THE ROLE OF LASER SCANNING IN THE PRESERVATION AND RENOVATION OF HISTORIC ARCHITECTURE

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ABSTRACT:

A Laser scanning can play an important role in the preservation and restoration of historic architecture, expanding beyond the traditional dependence on 2D representations of plans, elevations, and sections. The products from laser scanning can be integrated into commercial CAD and modeling applications that can be used from initial concept, throughout the design process to construction drawings. This paper will consider how scanning data can assist the architect exploring potential design alternatives in a renovation program. Presented to clients and government authorities these design solutions can be established within an accurate framework. When viewed within a virtual space, 3D models built from laser scanning data may ultimately improve the quality and understanding of a planned design for architectural reconstruction. A proposed renovation of the main sanctuary space for the Central United Church, one of the oldest churches in Calgary, Alberta, provides a case study illustrating how data derived from laser scanning can form the basis of an accurate 3D model that can be integrated seamlessly into the architectural design process.

1. INTRODUCTION

Laser scanning can play a critical role in the capture of 3D data critical to the preservation of historically important works of architecture and archaeology. However, if the architectural and archaeological professions are to adopt laser scanning as a common strategy, techniques and workflows must be identified to increase the value of this new technology.

2. LASER SCANNING: COSTS AND BENEFITS

Within any industry, the rate of adoption of new technology is a function of equipment costs, available skills needed to implement the new technology, and modifications to management and operations. Early adopters of a new technology assume some risks, as new workflows must be developed to take advantage of potential cost savings generated from the new technology. Industries that are more dependent on advanced computing technologies, those on the “bleeding edge”, face considerable financial risk, as recently introduced technology will inevitably come down in price, even over a very brief period of time. For those firms that adopt a “wait and see” approach, new developments can be watched and costs and benefits gauged by the success of earlier adopters (Flynn 2002, Layton 1974, Schumpeter 1934).

In the initial application of laser scanning, major engineering projects have acquired 3D data for creating as-built drawings of industrial and transportation structures. Capturing 3D structural data of oil refineries, bridges, and mines with laser scanning is faster and more accurate than other more traditional techniques. Improvements in hardware and software technology contributing to a technological convergence has revolutionized the use of laser scanning in industrial applications particularly with the development of software that converts point clouds into objects like pipes, valves and walls. Designed for industrial applications, CAD operators have the tools to create 3D databases of objects needed for the management of multi-million dollar facilities.

In heritage and architecture, laser scanning has been adopted first for projects of major significant cultural value. Often with the assistance of major research and educational institutions, the costs of data capture and processing are subsidized partially by grants and graduate student support (Addison 2001; Eakin 2001, Levoy 2000, Molenbrey 2001; Tchou, Chris, et. al., 2004; Tamblyn 2002). These efforts have been critical for demonstrating the value of laser scanning technology to the larger profession of architects, curators and preservationists. However, acceptance among those involved in the preservation, restoration and re-use of historic buildings is at an early stage. A greater understanding among practicing architects of the practicality of laser scanning is a critical factor before this technology is accepted as a common tool in architectural design. Influencing the culture of architectural practice will require:

· Education -Developing post-professional educational programs that expand awareness of the value of laser scanning in practice. Corporate culture development that considers the value of laser scanning in all aspects of operation, including marketing, design, working drawings, specifications and construction management.

·Skill development - Developing the ability to incorporate the advantages of laser scanning data into the design process from initial concept to work drawings by core architects, designers and CAD operators.

· Software development- Designing software for laser-scanning data translation, editing, and conversion in support of architectural practice.

· Capital investment -Overcoming barriers within architectural firms to make the needed investment in software and hardware capable of processing and converting points clouds into data needed in the development of a design.

· Workflow - Developing a design process that benefits from the collection of laser scanning data. Workflows should eliminate...
the re-entry and translation of data, and the design process should exclude the common practice of creating different 3D models to accommodate the various stages of the design.

- Client awareness - Helping clients understand the advantage of acquiring accurate 3D data sets. A willingness of clients in the private and public sector to pay additional costs associated with the acquisition and post-processing of data.
- Institutional development - Changing the data standards for site preservation by government institutions to encourage the use of laser scanning in design practice.

3. CASE STUDY CENTRAL UNITED CHURCH

The case study of the renovation of an historic building in Calgary’s downtown commercial core identifies barriers presented widely to the introduction of laser scanning in architectural preservation. As part of this discussion, the role of design conventions in architectural practice is considered a key factor in a more general acceptance of laser scanning.

The Central United Church is one of Calgary’s most important downtown historic buildings. The Central United Church’s unique octagon plan seating 1200 has served the community as a place of worship, as a concert hall and, during the 1930’s, as the location of the United Farmers of Alberta and the Wheat Pool Conventions. More recently the Central United Church has provided a place for community outreach programs. (Calgary Public Library)

Designed by Badgely and Nicklas of Cleveland, Ohio, this Romanesque revival church was constructed out of local sandstone, a common material for commercial buildings in the early 1900’s in Calgary. Building began with the placement of the cornerstone on May 13, 1904 on the site of the former Methodist Church. Damaged by fire in 1916, a reconstruction of the auditorium was supervised by the architects J.E. Burrell and R.E. McDonnell. In 1948, a three-story stone and brick gymnasium and banquet hall was added to main structure.

Calgary’s downtown core has undergone extensive redevelopment since the 1960’s, with many original buildings removed. The Central United Church is one of the few remaining buildings from the early period of Calgary history (Calgary Public Library).

With several modern renovations and the restoration program following the Second World War, a base line was needed for future renovations. Board members of the Central United Church decided that a 3D computer model could serve as the base model for future renovations for the main sanctuary space. David Reessor, a church board member, directed and engaged Chris Tucker (The Focus Corporation) and Richard M. Levy (University of Calgary) to begin the work of scanning the interior space of the church in December of 2003.

Laser scanning was seen as critical by board members for creating an accurate 3D model, in which to test out designs for a new balcony seating for the sanctuary. Without accurate as-built drawings, testing potential sightlines of future designs faced serious obstacles. Other concerns involved the removal of the existing main floor. Conceivably, changes in elevations between the main sanctuary space and the front and side entrances would impact access to the sanctuary. A virtual model would facilitate testing sight lines and movements through the circulation space on the main floor. Early on in the process, board members recognized the value of an accurate laser-scanning-based 3D model for communication with the congregation on proposed changes to the Church’s architecture.

The ability to walk through a model would provide everyone in the congregation with a clear understanding of proposed changes to the historic church. In addition, virtual walkthroughs from the web or CAVE facility at the University of Calgary would provide increased public awareness of the Church’s plans. Ultimately, a variety of media including, images, animations, and virtual worlds could help in the fund-raising efforts of future renovations.

4. WORKFLOW

Project began by scanning the interior space of the church. Using a CYRAX 2500 scanner, approximately 9 million points were captured from several locations within the main sanctuary space. At a later date (June of 2004) the exterior of the church was scanned from both street and roof top locations. With an accuracy of 5mm for each point, the CYRAX 2500 provides excellent data for modelling architectural space. Using Cyclone, a software application that supports the CYRAX scanner, individual scans were registered from the locations of 3D targets that had been placed in the view space during scanning. The 3D targets acted as anchors during the registration process, reducing the potential introduction of error. Accurate registration of the interior and exterior scans of the buildings provide the architect will useful information, such as wall sections and the three dimensions of window openings. Converting million of points into an optimised mesh is critical in the reconstruction process and requires several steps. A point file from Polyworks (PTX format) was imported into Polyworks (Innovmetrics www.innovmetrics.com) to create the mesh files needed for modelling. Polyworks is an application used in engineering and manufacturing. In this project, Polyworks was used to check the registration of the individual scans, and to create, edit and optimize polygonal meshes. An automated process repaired small holes created by lack of data. For more extensive repairs, it was possible to extend the curvature along the major and minor axes of the object. The last step, mesh optimisation, can be critical in scenes containing a number of potentially high polygon models. In optimizing the mesh, one approach is to reduce the number of polygons where surfaces are relatively featureless. This approach will result in a model that is significantly smaller than the original model, while still maintaining a high degree of similarity with the original object.

One of the goals of this project was to produce a model that could be viewed as a virtual world in a CAVE environment. In order to create a model that would run efficiently in real time stereo, the mesh was subdivided into individual architectural elements including: vaults, columns, walls, floors, pews, cornices and other architectural details. An OBJ (Flight) format for the each element was created and imported into Nubraf. Nubraf was used primarily for translating mesh files from OBJ format to 3DS format, a requirement of AutoCAD and 3D Studio VIZ (AutoDesk), which were used in the modelling process. Using AutoCAD’s surface fitting functions (RuledSurface, EdgeSurface), simplified mesh files were created for the vaults of the sanctuary, greatly reducing polyface count. An advantage of this approach was the elimination of holes not easily filled using Polyworks. Each simplified mesh was exported into 3D studio VIZ (3ds format).

AutoDesk’s 3D Studio VIZ is an application for creating and rendering 3D objects and entire worlds, commonly used in architecture, design, game and film-making. 3D Studio VIZ was used to create the model needed for animation sequences and renderings.
virtual world construction. In 3DStudioVIZ, substituting lofted forms reduced polyface count of more complex forms such as columns, ribs, organ pipes, pews and balcony railings. Cross sections for these lofted forms were acquired directly from the mesh files, while the paths for the lofts were created by tracing the outline along the edge of a column or rib. This approach allowed the number of polyfaces for the interior model (30,000) to be reduced to about .33% of the original mesh size (9,000,000 polyfaces). In creating the exterior version of the model, polyface count was reduced from 12,000,000 to 350,000 (Figures 1, 2).

5. LASER SCANNING AND ARCHITECTURAL DESIGN

One advantage of having a 3D model is that a variety of products can be created for design, public education, and marketing. In the modelling of Central United Church, products created from the laser scanning data included:

- Point Cloud Models - Created from the original data set, a series of point cloud models were exported from Polyworks at different resolutions.
- 3D Mesh Models - Mesh models were derived directly from the point cloud data created in Polyworks.
- 3D Studio Models - Optimized versions of the mesh model were based on the point cloud and textures mapped in 3D Studio
- Multimedia - Images, QTVR, animations sequences and virtual worlds were created.

In developing models for use by project architects, one issue arose early in the discussions: integrating the laser-scanning model into the architect’s existing approach to design. For centuries, architects have worked in plan, section and elevation. Working in a 3D CAD environment from design concept through to working drawings is only becoming a recently accepted approach in practice. Even on large-scale projects, much of the design work will be completed as plans and elevation studies, with 3D computer models created for maximum visual impact late in the design process. Historically, architectural education has stressed the use of drawing in 2D for the development of a design concept. Vitruvius (Marcus Vitruvius Pollio), a Roman military architect of the 1st century BC, discussed plan, elevation and perspective. His treatise, “The Ten Books on Architecture”, has been reprinted many times since its origin in 1450 (Virtruvius 1960). One explanation of why plan and elevation are often preferred is that the medium allows measurements needed during the design and construction phases to be easily and directly extracted (Addison 2000, Nuyts 2001). Before the emergence of CAD, the architect created perspective drawings and 3D scale models as presentation tools to educate and impress the client. Over the last decade, rendering and animations created from computer models have replaced these more traditional representations of 3D space.

The standard for documentation by institutions like HAER and HABS has contributed to the reliance on plan, section and elevation study in historic preservation. Though less versatile than computer models, these 2D drawings provide easy access into the basic dimensions of façades and floor plans, essential to every architectural work. The building survey of the Wilson meatpacking plant in Omaha, Nebraska in 2002 illustrates a dependency on 2D representations. In the documentation of this reinforced concrete building, a CyraX scanner was employed to capture the external form of the historic structure. Rather than a finely detailed computer model as the documentation format for this structure, a set of 2D drawings created in AutoCAD were based on this 3D data set. Output from this documentation included a set of mylar drawings which can be used to print...
In working with the architect who was engaged to develop the renovation plans for the Central United Church, a strong preference for 2D formats was identified that required the production of plans and elevations from the mesh model. Using Polyworks section operation, it was possible to create 500 sections along the X, Y, and Z-axis’s. These served as a basis for sketches showing proposed designs of the new plans for the balcony and main floor of the church (Figure 3).

Figure 3 Section Data, X,Y,Z

An issue emerged in the use of section data based on laser scans: the ability to represent the true surface of an historic structure with all of its imperfections. With masonry architecture built in the early part of the last century, forms are slightly less then orthogonal. Rough surfaces are revealed by small deviations in plan views as you progress along the vertical axis through a series of 500 sections. The more traditional measurement devices result in far fewer observations and can contribute to representation of the building as a more perfect form with orthogonal walls, and flat surfaces. Having more data can make the design process more complex by having to reconcile small changes in surface dimensions throughout the structure. Early in the design process, the desire for clean straight lines prompted the architect’s demand for a new survey, one that would result in far fewer points.

Ultimately, the 2D sketches created by the architect were converted by a CAD technician into a 3D model in 3D Studio, using the mesh model created from the point cloud data as a reference for elevation changes and the wall. This 3D model of the proposed changes for the design were then placed in the virtual model for real time walkthroughs and shown to the client in a CAVE environment at the University of Calgary, CCIT, I-Centre. In this CAVE, the 3D stereoscopic effect is created using four projectors supported by a cluster of four PC computers. Each PC in the cluster drives a single projection screen, left, right, front and floor. Dell Precision 650 with video cards from NVIDIA (FX3000G) display complex geometry in real time. Though possible to view these models on a single screen CRT with shutter glasses, it is cumbersome and for many users can produce a form of virtual reality sickness. Greater acceptance of stereo viewing and lower priced stereo projection screens may do much to encourage the use of laser scanning data in general architectural practice.

6. CONCLUSION

The design of the plans for renovating the Central United Church is a work in progress. By using laser scanning for the base line data collection, an accurate as-build 3D model has been created which has served as an armature for judging future recommendations. Though providing advantage over more traditional means of data collection, this approach would not have proceeded without the leadership of the client, who championed the use of laser scanning as a basis of 3D modelling.

If scanning is to be accepted by preservation architects, a new paradigm will have to be adopted in design. Virtual construction in 3D space will be required, rather than a more traditional approach which first works in plan and elevation and then converts designs into 3D computer models. However, tools for working with point cloud data within industry standard CAD programs will be required. More important, a new approach to design will need to be adopted, one that is dedicated to working in 3D space throughout the design process. Finally, lower cost display technology capable of stereo projection may do much to stimulate interest in using laser-scanning data in design.

7. REFERENCES

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