

MODULAR MODELING OF TEMPLE COLUMNS OF THE ANGKOR PERIOD

Pheakday Nguonphan, Michael J. Winckler, and Susanne Krömker

Interdisciplinary Center for Scientific Computing (IWR)
Heidelberg University
Im Neuenheimer Feld 368
69120 Heidelberg, Germany
Michael.Winckler@iwr.uni-heidelberg.de
<http://scotty.iwr.uni-heidelberg.de>

KEY WORDS: Cultural Heritage, Architecture, Modelling, Reconstruction, CAD, Graphics, three-dimensional, Multiresolution

ABSTRACT:

Geometric modeling of vast building complexes is a tedious and difficult task. In contrast to the a priori work of an architect who constructs a new building, the computer reconstruction of existing (old or ancient) buildings faces a serious problem: The computer model copies the real world - not vice versa. This leads to the question of model abstraction. While the real world building features a vast amount of detail, the model has to reduce these details to a point where a computer model is small enough to be manageable by current hard- and software.

The Angkor Temple Generator, which we developed over the last five years, addresses this dilemma behind the modelling process and exemplifies a modular solution for a defined class of buildings. In this paper we present the example of temple columns to explain the methods we use in the ATG for modelling Angkor style temples efficiently and with a high level of detail. Analyzing temples of the style of Angkor (Cambodia) leads to the construction of typical building blocks in this architectural family. All building blocks are based on sets of necessary parameters which are used to derive a suitable building block entity for the particular temple. The parameter setting can be accomplished by either using digitized data of specific parts of the building only or by deriving structural data, which is specific for each building block. Both techniques are presented on examples from Angkor Wat, one of the largest temples complexes in the world, for which we constructed a complete model using the ATG techniques.

1 MODELING ANCIENT BUILDINGS FOR SCIENTIFIC COMPUTING

When working on projects of scientific computing where the application area is a building or a assembly of buildings (such as a temple), one of the first tasks that we encounter is the geometric modeling of the architecture. While the techniques to establish such a geometric model are not new, special circumstances have to be kept in mind when dealing with ancient architecture instead of modern buildings.



Figure 1: High-detail basement model

The *level of detail* used when building up the computer model usually strongly depends on the application for which the model will be used. An example in three parts:

- For the *simulation of visitor movement* inside a large temple structure, the principal shape of the buildings, halls and archways is normally enough to construct a valid model of

tourist distribution over time using e.g multiple free agent systems or markov based models.

- In contrast, a *scientific research* of the placement of reliefs or paintings in a temple needs a quite accurate model of the temple geometry. The height and size of surface decoration relative to the overall structure and with respect to each other is an indicator for references between several decorative objects.
- For use in an *animation movie* the geometry as well as the texturing of surfaces influences the quality of the overall visual appearance in a decisive manner (figure 1). While surface details can be partially substituted by bumpmapping, geometric traces at visible edges have to be mapped down to minute detail to achieve high standards (c.f. figure 2 for the effect of lower geometric modeling (Levy, 2001)).

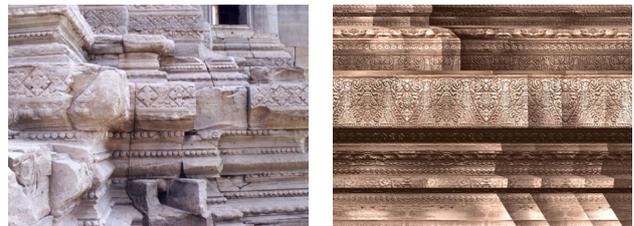


Figure 2: Temple detail and low geometry model

On top of this question on the level of detail, further problems pop up when dealing with ancient architecture. As construction data on the site is usually not available, all data for the reconstruction work has to be sampled from the building itself. This phase of data acquisition has to be done in context with the question,

whether small differences between similar parts of the building are addressed in the model or reduced to abstraction. This question becomes vital if parts of the structure are no longer completely intact or even run down and in ruins.

2 PRINCIPAL MODELING TECHNIQUES

Modeling techniques for buildings can be separated into two major categories. The *basic shape approach* starts out from a set of principle three-dimensional geometries (cube, sphere, pyramid, torus etc.). By subdividing the surface representation in a suitable manner and distorting the surface elements (usually triangles) to fit the geometric properties of the original building, the starting shape is converted into the model.

Comparison to the original shape is typically done by imposing images of the building from different angles into the modeling tool such that a perspective comparison can be visualized. This approach is also widely used in computer graphics for the game industry. One advantage in this application setting is the strong control over the number of triangles used in the modeling process. Careful subdivision of selected surfaces and the use of photos as immediate textures gives a fast and reliable test on the visual quality of the model in exactly the setting where it is mostly used: in medium resolution on a computer screen.

In contrast to this technique the *scan conversion approach* starts out with a detailed measurement of the surface of the building. Such data is usually acquired by laser scan techniques (for large structures) or light pattern scans (for structures up to a few meters in diameter). From the measurement a set of surface data points is generated, which in a postprocessing step is meshed to form a first representation of the surface. Automated or manual reduction of the vast data sets is used to control the memory footprint of the model and keep it manageable. The advantage of this modeling approach lies in the faithful representation of buildings down to individual surface properties such as cracks or bumps - at the cost of a highly complex data reduction step and the large size of the resulting model in general.

Methods of latter type are also used to rapidly produce first models of vast structures with a limited amount of manual work (e.g. based on digital aerial images): The input data such as elevation measurements is automatically converted to a relief-like model with virtually no horizontal detail (see e.g. (T.Sonnemann et al., 2006)).

3 MODELING WITH A MODEL TYPE IN MIND

The task we are addressing is the modeling of several different buildings with common feature sets. This is e.g. the case in the temple region of Angkor, Cambodia. Over the course of several years the Angkor Project Group (APG) at the Interdisciplinary Center for Scientific Computing (IWR, Heidelberg University) has modeled a range of temples in this area, from small temple structures such as the Kravann (35x10x20 meters) to Angkor Wat itself, one of the biggest religious temple complexes worldwide (600x1200x70 meters).

The emphasis in each model was to produce a series of model levels that are suitable for all different kinds of scientific simulations: From coarse-grain overview models down to stone-accurate detail reproductions. As the variety of uses of a geometry model is typically not defined when the modeling phase starts, our aim in current and future projects is to stay as versatile as possible with each model that we produce.

The traditional approach for such a goal is to produce a model with maximum accuracy and scale down the level of detail (LOD) with suitable LOD methods when later on a more coarse model is needed. The drawback is the lack of control over of the model regarding the accuracy of detail.



Figure 3: ATG production chain

Our approach (figure 3) in contrast starts out by analyzing the architectural type of model we are facing. Although the buildings we are dealing with are several hundred years old and were constructed over several historical periods, common structures of these buildings can be identified. The modeling process that we implemented in our software, the Angkor Temple Generator (ATG) exploits these common structures (for a full reference to the ATG refer to (Ngunphan, 2008)). Starting out with a standard model for each such structure, we analyze the building with a special task in mind: to collect all information needed to define the entity of the model type that is present in the actual case. This set of information can be collected very efficiently by methods specialized to harvest this data from measurements, photos or single scans.

Once the data is complete, the construction modules together with the data sets forms a complete description of the building. Based on this abstract computer representation (comparable to a model in a specialized modeling language), very compact and efficient geometric representations of the building can be computed. The derivation of the model from the representation can take into account the final resolution we are aiming for. In fact, it can produce a specially tailored version of each module taking into account where reduction of the complexity can be accomplished without a loss in the usability of the model.

4 ANGKOR STYLE MODULES - AN EXAMPLE

Elements for the ATG were selected by comparing several buildings of the Angkor Wat period and identifying common building blocks. In figure 4 we depict four of these building block: the crown, the roof, the pediment and the column. The column itself is not a simple element (in the framework of the ATG) - it is a complex element which in turn consists of three simple elements from two element classes, the column body and the capital/foot class.

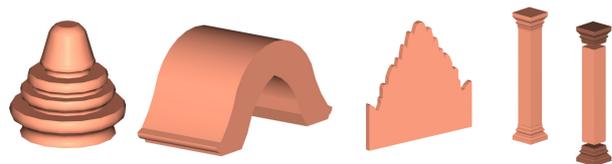


Figure 4: ATG production chain

For one of the elements, namely the column, we describe how a typical construction from the basic module is derived. In case of a standard column (with square shape cross section), the height of the overall column and the width of the column body are two

input parameters. Additionally, the structure of the capital and foot element have to be defined. For a first prototype, this shape can be derived from a photo showing the capital outline.

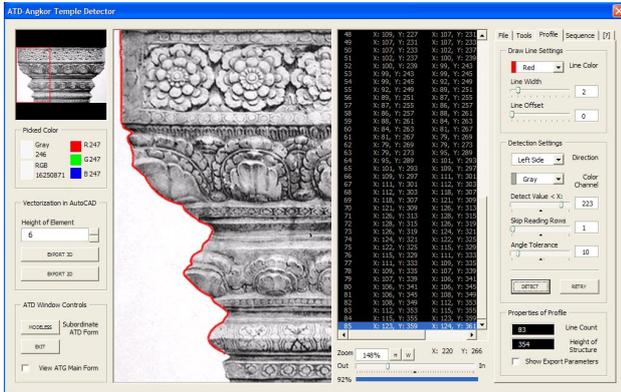


Figure 5: Detection of capital outline

In this construction step, several tools from scientific computing (in this case mainly image processing) work together to shorten the construction time and increase the quality of the result. For the ATG we constructed a special image detection tool (figure 5) to process silhouette images and derive line section representations of outlines. These line sections are later on converted into construction information which in turn is used to compute a geometry representation of the column head. This outline tool is widely used as a first analyzer for all elements which mainly draw their shape from a silhouette propagated around the perimeter of the element (e.g temple basements, column capitals etc.).

After the complete scan of such an outline, simplification steps have to be imposed to derive element representations with a lower resolution - for computer graphics this is identical to a lower number of triangles.. The reduction of surface triangles is closely related to the reduction of the number of points in the line section. An important postprocessing step is therefor to reduce the number of line segments while maintaining the geometric outline of the silhouette. For this task several algorithms were constructed, implemented and tested. Again, the problem at hand is a standard problem in scientific computing.

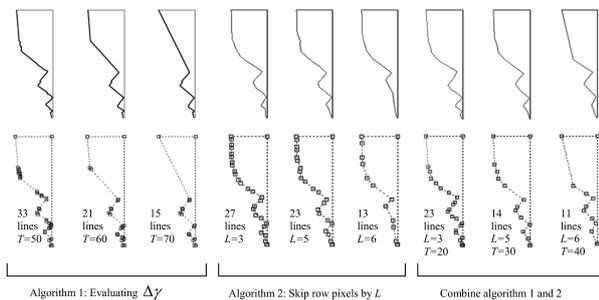


Figure 6: Two algorithms for reduction of the level of detail in line scans

In the ATG software we use two algorithms, which can either be employed separately or in combination. The algorithms we implemented were based on two assumptions:

- First, we analyzed the outline of several capitals and base-ments. In typical Angkorian architecture the lotus flower

plays a special role in the ornaments found in these elements. As the lotus is usually a round shape which is set apart from other ornamental structures by sharp intersections, we concluded that significant changes $\Delta\gamma$ in the angle of slope of the outline indicate a new important part of the silhouette. When computing a representation in lower resolution, we therefor reduced the outline complexity by combining several parts of the line section if their angle difference $\Delta\gamma$ was below a certain threshold.

- The second observation came from analyzing the *typical size* of a single outline shape element. As the handycraft methods used to build the temples were based on stonema-son techniques of the relevant era, minimal feature sizes are comparable for several temples in the Angkor area. Relative to the reproduction ratio of the photographical image used as a source for the line section, the placement of feature points on the silhouette can be bound from below by a distance of several pixels. We use this observation when generating the line section in the processing of the photo image by skipping a specific number of rows in the image before trying to identify a new outline feature point.

The effect of this technique can be observed in figure 6. In the left three image pairs the reduction of a line section using the $\Delta\gamma$ criterion only. While this approach keeps the sharp outlines of the lotus ornament in the lower part of the silhouette, the rounded upper part is increasingly eroded.

In contrast to that effect, the middle three image pairs show the change of the outline under the row skipping approach: While small but sharp features get eroded, the outline of larger components of the silhouette are maintained.

In an example as the one presented here, a combination of both algorithms (see the three image pairs on the right) significantly reduces the number of line segments while maintaining both the overall shape and the lotus flower motives.

5 GOING ONE STEP FURTHER

Up to this point, modeling of the geometry of Angkorian temples was based on a combination of refined image processing techniques and the modules of the ATG. While this approach holds much value for a rapid modeling of large temple areas, the refinement of the models was only based on *technical* reduction methods of the line segment representation of scanned input lines.

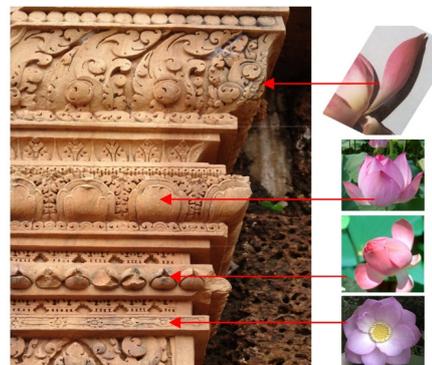


Figure 7: Lotus motives in decoration of column capitals

Further improvements are possible by analyzing the decoration pattenr itself and finding optimal representations for the silhouette by means of an interpretation based on architectural properties.

In decorations of basements, column capitals and other elements, the lotus flower can be found in several versions (figure 7) such as a single petal leave, an opening, partially open or full open petal. The use of this motive is closely related to the important role that the lotus flower plays in Khmer culture and architecture.

The outline of the flower is directly linked to the outline of the silhouette in the respective ornament parts. A full analysis of these ornaments (see the thesis (Nguonphan, 2008) for details) leads to an even more compact representation of silhouettes, namely by referring to the silhouette in terms of the structure of lotus elements found on the original building.

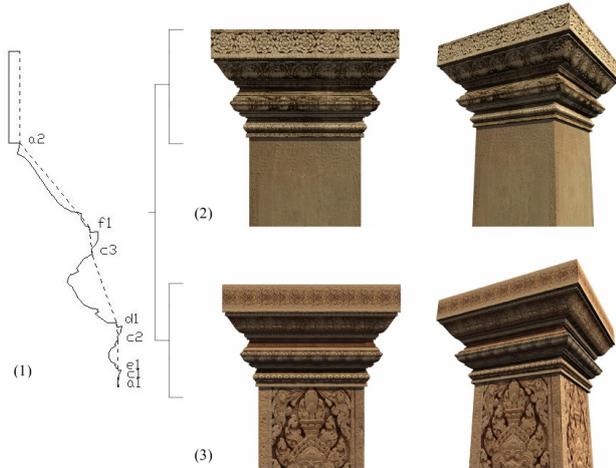


Figure 8: Analyzing the lotus motive: (1) motive series (2) column at Angkor Wat (3) Column at Banteay Srey

In this detailed analysis we found six different lotus motives, which appear (with minor variations) on several temples in the Angkor area. In figure 8 a column capital silhouette is broken up into a pattern of the lotus motives (1), which are described by the letters *a* to *f*. Two columns models with exactly this lotus pattern, taken from the temples of Angkor Wat and Banteay Srey, are shown in their computer reconstruction on the right.

The application of this lotus pattern analysis has several advantages:

- We found that both the shape and the relative scale of the pattern types in such a structure do not vary over the temples we have analyzed. So the outline can be very compactly stored by just the letters of the pattern plus the scale ratio with respect to the overall structure. This leads to a very efficient storage system.
- For highly detailed models, the shape of the outline can be optimized using Bezier splines for each part of the pattern. This results in a detail resolution which is not achievable by a scan of the photo und subsequent postprocessing of the scan line. Even three-dimensional models of the lotus pattern are possible.
- The analysis of different lotus patterns lead to substantial research on the art-historical development of these patterns in the Angkor period and the development of architectural stereotypes through the ages.

6 CONCLUSION AND VISION

The methods of the ATG were developed with a clear idea in mind: To use modern scientific computing techniques and model based descriptions of Angkor Wat style temples to improve the modeling process both in *quality* and in *speed*.



Figure 9: Computer reconstruction of a column of Preah Khan

The detailed modeling of columns using the analysis of the lotus pattern is an application of the quality issue: With a precise pattern description of columns in several Angkor temples the use of computer graphic models for art history research is a promising step into this direction. The models constructed with this approach can also be used for high-definition computer graphics (c.f. figure 9 for an example). Further examples are currently produced for a feature documentary with National Geographics television.

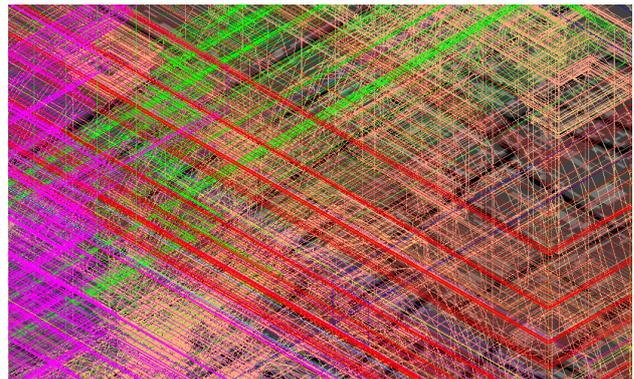


Figure 10: Small snapshot of the wireframe model of Angkor Wat

A Complete model for Angkor Wat – constructed with the use of the ATG – is an indicator that the speed of modeling is also considerable improved with this methode (see figure 10 to get an impression of the compexity of this model). Future work is exploring the possibility of extending the techniques to temples and monuments which are more loosely related to the Angkor periode. Here new modules and further techniques for image and scan processing e.g. for the capturing of bas-reliefs are under investigation.

ACKNOWLEDGEMENTS

The authors would like to express their deep gratitude to the Gottlieb-Daimler- and Karl-Benz-foundation for the financial support of Pheakday Nguonphan during his PhD project and to Prof. W. Jäger and Prof. H. G. Bock for their guidance in the development of the Angkor Temple Generator. The help and support of the World Monuments Fund during the data acquisition at the Preah Khan temple, Angkor temple region, Cambodia, was also greatly appreciated.

REFERENCES

Levy, R. M., 2001. Computer Reconstruction, Temple Site at Phimai, Thailand, Faculty of Environmental Design, University of Calgary.

Nguonphan, P., 2008. Computer Modeling, Analysis and Visualization of Angkor Wat Style Temples in Cambodia. PhD thesis, Interdisciplinary Center for Scientific Computing, Heidelberg University.

T.Sonnemann, M.Sauerbier, F.Remondino and G.Schrotter, 2006. Reality-based 3D Modeling of the Angkorian Temple Using Arial Images, Institut of Geodesy and Photogrammetry, ETH Zurich, Switzerland.