An Investigation of Using Photogrammetry Technology on 3D Digital Recreation of the Historical Progression of a Historic Building

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Abstract
The recreation of three dimensional "as-built" models of historic buildings can be a demanding process. Contemporary photogrammetry technology allows for easy data collection of a physical space in the form of a point cloud. A study of the technology's effectiveness when applied towards the recreation of a structure is reported here. Primary research was undertaken at a historical building on a university campus in the US that resides on the National Register of Historic Places. Data was collected using various photogrammetry hardware and software, as well as by hand, to be applied towards the generation of a series of digital historical building models. Archival research was conducted to identify existing construction drawings from prior alterations. During model creation, data gathered via photogrammetric means primarily served as a dimensional reference when locating particular architectural features, and not as a means of generating geometry. At present, photogrammetry technology is incapable of serving as the sole tool for as-built and historic model generation, but can be combined with alternative documentation techniques with effective results.

Keywords
Photogrammetry, Historical Building Preservation, Digital Recreation, 3D Modeling

1. Introduction

1.1 Background

Cater Hall was built in 1915 as the President's Mansion for the Alabama Polytechnic Institute, known now as Auburn University. Since its initial construction, the building has undergone countless renovations and redesigns to serve a variety of purposes. With the construction of a new mansion for the president in 1938, the President's Mansion became a social gathering location for the newly admitted women residents of the campus. It was renamed the Women's Social Center and shortly afterwards the west wing of the main floor was adapted to serve as the post office for the University. In 1946, Katherine Cooper Cater joined Auburn University as dean of women, and took up residence in the second floor of the Women's Social Center. In the late 1970s the Social Center was adapted for purely administrative use, and eventually served to house the university's Honors College. In 1980, near the end of her life, Auburn University renamed the Social Center in honor of Katherine Cooper Cater. In August of 2003, Cater Hall was listed on the National Register of Historic Places (National Register of Historic Places, 2003). As part of its 100-year anniversary, starting in late 2015 Auburn University was undertaking an extensive
exterior and interior restoration project, to bring the building's construction up to modern standards while simultaneously respecting and preserving design elements original to the building.

While Cater Hall's historic development has rich ties to Auburn University's heritage and culture, there are large gaps in its documentation since original construction commenced. The original building drawings have been lost to time. While a wide number and variety of renovation drawings and historical photographs exist presently, the historic progression of the building's interior, from both an architectural and design perspective, is largely left to guesswork. An in-depth investigation into the building's physical evidence during the renovation process using modern technology such as photogrammetry and BIM, combined with an all-inclusive examination of archival documents will allow an opportunity to create comprehensive 3-dimentional digital models detailing the construction and design of Cater Hall throughout its lifespan.

1.2 Photogrammetry Technology and Its Applications to Building Documentation

Photogrammetry in the present day is a technology utilized to capture three-dimensional data. The technology is dependent upon traditional photographic capture and requires a number of different images taken of the same object from different perspectives. Photogrammetry applications are able to identify corresponding points and edges within various images and match them spatially to create referential relationships between various elements (Zalama *et al*., 2011). Photogrammetry is universally valued for its economic feasibility and relative ease of recording. However, this advantage is offset to a degree by the technology's inefficiency in capturing geometry and unadorned surfaces. Due to its reliance on identifying and matching similar points in like images, the two primary errors within photogrammetry processing are caused when there are no visibly discernable points to match, or when identified points are mismatched, creating erroneous geometry (Alshawabkeh and Haala, 2004).

Photogrammetry has served as an effective and economical recording tool for a variety of disciplines, including topography, archaeology, biology, and forensics (Ginovart *et al.*, 2014). As it relates to construction and architecture, photogrammetry has high potential for as-built documentation and can serve as an effective tool in the management and documentation of ongoing activity and maintenance work (Zalama *et al*., 2011). Additionally, the point clouds generated from photogrammetry processing can serve as representations of a space and are regularly utilized throughout new construction, renovation, and facility management projects (Bosche *et al.,* 2015). As previously stated, photogrammetry has high appeal in building application due to the low cost and time investment required relative to other comparable technologies. Another aspect of photogrammetry with high benefit, particularly when working within historic building environments, is its ability to work remotely from the documented object, with no requirement for direct contact between the object and the capture device (Ginovast *et al.,* 2014).

1.3 Technology as Applied to Historic Building Recreation

Historical building documentation can tend to prioritize an accurate representation of existing conditions, with an emphasis on the reality of a building's deterioration. Extra attention is often given towards capturing the cracks and texture alterations resulting from the effects of time, in advance of repair or simply as means to document the effects of time (Grussenmeyer *et al.,* 2002). Photogrammetry and other technologies can be highly effective for accurately displaying the surface conditions of the present (Al-kheder *et al.,* 2009).

As voiced by Volk *et al.,* modeling of existing conditions within BIM can be "a time-consuming and error-prone process (2014)". The potential applications of effective as-built modeling seem to be extremely valuable, but depending on the level of detail needed, often require a synthesis of multiple technologies whose strengths complement each other's weaknesses (Fai *et al.,* 2011). Volk *et al.,* states that the use of BIM and imaging technologies "is only appropriate with precise, unambiguous and relevant up-to-date information (2014)"; pointedly identifying that a successful use of technologies requires advanced data collection, often beyond that which technology alone is capable. The level of detail required for the recreated model has a direct correlation to the amount of data and processing time required (Volk *et al.*, 2014). Additionally, a high level of detail requirement for modeling can greatly decrease the ability to automate the process and in turn increase the amount of manual intervention required (Tack *et al*., 2011). Current technologies have a wide array of effective application within the building industries, but as relates to the documentation and digital recreation of existing buildings, there are many issues requiring further study in order to overcome.

2 Methodology

2.1 Research Design

In order to recreate the interior of Cater Hall in a digital model form, dimensional information needed to be collected as it pertains to the interior layout and locations of architectural features. This information was gathered from existing archival construction drawings, hand measurements taken on-site, and photogrammetry data generated through on-site collection. With a goal of accurately representing Cater Hall as it existed at various timeframes throughout its lifespan, accurate capture of physical anomalies witnessed on location during building renovation was crucial in overcoming the limitations presented through the lack of comprehensive construction drawings.

To assess the effectiveness of photogrammetry and other technological data collection instruments in the application towards digital building recreation, it was necessary to collect data through traditional means to serve as a control variable. The archival drawings and information gathered from the examination of physical evidence during the Cater Hall interior renovation served the dual purposes of affirming or not the validity of photogrammetry data collected.

2.2 Archival research

While information representing all of the interior renovation and additions performed in Cater Hall since its conception in 1915 do not exist, a fair number of construction drawings and specifications were maintained by the Auburn University Facilities Department. Research was undertaken with consent and assistance from personnel in the facilities management department to collect and digitize any pertinent existing information relating the Cater Hall.

2.3 Collection of Physical Building Evidence

As the interior renovation commenced in 2015, Cater Hall was visually examined daily in search of anomalous elements that might serve as an indicator of prior alterations. When anomalous elements were identified, photographic evidence was generated detailing the extent of the anomalies. Additionally, hand measurements were taken to identify the locations of anomalies. Architectural finish samples were collected where salvageable for study and integration into the final models.

2.4 Photogrammetry Technologies as Applied to Cater Hall

Photogrammetry was selected as the primary technology for data collection due to its cost and ease-of-use advantages over laser scanning technology. Two different photogrammetry technologies were utilized by the researchers for data collection. The first was software named Agisoft Photoscan Professional, a photogrammetry program designed to work in conjunction with user-generated photographs in order to build a 3D point cloud. The second was a handheld photogrammetry scanning hardware, Trimble DPI-8 Handheld Scanner, which creates a 3D point cloud during the scanning process that is then processed in the software named Trimble Realworks.

2.5 Data Analysis and Building Recreation

Collected data was analyzed in conjunction with the creation and construction of 3D models of Cater Hall. In the development of partition layout within the models, archival drawings served as a primary data source. The dimensional data inherent in the generated 3D point clouds then functioned as an effective tool in reproducing intricate architectural detailing and locating said architectural elements. Image capture of identified onsite anomalies was cross-referenced against both archival drawings and point clouds to identify within the building's history the time period during which adjustments took place. The combination of onsite measurements, archival drawings, and photogrammetry-generated 3D point clouds allowed for verification of dimensional and locational data to ensure a high level of accuracy.

Trimble SketchUp Pro was selected as the software for digital model recreation. BIM modeling software, such as Autodesk Revit was evaluated but ultimately not utilized for several reasons. The parametric functionality of BIM modeling contained no inherent value to the recreations of Cater Hall due the difficulty of identifying material information within an existing structure, and impossibility of identifying no longer present materials from past time frames. Additionally, SketchUp allows for simpler generation of detailed geometric shapes for inclusion in the model. Finally, the DPI-8 handheld scanner and Realworks software are owned by Trimble, who also owns SketchUp. This shared ownership of multiple software and hardware allowed for easier distribution of data between programs.

3. Results and Discussion

3.1 Timeframe of Model Creation

With the objective of generating 3D digital models of Cater Hall's interior representative of various timeframes from the building's history, it was necessary to first establish which periods best represented the greatest level of interior architectural evolution. This information was then compared to the archival information and physical evidence collected to isolate time periods which could be recreated with a high degree of accuracy. Careful consideration of all the archival information and a thorough study of Cater Hall's evolutionary history identified the six distinct time periods as ideal for digital recreation. These six tie periods are shown on a timeline in Figure 1.:

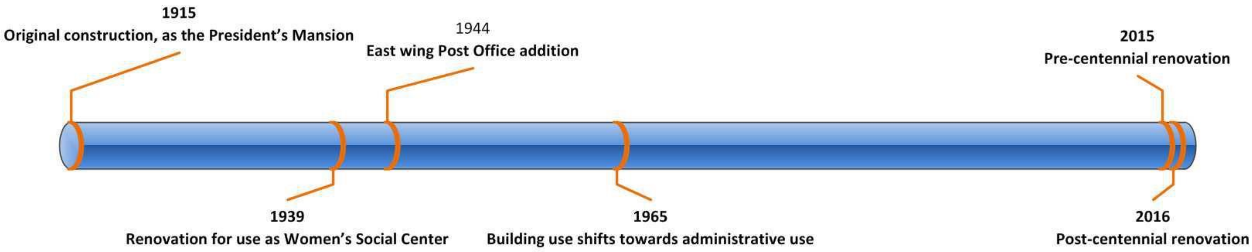

Figure 1: Time line of the six distinct time periods identified for the digital recreation of Cater Hall.

3.2 Application of Data to Model Creation

Independent 3D digital models were created for each of the six distinct time periods. Modeling progressed in three phases; 1) the development of floor plans, 2) the creation of component parts, and 3) the integration of the two into a final model state.

Initially, floor plans were established for each period, using archival drawings as the primary indicator of interior partition layout and opening locations. While measurement information was present in most archival drawings, this information often conflicted with onsite measurements taken of like-structures during research. Best judgments were made when conflicting information occurred with a prioritization of as-built measurements and thoughtful consideration given to locational consistency of building elements. A sample floor plan developed for 3D modeling and the plan view of its final 3D Sketchup model is shown in Figure 2. Component parts were developed for specific architectural details, such as doors, windows, frames, columns, molding, and others. Data collected through traditional onsite measurements and photogrammetry point clouds were useful in ascertaining the slight measurements associated with more nuanced architectural details. When integrating the components into the floor plans and building towards final models, all sources of data served equally essential roles in locating and validating the specific placements of architectural elements.

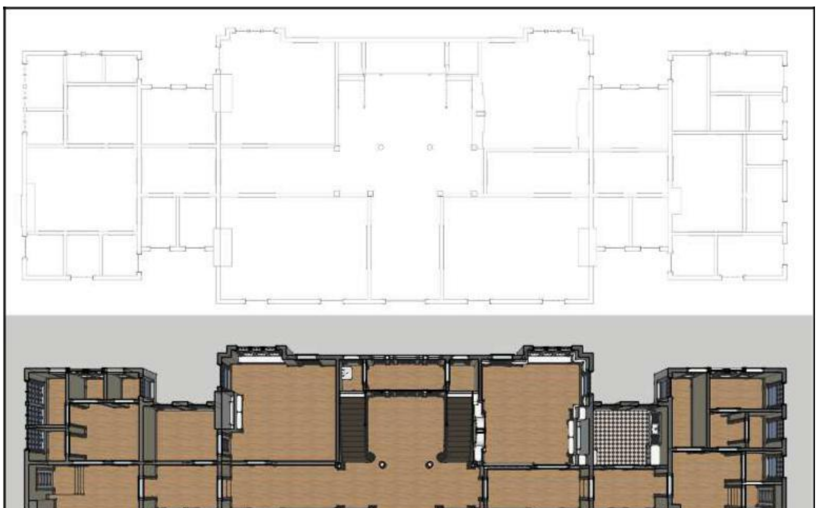

Figure 2: Recreated 1939 floor plan (above) and textured section cut (in Trimble Sketchup) from 1939 model (below).

3.3 Archival Drawings

As the archival construction drawings from past years were impossible to verify against current building conditions, except for where original building elements or orientations remained unchanged, models were created with an assumption of consistency between drawn building plans and the ultimate constructed product. A majority of both the central wing of the first floor and the second floor of Cater Hall were verifiably unchanged, in terms of partition layout and the presence of architectural features, from the original building construction to present day. This allowed opportunity to check onsite measurements against those documented in the drawings to make determinations when dimensional inconsistencies presented themselves. As documented during demolition, existing original walls have been re-finished many times since inception. As such, consideration was given to account for minor shortenings in recorded dimensions to account for the buildup of surface coatings over time.

Several archival drawing sets included elaborate detailing of specific architectural elements, allowing for a high level of confidence in their recreation. In the case of elements no longer present, measurements listed were considered accurate where no conflicting data existed. Trim detailing is outlined and measured in the 2015 interior renovation drawings, which provided baseline measurements, verifiable against dimensional data collected onsite.

3.4 Physical Anomalies

Throughout 2015 and 2016, as demolition and renovation commenced in Cater Hall, careful attention was given towards the identification of anomalous elements demonstrating prior building adjustments. Noted anomalies indicative of physical adjustments of partitions, windows or doors, and trim rarely presented new information, but served as further certification of shifts or notations detailed in archival drawings.

To demonstrate the anomaly identification process, a variety of wallpapers were uncovered in rooms known to serve as bedrooms originally. Consultations with experts confirmed that the discovered wallpapers would have been typical for bedroom décor. Additionally, the design was consistent with patterns popular at the time of Cater Hall's original construction. While the specific wallpaper's original manufacturer and manufacturing time was not discovered, it is with high confidence an assumption can be made that it was original. With limited physical wallpaper specimens to draw from, an exact repeat pattern recreation was impossible. All wallpapers were recreated as accurately as possible to best represent the design intent of the original architecture, if not the exact original design (Figures 3).

Figure 3: Original wallpaper (left) and digital recreation for 3D modelling (right)

3.5 Agisoft Photoscan Photogrammetry Data

The application of the Agisoft Photoscan Professional (Photoscan) software was ill-suited for the creation of point clouds representing an interior space. Photogrammetry typically is unable to properly capture and match points in locations with large, blank walls with undefinable features. While Cater Hall has a plethora of distinguishable architectural features in any given room, there were frequently large sections of blank wall that challenged Photoscan and its ability to create an accurate representation of the spaces. When blank walls were present, Photoscan was generally able to match points along the seams between walls and floors, but would leave large gaps with no point information in the blank areas of the walls, such as the grey areas showing in a Photoscan model in Figure 4. This could be remedied by manually matching points, however due to the large number of photographs being matched for any given room, the immense amount of time required rendered this approach ineffective.

Figure 4: Point cloud generated within Agisoft Photoscan, with informational gaps present along uniform surfaces

Photoscan showed promise in generating more localized point clouds that were focused in on a specific architectural detail, in contrast to an entire room. However taking this approach required a selective removal of unwanted matched points before the generation of the dense point cloud, a process that was also somewhat timely and at times imprecise. Once a dense point cloud was created, surface meshes could be added to create a geometric model. The point clouds and resulting meshes served as strong visual representations of the replicated area or detail, but were not suited for direct integration into a model. With the establishment of a scale within the point cloud, Photoscan was better suited towards providing dimensional data and allowing for digital measurement checks of anything contained within a scan. However, this benefit was infrequently used, as the ability to generate accurate dimensional data required highly accurate scaling of the model.

3.6 Trimble DPI-8 Captured Point Cloud Data

While the Trimble DPI-8 Scanner struggled with capturing and recreating blank wall surfaces in a way similar to Photoscan, its ability to visualize and review data as it was being captured helped to eliminate some of the more time-consuming elements of photogrammetry typical with Photoscan. As the on-screen display visually recreated the space being scanned and incorporated a color rating system to represent the integrity of the data collected, the DPI-8 served as a very efficient tool for data capture. Upon completion of a scan, a point cloud is immediately generated and users can visually verify the results on the scanner. A large benefit that this provides the DPI-8 over Photoscan is that by the time the data is exported for processing in software, the user has a strong assurance of the cohesiveness and quality of the source data.

When opened within the scanner's data processing software named Trimble Realworks on a computer, the data captured by DPI-8 could be evaluated in point cloud form. Individual point selections could be made, surface meshes could be generated, and dimensional data could be assessed. The resulting surface meshes suffered from some of the same planar inconsistencies that affected Photoscan, but were generally more accurate (Figure 5). Unfortunately, the created surface meshes, while accurate representations of existing conditions, were not easily editable to adjust appearances for previous time frames. Although Trimble Realworks offers an alternative geometry generation tool allowing users to draw out geometric shapes and areas scaled directly to the size and shape of the cloud, its interface for such task is visually difficult for extensive use for this research project.

Figure 5: Point cloud generated with Trimble DPI-8 as viewed within Trimble Realworks software

Ultimately, Realworks most effective tool in application towards model generation was its ability to check dimensional measurements. Unlike Photoscan, which requires establishment of scale, the DPI-8 is able to map the point cloud to an accurate measurement scale as a scan is created. Measurements recorded within Realworks were consistently accurate to within ¼ inch of hand measurements taken, with greater inconsistencies occurring infrequently enough to be attributable to human error from hand measurements.

While the photogrammetry technology utilized was not suited for direct geometry creation from the generated point clouds, three complementary branches of data were ultimately collected which could be used in conjunction with one another to verify the integrity of locational and dimensional data. The archival building drawings provided extensive dimensional data for details represented, most drawing sets were generated as a guide for the work to be done, and do not represent true, as-built conditions. By using the data collected from photogrammetry technologies and measurements taken by hand in conjunction with the archival drawing, measurements could be triangulated to confirm accuracy.

4. Conclusion

Recreating an existing building in a digital as-built state, while an involved task, is not an impossible one. Simultaneous collection of dimensional information and visual documentation of the general layout and appearance of building elements are crucial to constructing an accurate recreation. Photogrammetry exists as a technology with the potential to combine these two key elements into a seamless process, with the possibility to expedite the production of an end-product. Figures 6a and 6b show the final 3D Digital Model of Cater Hall (2016: post-centennial renovation).

3D model view of the first floor after the 2016 renovation

6b: 3D model sectional view after the 2016 renovation.

The application of photogrammetry to the documentation and recreation of existing buildings is consistent with the technology's typical uses within the building construction industry. Its ability to capture an existing state and represent it in a highly accurate point cloud has the potential to greatly expedite the documentation process when compared to traditional, hand-measurement techniques. However, photogrammetry is also limited for its applications in the design and construction due to lack of accuracy and quality. If the demand for accurate as-built building recreations increases, the technology may progress beyond serving as a referential tool and be able to offer better geometry creation options in hardware or software form. The application of photogrammetry in the world has widely ranged throughout a variety of occupations, and continued research into its possible uses has the potential to simultaneously identify to its developers the greatest areas requiring advancements and generate innovate new applications for the technology.

5. References

Al-kheder, S., Al-shawabkeh, Y., Haala, N., 2009. Developing a documentation system for desert palaces in Jordan using 3D laser scanning and digital photogrammetry. Journal of Archaeological

Science 36, 537–546. doi:10.1016/j.jas.2008.10.009 Alshawabkeh, Y., Haala, N., 2004. Integration of digital photogrammetry and laser scanning for heritage documentation. International Archives of Photogrammetry and Remote Sensing 35, B.5.

Bosché, F., Ahmed, M., Turkan, Y., Haas, C.T., Haas, R., 2015. The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components. Automation in Construction 49, 201–213. doi:10.1016/j.autcon.2014.05.014

Fai, S., Graham, K., Duckworth, T., Wood, N., Attar, R., 2011. Building information modelling and heritage documentation, in: Proceedings of the 23rd International Symposium, International Scientific Committee for Documentation of Cultural Heritage (CIPA), Prague, Czech Republic. pp. 12–16.

Ginovart, J.L., Costa, A., Toldrà, J.M., Coll, S., 2014. Close Range Photogrammetry and Constructive Characterization of Masonry Gothic Vaults. Revista de la Construcción 13, 47–55.

Grussenmeyer, P., Laneds, T., Voegtle, T., Ringle, K., 2008. Comparison methods of terrestrial laser scanning, photogrammetry and tachometry data for recording of cultural heritage buildings. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 37, B.5.

National Register of Historic Places. "Assetdetail". Focus.nps.gov. N.p., 2003.
Web. 30 Jan. 2016. Tack, F., Buyuksalih, G., Goossens, R., 2012. 3D building
reconstruction based on given ground plan

Volk, R., Stengel, J., Schultmann, F., 2014. Building Information Modeling (BIM) for existing buildings — Literature review and future needs. Automation in Construction 38, 109–127. doi:10.1016/j.autcon.2013.10.023

Zalama, E., Gómez-García-Bermejo, J., Llamas, J., Medina, R., 2011. An Effective Texture Mapping Approach for 3D Models Obtained from Laser Scanner Data to Building Documentation: An effective texture mapping approach. Computer-Aided Civil and Infrastructure Engineering 26, 381–392. doi:10.1111/j.1467-8667.2010.00699.x