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Integration of Surveying Methods for Digital 3D Solid Model Transcriptions of Historical Buildings

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ABSTRACT

There are many reasons for recording historical structures, not the least of which is for research work in Preservation and Architectural history. For many buildings, especially medieval and ancient structures, the building is the only source of evidence for understanding its story. One major area of research at the Historical Resources Imaging Lab at Texas A&M is to provide very accurate 3D models of historical structures so that these buildings may be more easily accessible to more researchers for study. We call these models 3D transcriptions. Because of their scale and complexity, completion of these models requires the integration of many different types of measuring devices (hand measuring, total station, photogrammetry, pulsed laser scanning) with various kinds of modeling and information software.

This presentation will discuss this research in progress as it pertains to the 13th century Cistercian abbey Valmagne in southern France, and the 19th century B. F. Goodrich house in Anderson, Texas. I will present the measuring and modeling problems and the integration solutions for each project with information pertaining directly to our use of digital and video photography, hand measuring, field notes in the electronic age, total station survey techniques, information processing, photogrammetry with Photomodeler, the Cyrax 2400 pulsed laser scanner, and solid and surface modeling software.

INTRODUCTION

One of the first lessons we teach our students about documenting historic buildings is the age-old dogma that you can't have everything. There is neither time, money nor perhaps even the ability to record all of the information about a building so we must decide what information to keep and what to ignore.

Computing power, however, has awakened the naïve dream “to have it all” by enticing us with the possibility of perfection. We no longer need to settle for typos, or colorless, featureless documents. We can format, correct and design forever. Maybe it is this naïve dream which truly drives the quest for digital transcriptions of historic buildings but I like to think that it comes from the simpler need to have access to information about a building that I do not yet know that I or someone else might need.

Misdirected as it might be, investigating the issues of transcription models brings brilliantly to the fore the theoretical and practical issues that all teams face when tackling problems related to historical buildings. For instance:
What information is relevant to transcription, i.e., is dirt, or stains or graffiti germane? Are the holes in vuggy limestone necessary while the holes created by nails used to hang garden tools insignificant? Is geometry the only issue or are color and texture and light important? The desire to transcribe a building into digital models forces one to take philosophical stances on these questions. This paper discusses some of the practical issues presented by transcription endeavors and the reasons why we have always settled for less. Two of the projects presented are medieval masonry buildings while the third is a 19th century wood framed house.

NARBONNE CATHEDRAL

The first move towards transcription occurred with the project to study the design and construction methods of the cathedral St. Just in Narbonne, France (Figure 1). The need for extremely accurate data was fostered by a need to perform comparative analysis on dimensional information within St. Just and also with several other cathedrals in the region. Our goal was to measure as precisely as our instruments would allow.

The field work for the project spanned from 1984 – 1992. The objective for drawing production was to produce very accurate 2D plans, sections, elevations, and details that could be used in our comparative analyses. We began by measuring and drawing everything by hand. Triangulation from constructed datum lines was the primary measuring method for the plan and the pier sections, but this method did not seem plausible for elevations.

Figure 1. Cathedral St. Just

The desire to produce very accurate elevations and sections posed two particular problems: A. How to accurately map elevations which rise to over 50 meters and B. How to draw everything accurately enough to a scale that was easily managed. These problems worked together to move us away from hand drawings and into the world of AutoCAD in 1986. At least with CAD we could produce images accurately without worrying about the errors inherent in a pencil width.

The move to CAD motivated a striving for more precision and accuracy in measurement. Even if scaffolding had been available it would not have satisfied out desire for a greater integration between measuring and drawing. To try and solve the problem of scale in elevations we wanted to adopt a remote sensing technique that would allow data to make a quick transition to drawings. We chose to use two theodolites to remotely triangulate points in space.

This method allowed us to tie the elevations and the plans together by tying the station points for the theodolites to the datum lines already created. This was important for our research since we needed to know how elements like clerestory windows and flying buttresses related to the placement of the piers. We hand-measured the distance between the instruments and then shot everything visible with both instruments. Since our instruments were not electronic we could not automatically transfer information into AutoCAD, so we recorded readings by hand, transferred the numbers into a spreadsheet so we could create script files to be run in AutoCAD

The scale of the building and the complexity of its design made even a limited 2D "transcription" difficult. For instance, instead of measuring every piece of tracery in every window, we had to be satisfied with measuring major points that would allow us to fit the geometry of the window to these points. Large irregularities were measured but routine weathering was not. Where "unimportant" elements like pinnacles repeated they were copied on the drawings to save time. In the end, transcription was mitigated by the erosion of time and economic resources (Figure 2).

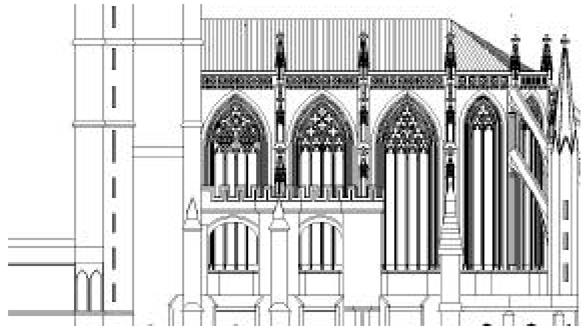

Figure 2. South Elevation, St. Just

ABBEY OF VALMAGNE

The Abbey of Valmagne is a Cistercian abbey located near Montpellier, France (Figure 3). The scale of the building (24 meters to the vaults, 26 meters wide and 80 meters long) along with greater simplicity in its design proved to be a great candidate for large-scale 3D transcription.

By 1996 digital hardware and software were powerful enough to permit 3D measurement and modeling of buildings. Modeling software like Softimage, Wavefront, 3D studio, or even AutoCAD along with digital total stations made taking measurements more automatic. Digital Photogrammetry was now readily affordable and new instruments like GTCO's Freepoint 3D digitizer created opportunities for new approaches in recording medieval structures. They also whet the appetite for the possibility for 3D transcriptions.

The time frame for this project (3 years) was too short to consider full transcription but we were able to carefully focus on significant architectural elements that gave a good representation of a variety of problem types. In terms of architectural features, these problems concerned piers, buttresses, and interior and exterior elevations.

Figure 3. Southwest view of Valmagne

Piers

Piers in medieval structures are very important elements for both structural and design reasons. The diameter of a pier helps determine the clear span and the height of the space it borders. The capital height relates the shafts of the pier to the neighboring vaults and thus is related to the diameter of the pier through its relation to vault heights. The shafts surrounding the pier are also tied closely with the pier base since it must be designed in such a way that the vault and arch ribs all relate properly with each other.

The challenges of accurately measuring a pier are many but most significant are the diameter or diameters of the pier core and shafts and their angular relationship to each other and neighboring piers. At Valmagne we have measured piers by hand, total station and a 3D digitizer.

Hand measurement: Piers are hand-measured by triangulation. A datum box is created around the pier. It is marked and divided into 1 cm. segments. The pier is divided into its significant levels from the floor to the level of the shafts. Dimensions are taken from known points on the datum to points on the pier such that a minimum of three datum measurements will define the location of one point on the pier. Depending on the complexity of the pier, a pier section can take anywhere from two to four weeks to complete (See Figure 4).

Problems:
1. The greatest problem is getting all of the data to reconcile. Much time is spent deciphering misread tapes or misrecorded dimensions that ultimately lead to an open or crossed geometry.
2. It is very slow in comparison to other methods.

Positives: Total immersion into the dimensionality of the pier makes the surveyor very familiar with all aspects of the pier. This level of familiarization is very helpful in comparative analyses.

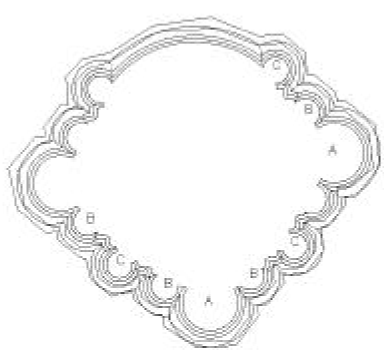

Figure 4. Crossing Pier at Transept

Total Station: The beauty of measuring a pier with a total station is that if the station points of the total station are tied to the overall plan, the model of the pier appears in its proper relation to the other important elements of the building. Like all points taken with a total station the information is stored in a data collector and downloaded into AutoCAD as a point entity. Before the information is actually input into AutoCAD it is inserted into a “survey” database so that it can be organized into relevant script files. Once the scripts are run for each level, the points are connected as a continuous polyline so that a lofted surface or solid entity may be created.

It is important for error management that a careful drawing or series of photographs be marked with the location of the points measured. When problems arise with the model the errant points can then be easily adjusted in the script files. The time frame for total station measurement is from one to two days. Modeling can occur within a few hours if the points are good.

Problems:
1. The complex angle of the pier bases and shafts means multiple setups of the total station. This can be very costly in terms of time and accuracy.
2. Complex concave curves are often impossible for good prism placement, thus requiring alternative methods to fill in the missing information.
3. Data organization in the fieldbook is complicated by multiple setups. Points must be taken for different levels from a single station point. This makes data organization slightly more time consuming.
4. Each point intended to be on the same level will actually have a different z coordinate value. Depending on the modeling software this can be a bit of a problem. For simplicity in modeling we can assign an average z value to each level in Microsoft Access. For producing 2D plan sections we can use Access to strip away the z and simply plot the curves.
5. Less familiarity with the pier and its dimensions. Understanding of the design and construction qualities is lessened due to focus on producing proper modeling data.

Positives:
1. Data acquisition is faster and more reliable than with hand measuring. Since the calculations of coordinate values are done within the fieldbook, there is little problem with transfer errors in getting data from the field notes to database.
2. Pier is placed with respect to other elements of the building.

3D digitizer: GTCO’s Freepoint 3D digitizer is able to measure objects up to a 2.5-meter cube. It is not a remote-sensing device since one needs access to the desired point with a hand-held wand. Once the wand is placed on the point a trigger is pulled that sends a sound signal from two emitters on the wand. A triangle of receivers picks up the signals and calculates the coordinate points of the tip of the wand. Through windows DDE the Freepoint software can send the coordinate information directly into a CAD package like Microstation or AutoCAD so that the modeling and data gathering of the pier are simultaneous.

Problems:
1. Since the transmission signal is an audible frequency ambient noise can pose serious problems. For instance, molding profiles that were attempted on the exterior of west entrance of the Narthex were impossible to measure because of the interference of things like tractor, automobile or plane noise. Speech, however, does not seem to be a problem.
2. Reflections of signals when the receiver and transmitter are in tight locations were a problem. For instance, we had no trouble measuring the nave pier out in the nave, but once we tried to measure the pier that inside the aisle position next to the wine barrel the information was jumbled.
3. Interference of physical objects with the signal can cause erroneous readings.

4. Multiple setups and registration is required. Setting its local coordinate system to the overall building coordinate system as established with the total station is very helpful.
5. The three-meter cable that connects the wand and the receiver array is fragile and not really suited to harsh field conditions. A sturdy flexible conduit around the cables would help.

Positives:

1. The curves for lofting (Figure 5) are created in the modeling package simultaneously with coordinate acquisition. Errors in the model can be assessed immediately and remeasured immediately.
2. Time frame for modeling is greatly reduced. A complete lofted model of a fairly complex crossing pier took 4 hours for complete setup and measuring and an additional hour for data manipulation and surfacing.
3. The accuracy of the curves is very high. The instrument claims a precision of 1 mm.

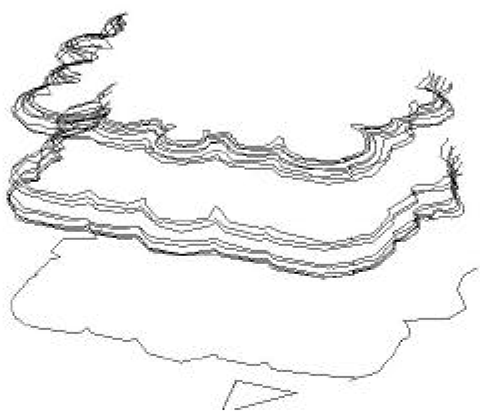

Figure 5. Lofting Curves Crossing Pier South

Elevations

As with St. Just in Narbonne, elevations presented a challenge due to their scale. If one is sincere about transcription then one cannot assume that lines are vertical or that walls are straight. Additionally exterior information must be consistent with interior information measured on the same wall. At Valmagne, since we were not using the dual theodolite method because of time considerations we decided that the elevations would be measured in two ways: A. Using the total station with a building plane program to record information beyond the reach of the prism. B. Using the total station to record target points for controlling photogrammetry models using Photomodeler.

Total Station: Wherever possible the information taken with the total station as seen in the point cloud of Valmagne (Figure 6) is obtained using the prism to get precise coordinate information. However we have experimented with the building plane option to define a plane which will allow us to "assume" a plane for points too remote or too plentiful to measure by prism. The objective in defining a plane is to define it with as great a spread as possible so that the plane is not subject to local irregularities. For the purpose of producing very rich drawings with good dimensional information this technique can work very well.

Points on the north elevation of Valmagne were taken in this manner. Initially we shot three points with the prism to define the plane, but even with the aid of a ladder these points do not provide an adequate spread to take care of an imperceptible splay of the wall. We attempted to counter this problem by using the building plane program on a perpendicular plane to the wall (a buttress) whose profile would match the wall but whose plane definition was much more accessible. This procedure is problematic from two points: A. It introduces nested errors similar to producing an overall dimension by the addition of smaller dimensions. B. The walls are most likely to be splayed between the buttresses rather than at the buttresses. Nevertheless, we proceeded because we had measured the interior transverse arches (which lie in the plane of the buttresses) and found that they exhibited a definite splay. Since a solid masonry wall will most likely deform on the exterior consistent with the interior we chose to use the buttress information to define building plane points at the upper level of the clerestory.

Problems:
1. Setup location is critical to the success of the building elevation. We had a difficult time avoiding trees and flying buttresses. Shooting the north elevation required many setups especially when one shoots the hemicycle on the east. Each chapel required two or three setups to be able to see all of the points we needed.
2. Data reconciliation for modeling was more difficult for the elevation than for the pier. The scale of the pier made it clear that lofted curves would be the best way to go. On an elevation it isn't as clear because the data definition of the curves is much more difficult on remote areas. Unless there is a clear mortar line to follow it is difficult to maintain a consistent z coordinate. We chose to treat the elevation like a drawing for each plane we were marking and code the points according to that plane. Major elements in the plane like windows and moldings would be measured and pulled together later. We chose not to map the elevation stone for stone.
3. Administration of measured points was difficult because of the order of their acquisition. Very careful drawings of the elevation upon which point markings were placed proved far more helpful than digital photos. The perspective in photos prevented them from acting as good field sketches. Good drawings are usually proportionally correct and have the added advantage of highlighting relevant detail within a small frame.

Positives:
1. The building plane offers a good semi-transcription option for remote recording needs. Careful observations of architectural elements and knowledge of their relationships in medieval structures helps to determine appropriate plane definitions.

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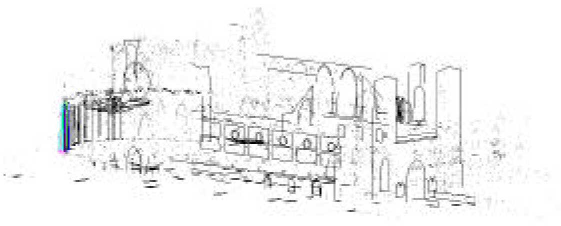

Figure 6. Total Station Points and Lines

Photogrammetry: Photogrammetry on the north elevation is challenging for all of the same reasons it is challenging for the total station with the added burden of new hardware and software to contend with. We used target points shot with the total station as controls for our models. We shot the photographs using Photomodeler's dual fiducial insert in a calibrated camera with a 50mm lens where possible and a 28mm lens if needed. For most of our elevation shots the 28mm lens proved the most useful though we are concerned about the accuracy. The photos were taken with print film so that we could get the images developed on the same day for evaluation. Selected negatives were then scanned at 2000 dpi. We did not have fast computers on site (133 MHZ Pentiums) so we were concerned about the file size. Still we decided to scan the negatives in color so that we could create a more believable texture maps for the model.

Problems:

1. The most significant problem for accurate results was getting enough images with the same data at the appropriate spread. Since we were forced to avoid trees and buttresses we found it difficult to obtain a wide variety of shots.
2. Administration of the photos and creation of the photogrammetry projects required an enormous amount of time. Even with two people dedicated to photography on this project they were unable to attend to all of the scanning and administration required on site.
3. We tended to use the photogrammetry information much like the building plane program for the total station. Detail was added through surface draw on surfaces created from processed points. We tried to ensure that there were plenty of small surfaces from processed points so that any splay in the walls would be approximated by them
4. It was a very time consuming operation, but only because we could now get more information modeled off-site than with the total station. Since most of the photogrammetry modeling occurred off-site it was imperative that we had good total station data at important points for error correction. The total station became the normative structure into which we fit the detailed photogrammetry information.

Positives:

1. Potential to create very elaborate drawings and models for areas difficult or impossible to reach.
2. Can be a good check for hand-measured and total station data.
3. Probably saves money and time in the long run due to shorter site visits.

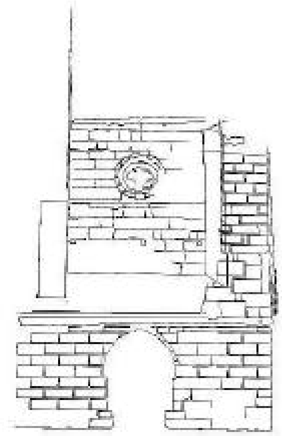

Figure 7. Photogrammetry Model
Lower Level Bay 1 North

Goodrich House

The Goodrich House is a good example of the complexities of transcription. Built in 1850 in Anderson, Texas, USA it is considered an historic landmark and yet will probably collapse soon. This project was the focus of a grant by the Nation Center for Preservation Technology and Training (NCPTT) to explore the problems of creating 3D transcriptions in digital solid models. This house was originally chosen for study because of the simplicity of its design and its relatively small scale. This house was hand-measured in 1994 so we already had accurate 2D drawings and information. The idea was to use the total station and photogrammetry to try and map this house with a minimum of site time and personnel. After this effort we were fortunate enough to be able to use the Cyrax 2400 Pulsed Laser system to compare its results.

Figure 8. Goodrich House

Photogrammetry: The primary issues of photogrammetry were the same on this project as at Valmagne, with the significant difference being scale and the fact that site was only 90 KM from our office. We were concerned with measuring as much detail as possible as accurately as possible with a maximum of three days in the field. We ended up spending 2.5 days in the field with three people. While two surveyors operated the total station the third took photographs for photogrammetry.

Problems:

1. Getting good unobstructed views of the building was as problematic on this small structure as at

Valmagne. Outbuildings and trees close to the house obstructed many of the key elements in the photographs and required specific areas to be retaken. This was not apparent during the three days of fieldwork but only after the photogrammetry work had commenced.
2. Small projects like this are similar to large-scale projects when the weathering of the building increases the level of detail required. Building planes had to be set up very carefully so that the sagging walls and loose siding were accurately measured. The level of decay was so great that we were overwhelmed with detail. Obtaining any model within a reasonable time-frame required giving up on some details like the overlap in the siding or the twisted window trim or warped corrugated roof.
3. Incredible number of photographs required
4. Photograph administration

Positives:
1. Very short site time.
2. Accurate (ideal) model in a short amount of time. If one wanted a believable texture-mapped model of simple exterior vertical wall planes, then this was easy to do. By making some good decisions about planes a decent digital model could be built from the data within a few days. As informative as this might be and as valuable a record as this might be it falls very short of our idea of transcription.

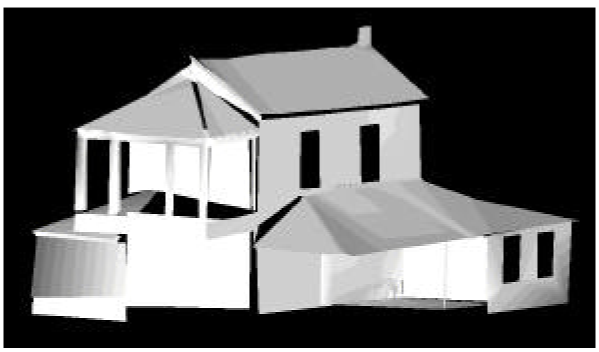

Figure 9. Photomodeler Surfaces

Cyrax2400

The Cyrax 2400 is a pulsed laser scnner that is capable of making prismless measurements of coordinate values to within 2 mm at 50 meters distance. We asked the representatives from 3D Laser Technologies to work with us on the Goodrich house as a test and demo of the machine (Figure 10).

Setup time is about 20 minutes. The setup point does not need to be known since the software will stich various scanns together. The laser is adjusted to view a particular area based on a digital photo taken from the scanner body. The scan resolution can be set to .5mm at 50 Meters. We chose a 2.5 cm resolution for this test. The system calculates coordinate values for each scanned point and it can scan at a rate of 800 points per second. Once the scan begins the software allows the operator to rotate the scan in 3d so that problems may be spotted. The software can provide a polygonal surface over the points and also map intensity fo reflection on surfaces.

Problems:
1. Price. Currently the machine runs about $200,000.00 at an academic rate including warranties.
2. File Size. At high resolutions the file size of a point cloud for the Goodrich House is about 30 MB. When all of these scans are stitched together the combination is very difficult to work with.
3. Currently the output tranlations are DXF and DGN. Others are expected soon.
4. Instrument size. Difficult to get shots in tight areas or from very close range. Difficult does not imply impossible, but the job is much more time consuming.
5. Modeling. One must still deal with the point cloud to get a model in a form that is actually of some use.
6. Almost total removal from field evaluation of of building for data acquisition.

Positives:
Time and accuracy. Pulsed Laser Technology will probably become very commonplace in the near future. It is as close to "having it all" as once can get at this point.

Figure 10. Cyrax point entities in AutoCAD

SUMMARY

I have tried to avoid making a case for the superiority of a particular instrument or methodology for documentation. It might be enticing to think that if only we all had Pulsed Laser systems that we could transcribe our built heritage for richer exposition and exploration. While this may be true to some extent we all are aware that faster computers or "better" technology have not made our working lives shorter or less stressful. On all of our projects we have found that the new technology is often enriched when thoughtfully integrated with well-practiced traditional methods and that each method serves to validate the other. The best way to be sure that your total station control points correctly control your photogrammetry project is to pull out your tape and work with a friend to directly engage the building.

Notes and References:

1. Warden and Vasquez, “Telematics in historical survey and documentation projects”, arq, Summer 1997,CUP
2. Information about Cyrax can be found at www.Cyra.com