Using 3D Terrestrial Laser Scanning to Model the Interior of an Abandoned Theater for Renovation Purposes

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Abstract

Creating a model of an existing, complex architectural structure like a theater can be a time consuming and difficult undertaking. Issues such as line of sight, accuracy, and time constraints can pose problems when creating such a model and, in turn, when plans for renovations are made from that model. These issues can be overcome and alleviated with the use of High Definition Survey (HDS) scanning, also referred to as 3D laser scanning. Martinez Corporation, a photogrammetry company, was chosen by Miller Dunwiddie Architecture to create a model of the interior of the abandoned Shubert Theater in Minneapolis, Minnesota. Miller Dunwiddie was looking for the fastest and most accurate way to obtain a model of the existing conditions within the theater so that they would be able to take measurements and derive a plan for the renovation process. It was decided that 3D laser scanning would be the most efficient and most accurate method to produce a model of the interior. Miller Dunwiddie wanted the model tied to a real world coordinate system so that it could be referenced to existing CAD files of the surrounding area. This model will be used in the creation of renovation plans and in public presentations about the future Shubert Theater.

Introduction

3D laser scanning technology was introduced in 1998 as a new tool that would aid surveyors in capturing data. The technology works by emitting a laser from a scanning device which bounces off of all of the objects in its field of view sending the laser pulse back to the scanner. The scanner records thousands of points per second and each point has intelligence, or location coordinates and elevation information. All of these points are placed into the same local coordinate system to make up a point cloud which represents the area, building, or object being scanned in a 3D space. Most modern scanners are rated to have their best accuracy at distances out to 100-130 meters. This means that objects and areas can be scanned from a distance if access to areas is a problem.

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The scanners (Figure 1) themselves have developed from stationary scanner mounts that could only scan in one direction with a limited field of view, to the newest models that rotate in a 360 degree plane and can scan a complete dome around the scanner. This allows for a large amount of data to be collected from one location.

Figure 1. Image of HDS 3000 scanner mounted on tripod.

When first introduced, the benefits of the technology were immediately apparent to the survey industry. Users of 3D laser scanners were very impressed with the speed at which they captured information, the ability to conceptualize survey projects in 3D, its ability to scan objects and areas at a distance, and the density of its point collection (Jacobs, 2004a). Conventional surveying techniques involve collecting important points and features using a total station or GPS. This can be a slow process since individual points have to be collected one at a time. 3D laser scanning has given surveyors the ability to collect information much faster, at upwards of 1,000 points per second. The points obtained from conventional survey techniques have to be transferred into mapping software to be represented spatially. HDS scanning creates a 3D point cloud on the fly as it is collecting data. This gives the surveyor the ability to visualize the project area right away while at the site (Figure 2). Modern surveying is often done on or near roadways, highways, or areas of construction where safety can be a concern. Laser scanning technology enables the user to scan objects and sites from a distance, essentially removing the operator from harms way. Most importantly, traditional surveying captures the minimum number of points that will successfully and accurately accomplish the task at hand. 3D laser scanning can collect a very high density of points which aides in creating highly detailed plans and designs.

While the benefits of the technology could immediately be applied to the survey industry, it was not until recently that the benefits of 3D laser scanning began to be applied to other disciplines. One such discipline is the architectural field. With any architectural project, be it new construction or renovation, the current state of the building site or existing structure are important aspects of the planning that goes into a project.

Architects need current, accurate, and detailed information in order to create the plans and designs for the project at hand. Also, there is a great benefit in being able to create a 3D representation of the proposed design or, in the case of building renovation, existing conditions.

Not only does a 3D representation help the architect develop plans for renovation, a 3D model can

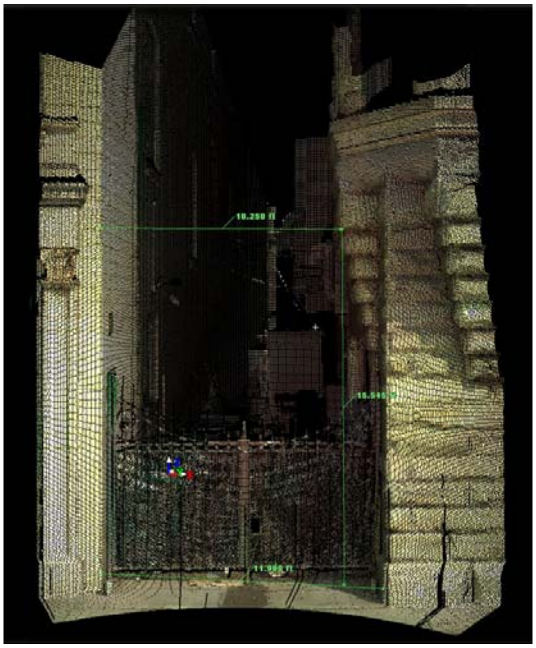

Figure 2. Example of a point cloud obtained during a typical scan.

can help other people involved in the project see the existing state of the building without actually setting foot inside. Be it presentations to the public, to investors, or for use among project designers, a 3D model is a useful tool in an architectural project.

The Shubert Theater on Hennepin Avenue in Minneapolis, MN has been abandoned since the early 1980s. In 1998, the entire structure was moved from its original location to approximately 1 block away where it sits now. The years it was abandoned, and the move have caused a substantial amount of damage to the theater. There are many areas on the ceilings and the walls where the plaster and other materials have worn or broken away. Areas of the ceiling have even fallen away to expose the steel gurters. A large amount of debris is present all throughout the theater. Some of the ornate plaster work on the balcony and columns is in an advanced state of disrepair. Overall, the conditions in the theater are poor. The architectural firm in charge of the renovation project, Miller Dunwiddie, was interested in very accurate information throughout the theater. In particular they were concerned about the condition and integrity of the ceilings, if there was any pitch to the balconies, lines of sight throughout the theater, and the state of the ornate terra cotta inside and on the front (facade) of the building. To accomplish this, a 3D model consisting of lines, meshes, and planar surfaces that represent the theater was to be constructed. This model will be what the architects will use to take the measurements they need and to make plans and designs for the renovation. Additionally, the model needs to be registered to surveyed coordinates around the exterior of the building so that it can be used in conjunction with existing data for the surrounding area. The best method to complete this project was one that would complete the task quickly and provide accurate measurements to within ¼ inch.

The decision to use HDS scanning to complete this process was almost the only option available to acquire all of the information the architect desired. The only other option the architect was considering was hiring college students to take manual measurements with a tape measure and other tools in order to obtain the data that was needed. Not only would this have proven to be very time consuming, but a lot of error would be introduced and accuracy would be compromised. Therefore, upon completion of the scanning process, computer software called Cyclone would be used to extract information from the point clouds to create the model of the theater.

Methods

Data Collection

All data for this project was newly generated. No as-built (original construction) drawings exist for this building, and no data sets (digital or hard copy) were used as references or as enhancements to the data. All of the data was collected using a Leica HDS 3000 laser scanner. The scanner operates through a program called Cyclone. The first step the scanner takes is to take a digital image of the area from each setup. This image shows the entire 360 degree global view from the scanner. This image is then used to highlight areas that are to be scanned. The option to scan the entire field of view is available as well. Therefore, once the image is taken, the scanner operator uses the image as a reference for what will be scanned. These scans can all be set up to run in a script so there is no operator intervention once the scans are scripted (Jacobs, 2004b).

To start the data collection process, a plan was created that outlined each different location that the scanner would be set up at, or scanworld. This would ensure that all of the information for the theater was captured. It was determined that 26 scanworlds were necessary to obtain all of the data. The high number of scanworlds was due to line of sight obstructions within the theater. Remaining seats, debris, and hallway turns are some examples of aspects of the theater that posed line of sight issues. Two of the scanworlds would be from vantage points that would enable the scanner to view out of the theater windows. This was necessary so that common points could be found between the scanworlds and the existing survey of the surrounding area. These common points would act as control points for registering the final point cloud to the known coordinate system.

The Cyclone software allows a user to set the scan density, set the area to be scanned, set up scan scripts that will perform numerous scans one after the other, and view the point clouds as they are being created. At each scanworld the scanner was mounted on a tripod and set to take a full 360 degree scan of the area from that vantage point at a low point density (Figure 3).

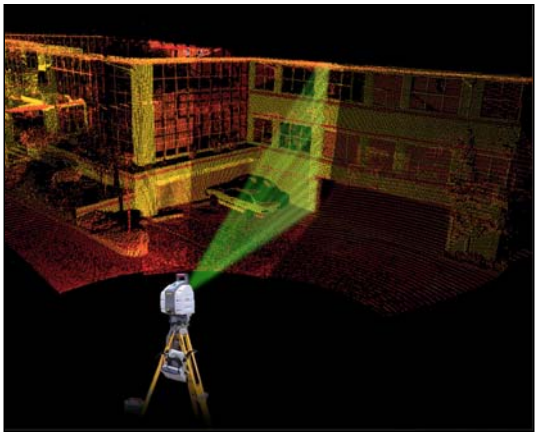

Figure 3. Representation of scanner at work, with a sample point cloud.

While the scanner was performing this initial scan, a script was set up to scan areas of high interest or areas that needed a higher density. A higher point density means that the space between points is less resulting in a finer detailed scan. These areas included the balcony faces, columns within the theater, detailed terra cotta on the façade, certain areas of the ceiling that were identified by the architect, and other areas that the scanner operator thought needed further point density (Figure 4). This was an important aspect of the scanning process because higher point densities make it easier to extract the lines, TINs, and planar surfaces for the model.

Figure 4. Image showing scanner set up and at work in Shubert Theater.

Next, since numerous scanworlds had to be created, it was necessary to be able to register them all together. To accomplish this, seventeen targets were set up in locations around the theater before the scanning started. At each scanworld, Cyclone was used to take highly detailed scans of all of the targets that could be seen from that vantage point. The targets have a highly reflective center point on them. Cyclone has algorithms within it that know to look for this point when scanning targets. Once this point was detected by the laser from the scanner, a control point was automatically placed in the center of the target within the point cloud. Once the scanning was complete, these targets were used to register all the scanworlds to one another. Differences in control point location resulted in the generation of some residual error. This error corresponds to the accuracy of the scanner. A similar process was performed for the registration to a recognized coordinate system. Coordinate locations around the exterior of the theater were provided by a survey team that performed survey services for the architect. These locations were input into Cyclone. Control points were manually selected from the point cloud at the same locations as the survey points. The registration process was performed and error was generated for each control point. Similarly to the local registration, the error from the registration to a fixed coordinate system represents the accuracy of the scanner.

Data Creation

The raw point cloud data created in the scanning process is a valuable tool, but it is not easily manipulated by most mapping software. Typical mapping softwares, such as ArcGIS, AutoCAD and Microstation, have a very difficult time interpreting files that consist of many hundreds of thousands, if not millions, of points (Figure 5). Because of this, features that are functional with the softwares listed above, such as lines, TINs, and polygons representing the structure of the theater, needed to be extracted from the point cloud. These features will make up the model of the theater.

Figure 5. Example of large point cloud of building next to Shubert Theater.

Once all of the scanworlds were registered to one another, the process of extracting the 3D model from the point cloud was started. Cyclone software was used to create lines, TINs and planar surfaces that represent walls, floors, steps, ceilings, and any other features within the theater. For example, points were selected from the point cloud that represented the top of a stair and a function within the software created a line representing the top of that stair based on the selected points. Similarly, points representing a portion of the ceiling were selected from the point cloud and Cyclone found all points in the point cloud that were similar in color value and intensity along a planar surface to create a surface that represents the ceiling. In areas of highly detailed architecture, such as the balcony faces, or the columns inside the theater, detailed TIN surfaces were created that modeled the ornate textures of these surfaces.

Results

The immediate results from the scanning process were the digital point cloud representations of the theater. The point clouds from the interior of the theater offered a large amount of data for the entire inside of the building (Figure 6).

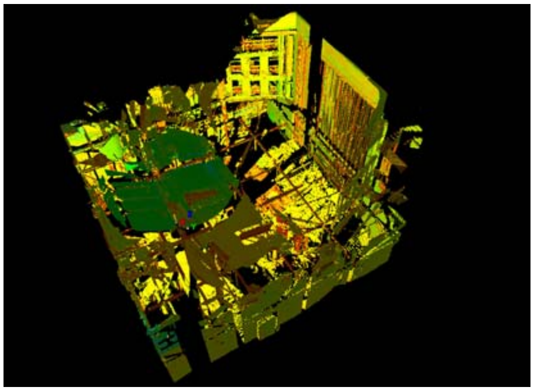

Figure 6. Point cloud from inside the theater.

The high density of these point clouds made it much easier to extract the line work, TINs, and planar surfaces that would make up the model of the theater. In addition to areas inside the theater, the point cloud of the façade of the theater was scanned at a high enough density so that the intricacies of much of the terra cotta stone work and architecture would be represented (Figure 7).

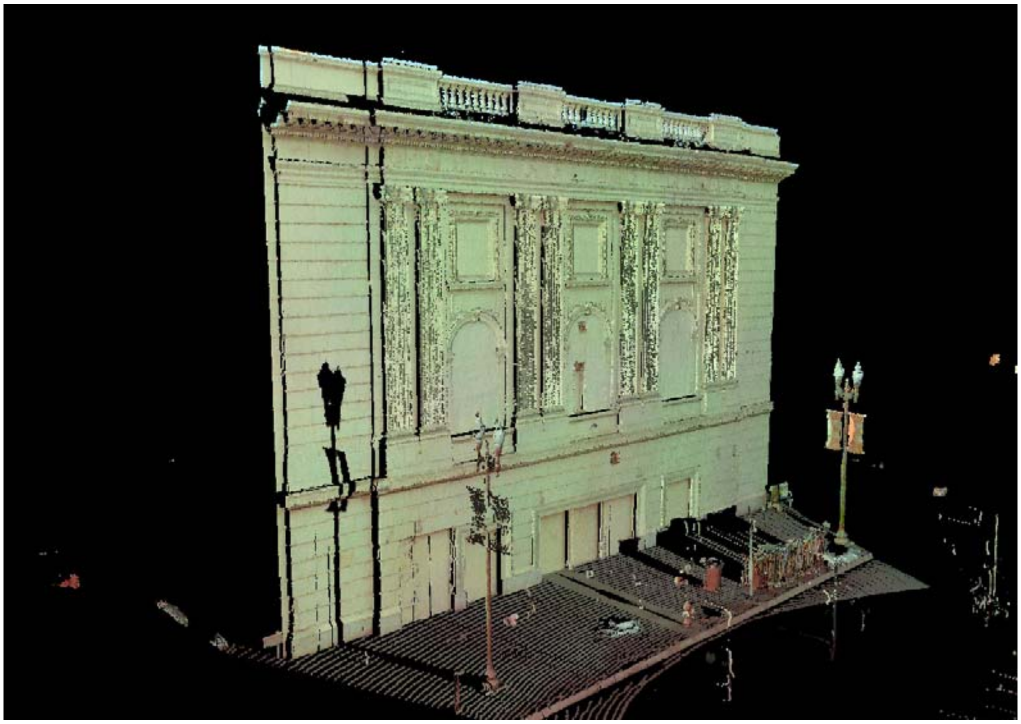

Figure 7. Point cloud of façade of Shubert Theater.

The accuracy of 3D laser scanning was really the key to this project. The processes of registering the point clouds to one another and registering the final point cloud to a known coordinate system provided the analysis of the scanner's accuracy. The relative registration (registering the point clouds to one another) provided mean error values in feet for each control point. These values represent the differences in coordinate values for each control point between all of the scan worlds (Table 1). The total mean error for the relative registration was calculated to be 0.008 feet. This means that within the theater environment itself, the scanner was accurate to within 0.008 feet.

Table 1. Mean error values for control points in relative registration.

Target ID	Mean Error (ft)
Sphere 15	0.0084
Sphere 18	0.013619
Target 1	0.003333
Target 10	0.027286
Target 11	0.0098
Target 13	0.012286
Target 16	0.0042
Target 17	0.002542
Target 2	0.005192
Target 3	0.004964
Target 4	0.004333
Target 5	0.006733
Target 6	0.0048
Target 7	0.007429
Target 8	0.00413
Target 9	0.008813

The fixed registration (registering the point cloud to a known coordinate system) provided mean error values for control points outside the theater. These values represent the differences in coordinate values between the survey and our scans of the surrounding area of the theater (Table 2). The total mean error for the fixed registration was calculated to be 0.086 feet. This means that, in the fixed coordinate system outside of the theater, the scanner was accurate to within 0.086 feet.

Table 2. Mean error values for coordinates in fixed registration.

ID	Error (ft)	X,Y,Z Error (ft)
bench	0.051	(0.007,0.034,-0.038)
Cnpy_SE	0.064	(-0.038,-0.048,-0.018)
CnpySW	0.056	(-0.055,-0.009,0.008)
CB	0.341	(-0.293,-0.173,-0.024)
CCL_SE	0.05	(-0.020,-0.042,0.019)
Cor1	0.019	(-0.009,0.009,0.014)
Corner	0.167	(-0.068,0.151,0.023)
FH	0.18	(0.173,-0.009,-0.050)
FH1	0.034	(0.011,0.023,0.023)
int1	0.062	(0.023,0.057,-0.012)
lgt1	0.033	(-0.028,-0.017,-0.004)
LL_SL	0.031	(-0.030,-0.008,0.002)
LR1	0.042	(-0.030,0.018,0.022)
MH	0.02	(-0.002,-0.020,0.003)
MH	0.084	(0.008,0.078,0.029)
MH	0.102	(0.010,0.098,0.026)
PLI	0.223	(0.170,-0.145,-0.004)
UR1	0.033	(-0.003,-0.018,-0.028)
UR2	0.056	(-0.005,-0.048,0.029)

The only alternative method that the architect had available for this project would have been to have student interns take the necessary measurements manually with a tape measure. In order to get all of the measurements needed to create an accurate model, it would have taken approximately twelve weeks with a team of 4-5 people (Stark, 2006). In addition to the time, this method would have been limited by the access to different areas of the theater and by safety concerns when attempting to get difficult measurements across large gaps and because of the building condition. Using 3D laser scanning this project was finished in two weeks with only two people. Also, the method of manual measurements can introduce a large amount of error, up to 1 inch (0.08 feet) over 100 feet in some cases (Stark, 2006). This may not seem like a lot of error, but when one is planning a renovation of a building like a theater where sight lines, acoustics, and lighting are going to play a major role, it is important that the measurements be as accurate as possibly. With 3D laser scanning, the error in the model that was created was 0.008 feet, which exceeds the ¼ inch accuracy that the architect was looking for.

The final point cloud that resulted from registering all of the scanworlds together was extremely dense (Figure 8). This made it much easier to extract the line, TIN, and polygon work to model the theater (Figure 9). Figure 8 shows an image of the final point cloud. The view has been manipulated so that the viewer is able to see through the wall into the interior of the theater. If the point cloud was viewed without this software manipulation, it would be difficult to distinguish any features of the theater. Figure 9 illustrates the theater from the same view, but instead of the point cloud the resulting model of the theater from that view is displayed.

Discussion

The development of 3D laser scanning technology has already had huge impacts on the survey industry. The benefits it provides, speed of data acquisition, richness and high density of data, highly accurate data, are all things that are preferable to many in the engineering, planning, and mapping industry. It is only logical to continue the development of the technology and apply it to other industries.

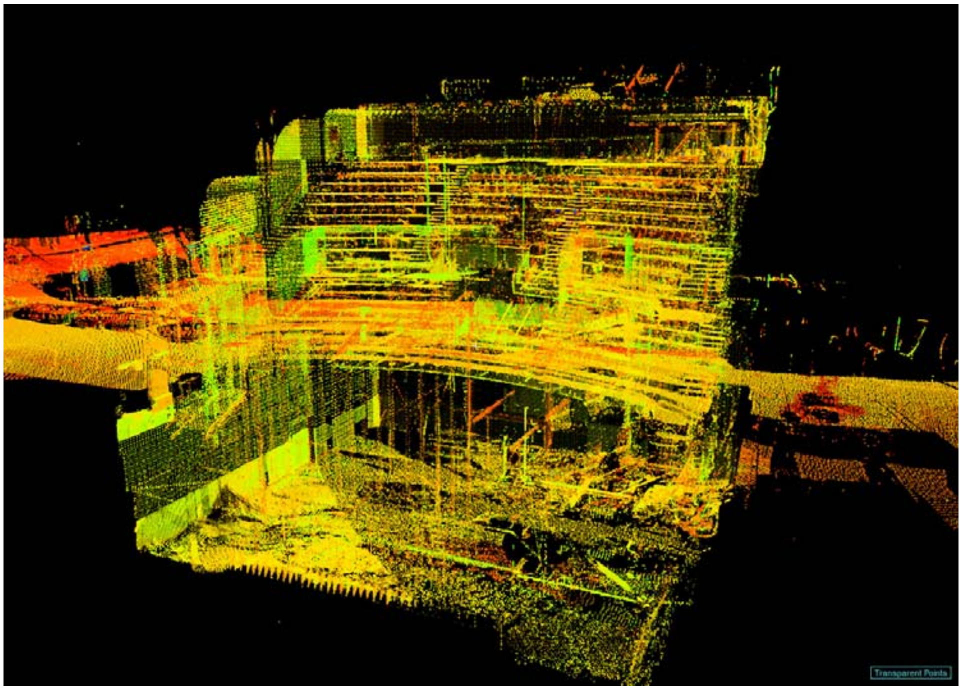

Figure 8. View of final point cloud.

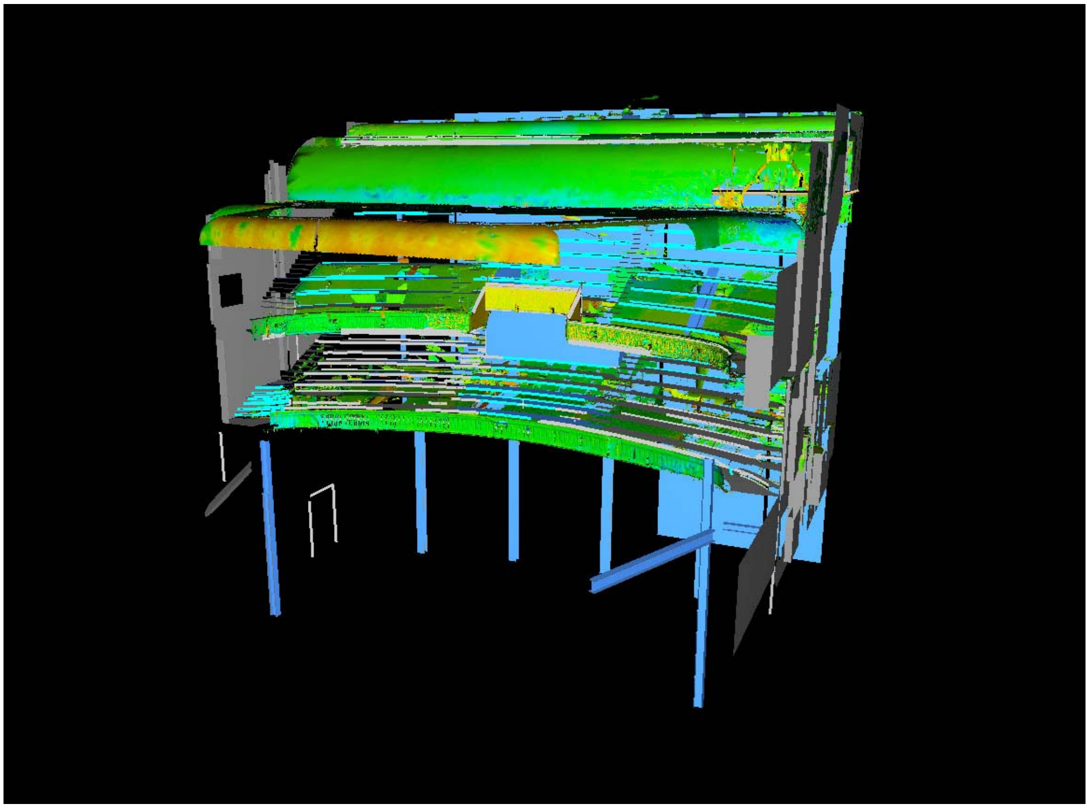

Figure 9. View of the model created from above point cloud.

The architecture industry is a perfect example of how the benefits of 3D laser scanning can yield immediate positive impacts in a different field. In a competitive field where time, accuracy, and better informed clients are high priorities, 3D laser scanning offers a perfect solution (Jacobs, 2005). The ability to scan a potential building site, or, in this case, an existing building in a short amount of time equates to more time spent developing a good design and a faster project start/completion date. Costs can also be reduced due to decreased field time. The immediate return of a 3D view of the building is also a great benefit. With an immediate view of a building or site in 3D allows architects to begin to envision their design and ideas before plans are even drafted up. The high density of data that is collected with 3D scanning ensures a high degree of accuracy and a more effective 3D representation of the space. Finally, the highly accurate information obtained from 3D scanning is invaluable to the architecture industry. Traditional survey methods (total station, GPS, etc.) are often thought to be the most accurate methods of data collection. 3D laser scanning returns data that is very comparable to these methods in accuracy and is easily transferred to the architecture industry where other methods are not.

As the digital modeling and mapping industry continues to grow, the potential for 3D laser scanning grows with it. An increasing amount of engineering and mapping firms, as well as government entities, are looking for improvements in digital information and ways to incorporate GIS and other technologies into their everyday operations. The application for 3D laser scanning in these types of industries seems to be virtually limitless. The benefits of the technology need to be continually applied to new and different industries so that more people can understand the usefulness and value that 3D laser scanning offers.

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References

Jacobs, G. 2004a. An "Ultra-fast, High-Definition, Reflectorless Topographic Survey." Retrieved July 15, 2006 from http://www.profsurv.com/archive.php?issue=88&article=1236.

Jacobs, G. 2004b. 3D Laser Scanning: Versatility-The Other "Hidden Instrument" Inside Laser Scanners. Retrieved July 15, 2006 from. http://www.profsurv.com/archive.php?issue=93&article=1310.

Jacobs, G. June 2005. 3D Laser Scanning: Uses in Building and Architectural Surveys. Retrieved July 19, 2005 from http://www.profsurv.com/archive.php?issue=101&article=1428

Stark, J. 2006. Personal Communication