Library of Congress. The drawings of Taliesin West, produced by the students from University of Texas at San Antonio, are done in AutoCAD and later submitted to

¹⁴⁵ Emily Butler (Director of Preservation at Taliesin West) in discussion with author, November 2019.
HABS. By creating three-dimensional models in SketchUp and employing AutoCAD as part of the software package, all necessary plan, sections and elevations from the three-dimensional model can easily be exported to AutoCAD. To export the drawings users, need to make sure their “camera view” in SketchUp is in parallel projection. This process will prevent the two-dimensional drawings from having perspectives. Once the two-dimensional drawings are opened in AutoCAD some work must be done for the drawings to be HABS quality. Assigning lineweights is the main task that needs to be addressed. SketchUp exports only as a line drawing, which will all be included in one layer with one lineweight. This process involves creating a CTB following HABS guidelines, to then be applied to the line drawing. This process will ensure the drawings plot with the correct Lineweights.

5.2.2 ArcGIS and Google Earth

ArcGIS is another tool that complements SketchUp since it offers a platform that creates, manages, shares, and analyzes spatial data in the form of maps. This software, like AutoCAD, is already part of Taliesin West’s toolkit. The three-dimensional models and base plans produced in SketchUp can be exported into ArcGIS as well as Google Earth. Until the introduction of ArcGIS 10 this was a pretty cumbersome process, but now this workflow has become much easier, requiring the data export from SketchUp as a COLLADA model and then replacing older geometry with the new one in an ArcGIS edit session. SketchUp models in ArcGIS

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146 Emily Butler (Director of Preservation at Taliesin West) in discussion with author, November 2019.
148 A CTB file extension is for a color settings file used with AutoDesk AutoCAD software. The CTB will define the colors and Lineweights the drawings will plot to. Margaret Rouse, “CTB File Format,” TechTarget, 2010, https://whatis.techtarget.com/fileformat/CTB-AutoCAD-Color-dependent-Plot-Style-Table.
will help visualize different project scenarios to understand development impacts of the project or new projects to historic sites.\textsuperscript{150} An example of a Historic Site using ArcGIS is the case study of Mount Vernon discussed in Chapter 3 of this thesis. Google Earth is also a valuable tool to export SketchUp models to. This will allow the models to have a visual context and landscape.\textsuperscript{151} Google Earth can also be used to import data to SketchUp like terrain. Due to time constraints these software were not heavily investigated and more research should be pursued.

5.2.3 Excel

Excel is a multidisciplinary spreadsheet software that has served many fields, including AEC professionals for the past 35 years. This program is included in Taliesin West’s toolkit to manage schedules, project data, budgets etc. Although the benefits and uses of Excel have already been discussed in Chapter 4, it is important to remind the users of the possibilities as a secondary software. Excel cannot be limited to the managing of budgets and scheduling. This software is powerful, enough to import data from SketchUp that can store characteristics of historic sites like conditions, collections and programs. In the approach discussed in this chapter the extension SU2XL is used to export data to Excel through a set of toolbars. Another possibility available with this extension is importing data to the SketchUp components from the Excel linked file. This process allows the users to not solely depend on the SketchUp model to access the data but, if a quick reference is needed, open the excel file and manipulate it (figure 30). Apart from being a tool to organize and analyze data, Excel also provides visualization solutions of the data with charts and tables.


\textsuperscript{151} For more information regarding viewing models of SketchUp in Google Earth please visit this website. https://help.sketchup.com/en/sketchup/viewing-your-model-google-earth
There are many possibilities for secondary software for this approach, but the ones selected have been software that are already included in the sites toolkit or are ubiquitous in the field. The main characteristic to understand from this approach is that SketchUp has several options for exporting data including two-dimensional drawings, three-dimensional models, and text data that can be used for management, maintenance and educational resources.
6. Taliesin West Office

Frank Lloyd Wright’s office at Taliesin West is located at the north-western side of the site in the foothills of the McDowell Mountains at the eastern edge of Scottsdale, Arizona. The office building is the first stop of the visitors’ tour, with its west elevation facing the tour meeting area. The Office has two access points, one through the west elevation and one through the south elevation. Guided tours enter through the west, metal and glass geometrical, door into a small office and reception area which contains an enclosed interior garden to the south, facing the Drafting Studio (figure 31). To the east side of the building is the larger open office space which contains a large desert masonry fireplace in the northeastern corner (figure 32).

The south elevation faces the drafting studio and the north and east elevations face the cabaret theater. The office is a one-story rectangular low-slung building comprised of three bays defined by the built-up beams, as well as the west office reception area. The roof is a shed roof sloping in one direction the entire width of the building from north to south.

The structure is primarily composed of masonry, wood and glass. The masonry is constructed of cast concrete and loosely stacked desert boulders using Wright’s unique “desert masonry”. The sloping shed roof is composed of four built-up wooden flitch beams supported by concrete piers on the north elevation and resting directly on top of the concrete wall to the south. The Build-Up beams, painted Cherokee red, support roof panels constructed of fixed translucent acrylic sheets with a supplemental suspended canvas interior panel which create the tent like effect. For two of the three bays of the north elevation, where the roof is at its

153 Ibid., 142.
highest point, clerestory windows fill the spaces between the supporting piers, which allow
diffused light to filter into the space. The third bay, farthest to the east contains the chimney of
the large fireplace. The upper most section of the east and west walls are also clerestory
windows, triangular in shape and located directly beneath the first and fourth build-up beams.
These windows include external wood sunshades painted with a checkerboard pattern; each
being supported by wood pinnacles (figure 33). 

Each of the masonry walls are sloped and irregular in height for each of the different
elevations of the building. These sloped concrete walls also contain distinctive horizontal
grooves in their surfaces. Located at different heights, these groves are Wright’s attempt to
mimic what he observed in the natural landscape of the surrounding Canyons. Both the east
and west walls are approximately 7 feet at their highest point sloping downward towards the
south wall which is only 4 ½ feet. At its highest point, the north wall is approximately 9 feet, 3
inches tall (figure 34). The roof over the western reception area is also constructed from fixed
translucent acrylic panels with a supplemental suspended canvas interior.

6.1 The Earliest Efforts

A site visits to Taliesin West occurred in early January of 2020, but the process of
creating the first three-dimensional model of the office began well in advance. Three-
dimensional models differ greatly from two-dimensional drawings in a variety of ways. While
both of them are interpretations of the real world, two-dimensional drawing can, at times, take
greater liberties than a three-dimensional model can afford, in order to produce a perfectly
successful product. This initial effort for the Taliesin West project focused on getting a better
understanding of these differences. Not knowing the building before the site visit, a first

154 Ibid., 142.
155 Ibid., 22.
attempt to build the model was made, working only from the available HABS drawings, in an
effort to determine how well the two-dimensional data would translate. Photography is a
common, and a very traditional, method of adding information to a documentation package and
is the reason that HABS works with both drawings and photographs. In this initial effort,
however, photographs were intentionally avoided to see if only the information from the
drawings could provide enough data to create a fully realized three-dimensional model. The
resulting model, while complex and informative, is not complete, resulting from an inability to
understand certain parts of the building from the two-dimensional data (figure 35,36,37, and
38). The fault was not from a lack of effort on the part of the original recording team, but due to
the compound nature of Wright’s cast walls, which can be difficult to understand even in three-
dimensions. Given the irregular masonry construction of the walls, some of the extracted
measurements from the two-dimensional drawings required interpretation and the available
plans, sections and elevations alone were not enough. The results, in some cases, were features
intersecting each other where measurements did not correspond and had to be adjusted, the
horizontal grooves in the masonry walls being a perfect example. In some of the drawing
elevations it was difficult to differentiate between materials such as wood, glass and metal.
Many areas were identified with labeling to indicate the material, but the unique means by
which Wright put together the elements, made it difficult to understand where each material
ended, working from only the drawings.

As was discussed in a previous section of the thesis, working with AutoCAD typically
entails producing several different drawings, each independent from the others, and each
serving its own function. In the case of most drawings, the level of detail incorporated is a
reflection of the scale of the drawing. To avoid busyness in drawings, details are typically left
out, being addressed separately in actual detail drawings. Because the office drawings were
made to represent entire elevations, some details were understandably not included, adding to the difficulty of creating a complete three-dimensional model. All the details of how elements were constructed could not be included in the full elevation drawings because of their scale and the number of detail drawings that would have been required to address this discrepancy would have made the original recording project an insurmountable process. The number of drawings were justifiably limited; however, more sections would have been helpful to better understand all aspects of the building. A small pent roof which extends off the north elevation and separates two rows of clerestory windows was difficult to create in the three-dimensional model because there was no section drawing through this portion of the building. For the HABS work, two-dimensional section drawings were created in logical locations of the building but could not provide all of the necessary information for all three-dimensional aspects of the building. Clearly, not using images of the building and its components for reference made it difficult to fully understand its spatiality and composition, showing the importance of the full HABS methodology.

Another limitation was areas of the structure that, without direct intervention, couldn’t be understood, and therefore couldn’t be drawn. The viewable surface of the roof panels, from the interior of the office, is of canvas stretched on wooden frames, while the exterior view is of the acrylic panels. The construction of the support system between these two layers is difficult to understand, but clearly is necessary for supporting this two-layered system. The previous recording team did not create detail drawings of this interstitial space with no apparent negative impact on their drawings; however, for a three-dimensional model, overlooking these details would prevent the model from being completed and was, therefore, a fundamental requirement for the modeling process. The easiest way to identify the elements of this system would have been to dismantle one of the panels; however, due to the frequent use of the space for tours,
dismantling a section of panel was not feasible. Without direct physical intervention, but by following clues and looking through small gaps between panels, the structure of the roof was included in the model.

This first modeling effort, working from the existing HABS drawings also provided an opportunity to test out the difficulty of moving files between two of the software in the package. In this case the available .dwg files were imported into SketchUp and several problems did occur with the initial import. The first step involved importing the available .dwg files into SketchUp, which did not import at the correct scale. Additionally, there were too many overlapping lines in the .dwg, which made it difficult to understand certain aspects of the two-dimensional files. Excess lines proved to be problematic and it was apparent that more detailed information, or images, would be needed to decide which lines could be erased.

6.2 The Site Visit

Five days were committed to on site data collection. This period included field recording but also meetings with the management staff for discussion regarding their needs and approaches for the proposed methodology. Most mornings were dedicated to collecting data, working with tape measures, laser distance measurers, field drawings and photographs, as is typical with any HABS field recording. The afternoons were committed to modeling sessions, attempting to construct as much of the model as possible while on site. By the end of the site visit most of the building walls and typical beams were modeled. What drew attention to the more complex nature of recording for three-dimensional modeling was the way in which early field measurement was carried out. Several times during the process, measurements were taken

156 The scale issue can be counteracted by scaling it afterwards to the correct dimensions. The issue of excess lines can be counteracted by cleaning the drawing documents before importing to SketchUp but be careful because eliminating too many lines may reduce the amount of information that is available to build this model.
thinking in two-dimensions resulting in missing dimensions. After several trials the team understood that more data was required for the purposes of modeling.

The model components were organized in Layers. A decision was made to organize elements of the building in layers based on logical architectural groupings, including Roof, Walls, Windows, Doors, Landscape, Mechanical and Terrain. Within each layer, sub-layers were also defined to divide each component into smaller units. For example, “wall” is a main layer. Each of the components created for the walls were assigned to that layer, but the individual entities within a component (lines and planes) were assigned another layer corresponding to building orientation of north, east, south, or west. With this internal subdivision, site managers can turn off walls using two different categories. Walls corresponding to specific cardinal direction can be turned off using that specific area sublayer, but all walls can be turned off using the main Wall layer as well.

6.3 Challenges and Benefits of Modelling Process

While traditional CAD based drawings work with lines, three-dimensional modeling works with both lines and planes to develop three-dimensional forms. In many cases the easiest means to create features in a SketchUp model is to extrude them by creating a two-dimensional profile which can then be “pulled” out to create the three-dimensional feature. It was assumed that, with what appeared to be consistent shapes of formed concrete, this would be the best approach. For several locations, though, this proved not to be the case. While there were several instances where these types of modeling issues played out, the southwestern most corner of the structure, which defines the outer limits of an enclosed garden space is a perfect case in point. This single intersection proved to be exceptionally challenging to construct in
SketchUp, due to the complex nature of Wright’s form work, but also showed the incredible value of employing a three-dimensional model (figure 39 and 40).

This wall intersection consists of two running lengths of cast concrete. The west exterior wall, which runs north/south, was physically built with a top that increases with slope to the north, but which in two-dimensional plan view is composed of a set of just six parallel lines (figure 40). The western two-dimensional elevation drawing of the office shows this north sloping aspect of the wall, but the combined drawings don’t effectively show the surprisingly complex nature of how this wall intersects with its 90 degree partner (figure 41). Intersecting with this west exterior wall, at the corner, is the south exterior wall which is also composed of a running length of concrete. For this wall, the top runs parallel with grade, and neither of the two wall tops is simply flat, each being composed of shedding surfaces which meet at a sharp peak (figure 42). Due to the unique shapes of the tops of each of these two intersecting walls, and the different ways they slope, nothing in a two-dimensional drawing could convey the complexity of how these walls meet (figure 40 and 43). This is not the case with a three-dimensional model, which can be used to create a wide array of different representations. First, the model can be used in its three-dimensional format, employing perspective and shadow to help convey the concrete forms. In addition, any number of sections and plans can be created, just from the single model, as a way to help explain the complexity of this intersection (figures 44, 45, and 46).

What also proved to be of value in the process of virtually constructing the three-dimensional form of these intersecting walls was a better understanding of how the actual form work would have had to be constructed in order to build the intersection during original construction. While the advantages of the three-dimensional model should be evident in a case like this; when compared with the standard approach to two dimensional drawing, the slope and angle differences between the two intersecting walls created a unique challenge in the modeling
process because simple extrusion of the two walls was not an option. The basic shape of the west exterior wall was initially extruded, but then needed to be edited in order to add the different slopes and angles of the top. These challenges are common with most sites that have characteristics like the office in Taliesin West. It is the job of the site management team to define the level of detail and explain to any group or individual producing drawings what their objectives in recording this space should be. This communication can result in a more comprehensive product for the site and benefit the long-term management.
7. **Conclusion**

During the lifetime of both Wright and his apprentices, the buildings of Taliesin West were intended to evolve and change through time. Today, the rules have changed, as preservation has become the primary focus of the site. With that said though, some preservation at Taliesin West requires intervention and, therefore, change is inevitable. This thesis has explored topics regarding the responsibilities of site managers and how readily available, cost effective software, working together as a package, can impact the short and long-term management of Taliesin West by creating a rudimentary BIM platform to which additional data can be attached as it becomes available. Preservation site managers have always had access to a variety of different tools to manage their day-to-day activities and with the advent of computing, these options have significantly increased, leaving managers in the position of having to make choices about software for which they unfortunately may not have the proper training or knowledge. One of the most important reasons why, in the current preservation management market, professionals are relying more on digital technologies is because of the benefits of enhanced collaboration and quicker project turnaround. And while it may seem daunting, as a manager, to have to make decisions about software, having a basic understanding of site needs and limitations can go a long way in helping to determine which is the most appropriate. The tendency now, though, is for professionals to try to find a single software that will tackle all of the tasks at hand, instead of taking advantage of all the strengths that a multi-software approach can offer. While single software packages have their benefits, the assumption being that a single software is easier than having to deal with a range of programs, working this way can lock a site into that software, forcing them to have to live with both the strengths, as well as the weaknesses of that program.
The idea that a single software is better than multiple software can be a bit misleading, as there can be great benefit when several software, especially software that are in common usage, are implemented as a package. This type of synergy has distinct advantages for a variety of reasons. Most highly ubiquitous software, like AutoCAD and Excel are already in common usage and it is unusual for someone working in the AEC fields to not already know how to use them. Since the “basics” of these software are already understood, time can instead be committed to learning how to maximize the extensive number of useful tools within them. The key to this strategy, though, is providing direction in how these software can speak to each other, showcasing their true synergy. Software like AutoCAD and Excel, which are common software in today’s technology market, can communicate with each other, where changes to a table in Excel can directly impact the data within a drawing. ArcGIS, the most ubiquitous mapping and spatial analytic software, can communicate directly with AutoCAD, allowing the creation of highly detailed maps in AutoCAD that can be incorporated directly into existing shapefiles. A databasing software like Microsoft’s Access can work directly with ArcGIS, both software being constructed around database platforms. The benefit of this multi-software approach cannot be overstated, since these high usage software typically have been designed to serve a single purpose extremely well. Excel, for example, was intended to serve people who worked with tabular data. Incorporated into that software, alone, are more than 470 functions, each of which deals with tabular data and which can be brought to bear on the varied intricacies of a project. While it is fair to say that few people truly know how to use all of the tools in these common software, most people who have the ability to use a computer, understand how to use these software and use them on a regular basis. Because these software have become so common in daily use, training people to use the more specialized options within them is
relatively easy since there is no need to teach the basic user interfaces, typically the first and most difficult part of teaching any software.

When working to develop a software package, incorporating specialized software into it, such as SketchUp, can be problematic, since time is required to teach the user interface. Unless, of course, the user interface is so simple that very little time is required to teach it. SketchUp was designed to be just that software. @Last Software’s goal in 1999, when designing SketchUp, was to “make the design process easier, more intuitive and more fun”. 157 Were they successful? At the AEC Systems Fall 2000 exhibit, SketchUp won the award for “Best New Products or Services”. 158 Even young people, like grade school students, have shown the ability to quickly learn and use SketchUp, and through the SketchUp for Schools program offered by Trimble, Taliesin West could offer another way in which to engage young people in the wonders of their site, by offering the opportunity to work with the available three-dimensional model data. The question of why to create a three-dimensional model in the first place is important to consider since Taliesin West has been laser scanned, resulting in a highly detailed virtual representation of the site in points. It can be argued that the point cloud offers many of the same benefits as a three-dimensional SketchUp model including higher detail. Higher detail in points is not always the best solution though, and while the argument in favor of scanner data may be true to some extent, it overlooks the clear benefit of working with an inexpensive, easy to use, readily available software that requires very little training in order to become proficient. Most point cloud software are expensive, complex and difficult to use which is in direct contrast. In addition, working with complex proprietary point cloud data conflicts with one of the clear

157 Bethany, “Everything You Need To Know About SketchUp,” Scan2CAD (Scan2CAD, March 12, 2018), https://www.scan2cad.com/cad/everything-about-sketchup/.
158 Ibid.
advantages of the SketchUp model, where anyone provided the model can easily use that data with the free version of SketchUp, producing new material which can then be incorporated directly into the existing data, allowing the resource to expand at no additional cost to the site. Point clouds, while “attractive”, typically need to be converted into planar models before they can be used for the purposes of BIM, a process that can be difficult to accomplish without high level training, and which can take a fair amount of time and money to accomplish. Laser scanning has its clear benefits, but in this case, it is not necessarily the best, or only answer to the needs of the Taliesin West management team.

The approach discussed in this thesis, consist of SketchUp as a primary software, and a set of secondary software to complement each other, which will enable the Taliesin West management team to build each structure as a three-dimensional model and produce accurate plans ready for the day-to-day maintenance and conservation found on site. In addition, the resulting three-dimensional models can provide for other uses, including a means by which two-dimensional drawings can easily be generated that will meet the requirements of the Historic American Building Survey (HABS). HABS guidelines do not stipulate specific software for the purposes of creating drawings for submission, so it generally falls to the recording team to identify which is the most appropriate to use. Typically, AutoCAD is the software of choice, but in this particular case, the use of SketchUp, and the creation of three-dimensional models, allows the recording teams to help the management team and the management team to help the recording teams. With this approach, the University of Texas San Antonio (UTSA) recording teams can continue to create HABS drawings working from the model data exported to AutoCAD. Incorporating line weights and establishing layering is necessary regardless of where the data originates. But the created data, in the form of a three-dimensional model can be used by the site management team as well. The model becomes a digital resource for identifying such
things as change over time, material quantities, manufacturers or frequency of replacement, all through the embedded attribute data associated with built components that can be extracted to secondary software like Excel, allowing for calculation and construction takeoffs, similar to that applied to BIMs. These options are not readily available in the AutoCAD platform typically used for HABS work. Where opportunities may not be as obvious, is in the use of the three-dimensional model when addressing how changes will impact the historic integrity of the site. The model can offer more realistic virtual representations to ensure that new construction meets the requirements of any preservation organization before the work is actually implemented, by offering a rotatable model which can be seen from virtually any direction, helping to show how a designed solution can minimize visual impact. This same resource can also be used for didactic purposes when implemented into the Taliesin West educational program at no additional cost for creating the data.

The work done for this thesis was intended to be a proof of concept and was never meant to solve all existing issues related to the creation of a single three-dimensional BIM approach for data management. BIM is an incredibly complex concept that has not been fully realized yet. This project is a starting point, and for a site like Taliesin West, keeping abreast of BIM developments is critical, if the future goal is to become a fully collaborative site where the management team can work with collaborators using the same data resources. Before moving forward several issues should be considered for Taliesin West, including two issues discussed earlier, consisting of a full comprehensive BIM execution plan and clear definition of the level of detail that needs to be attained on different elements of the model. One additional concept that should be considered is relatively new to BIM and has to do with levels of BIM maturity known as BIM levels. This concept has not been fully realized in the United States, but is a concept being pushed forward by the British Government in regard to OpenBIM, an approach which is
about recognizing the need for vendor-neutral (non-proprietary) methods of exchanging
information throughout a project, a concept that is difficult, although not impossible to achieve
in the current digital environment. “The British Government recognized that the process of
moving the AEC industries to a fully collaborative environment will be progressive, with distinct
and recognizable milestones being defined within that process, in the form of ‘levels’.”
While there is some debate about the exact meaning of each level, the broad concept is solid. BIM
Level 0 is considered non-collaborative, or low-level collaborative, and is generally seen as an
obsolete level for BIM even though many historic sites around the world are still working at this
level. It makes use of two-dimensional drafting techniques, the main goal being to generate
production information in the form of paper or electronic prints (not plots). As far as BIM usable
data is concerned, the HABS collection, being served in the form of scanned rasterized digital
drawings (or prints) falls into this category, helping to showcase the expanding gap between the
work being created for the HABS collection and the data needs of sites like Taliesin West for the
purposes of long-term management. BIM Level 1 is considered moderately or partially
collaborative and involves using both three-dimensional CAD and two-dimensional drafting. In
this case, however, the three-dimensional CAD is only used for conceptual works, whereas the
two-dimensional drafting is used for generating the actual production information. This is a
common level in the current market for small scale projects that are not employing expensive
complex software. At this level, data sharing can happen electronically using a common data
environment managed by a data administrator or project manager. Although considered
collaborative, the output work and production are not based entirely on a single three-
dimensional model, the model being used as the conceptual source of the data, but output, such

159 Bill Adams, “Understanding Levels of BIM,” A2Kstore, accessed May 27, 2020,
https://www.a2kstore.com/understanding-levels-of-bim.
as two-dimensional drawings, are being created using secondary software for processing. BIM Level 2 is considered fully collaborative and works by providing each project member their own identical three-dimensional vector model. Collaborative working is what distinguishes this level and it requires streamlining information exchange related to a project, as well as seamless coordination between all the systems and the stakeholders. At level 2, a predefined BIM executive plan is critical since all of the players need to be on the same page at the same time.

The Taliesin West project for this thesis sits somewhere between level 1 and 2 where the three-dimensional model is more than just a conceptual resource, but two-dimensional output is still taking advantage of secondary software. BIM level 3, often termed as ‘Open BIM’, hasn’t been fully defined, though it promises deeper collaboration between all stakeholders through a shared model stored in a central repository. This level enables all the participants to work on the same model simultaneously which eliminates the chance of conflicting information. Level 3 proposes the use of an integrated solution built around open standards like IFC where a single server stores all the project data. Taliesin West needs to determine what BIM level they feel they need to achieve and strive to achieve it by working to convert their existing data into formats that work at the defined level.

The approach taken for this project is not perfect, by any means, but it offers a strategy for Taliesin West site managers to better manage site data based on the identified criteria mentioned earlier. Revit may have been the best option to handle all the data and production of drawings, the software offering enhanced benefits for collaboration and data inclusion which could provide Taliesin West a means of achieving a higher BIM level, if that is what is desired,

but costs and training are clearly an important factor which can’t be ignored. This site is proven to be significant for many reasons and the proposed method in this thesis is a steppingstone for providing a digital record database of Frank Lloyd Wright’s legacy. At the same time, it offers a means to produce documentation that can benefit both the site, as well as other stakeholders such as the Historic American Building Survey with little additional training and effort. This approach is not a “one size fits all” method, but it can prove to be helpful for sites that have limited resources in order to achieve a basic level of BIM functionality. If a site wants to pursue solutions, like that used at Mount Vernon, involving more expensive software and a highly level of software training, it is a worthy approach, but one that requires serious consideration before moving in that direction. A commitment at that level requires a much larger output of funding, which may or may not provide a better solution to the one outlined here. With so many software available to choose from, the goals and objectives of sites have to be considered for the selection of the best approach.
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<th>Definition</th>
<th>Example</th>
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<tr>
<td>100</td>
<td>The model element may be graphically represented in the model with a symbol or other generic</td>
<td></td>
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<tr>
<td></td>
<td>representation but does not satisfy the requirements for LOD 200. Information related to the model</td>
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<td></td>
<td>element (i.e., cost per square foot, the tonnage of HVAC, etc.) can be derived from other model</td>
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<td>elements.</td>
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<td>200</td>
<td>The model element is graphically represented within the model as a generic system, object, or</td>
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<td></td>
<td>assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information</td>
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<td></td>
<td>may also be attached to the model element.</td>
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<td>300</td>
<td>The model element is graphically represented within the model as a specific system, object, or</td>
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<td></td>
<td>assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may</td>
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<td></td>
<td>also be attached to the model element.</td>
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<tr>
<td>350</td>
<td>The model element is graphically represented within the model as a specific system, object, or</td>
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<tr>
<td></td>
<td>assembly in terms of quantity, size, shape, orientation, and interfaces with other building</td>
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<td></td>
<td>systems. Non-graphic information may also be attached to the model element.</td>
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<tr>
<td>400</td>
<td>The model element is graphically represented within the model as a specific system, object, or</td>
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<td></td>
<td>assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication,</td>
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<td></td>
<td>assembly, and installation information. Non-graphic information may also be attached to the model</td>
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<td></td>
<td>element.</td>
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<tr>
<td>500</td>
<td>The model element is a field-verified representation in terms of size, shape, location, quantity,</td>
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<td></td>
<td>and orientation. Non-graphic information may also be attached to the model elements.</td>
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NOTE: The LOD 100, 200, 300, 400, and 500 definitions are produced by the AIA (2013) and have been reproduced with permission of the American Institute of Architects, 1735 New York Avenue, NW, Washington, DC 20006. The LOD 350 definition was developed by the BIMForum (2013).

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