The Generation of Superstructure Geometry in Latina Temples: A Hybrid Approach.

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Abstract. *The Nâgara tradition of temple building created a rich corpus of Latina (single-spired) temples spread across Northern India between the fifth and thirteenth centuries. Computing methods offer a distinct methodology for reconstructing the genesis and evolution of geometry in this tradition over time. This paper reports a hybrid technique, comprising three distinct computations for recovering and explaining the geometry of temples. The application of the technique enables scholars to bring together fragments of evidence, construe "best-fit" strategies and unearth implicit or hidden relationships. The advantage of this approach is that changes in assumptions and testing of geometric alternatives can be easily simulated from multiple sources of information, such as texts, sacred diagrams and individual temples.*

Keywords. *Generative Design: 2D Representation; 3D Modeling; Visualization; Constraint Based Design.*

Introduction: Latina temples

The Nâgara tradition of temple building created a rich corpus of Latina (single-spired) temples spread across Northern India between the fifth and thirteenth centuries. The richness and complexity of the geometry in the superstructures of these temples continues to challenge scholars. In the absence of direct evidence, explanations of geometric relationships derived from canonical texts, diagrams and individual monuments remain circumstantial and fragmentary.

Computing methods offer a distinct methodology for reconstructing the genesis and evolution of geometry in this tradition over time. This paper presents a hybrid approach for the generation of the geometry of individual temples of the tradition combining their basis in textual canon; sacred diagrams and cosmogony and their stylistic antecedents.

The hybrid approach comprises the combination of three distinct computations. First, a generic archetypal model of the superstructure surface using rule-based computation is generated. Second, detailed models of motif geometry from individual temples are recovered using close range photogrammetry. Finally, the superstructure geometry is computed using a parametric model that combines the first and second computations to generate a three dimensional solid geometry of the superstructure. Using the geometry of a tenth century Latina temple as an illustrative example, each of the above computations is described.

Approach to the generation of superstructure geometry

Rule-based Computation

Geometrical and technical principles of historical artifacts can be researched effectively within a rule-based generative environment. Archetypal forms of superstructure can be computed from generic descriptions of geometric construction using rule-based generation. The constructive and implicit relationships are reconstructed based on the literature on temple geometry (Kramrisch, 1946; Chandra, 1975; Meister, 1979).The three dimensional form of the superstructure is based on encoding two control profiles: the horizontal plan profile and a vertical curved profile (Figure 1). The profiles are computed using a set of boundary solid grammars (Heisserman and Woodbury, 1993) shape rules derived from the literature on temple geometry. The generation of geometric form with this technique allows a large class of profiles, and by extension superstructure forms to be explored.

Underlying the plan of most temples is a ritual diagram of 8 x 8 = 64 squares (mandala) prescribed for temple building in the Brhat Samhita and later texts. This grid is used to generate the ground plan and control measure in the configuration of stone temples (Meister, 1979). The horizontal profile depends on the number of offsets (angas) and the proportional relationships between each offset based on the subdivision of the sixty-four square grid.

Rules describe the operations involved in elaborating a profile from a simple square. By recursive subdivision, offsets are generated on each side and proportional relationships attached to each of the offsets.

The extrusion in the vertical direction is based on a curved profile (rekha). This profile establishes

Figure 1. Superstructure of a latina temple from the Maha-Gurjara school of temple building, 960 CE from western India. A hybrid approach that combines rule-based generation, photogrammetry and parametric modeling is used to explain the geometry of the form.

the degree of curvature of the superstructure and controls the overall geometry of the superstructure (Figure2). Following Kramrisch (1946), Datta (2001) shows how the control curve can be generated based on descriptive rules from canonical texts.

Computation of motif geometries

Many approaches have been proposed in the literature for recovery and reconstruction of architectural geometry from photographs. DIPAD (Streilein and Niederöst, 1998) combines digital photogrammetric methods with CAD models. The

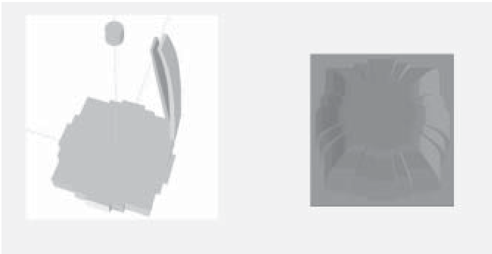

Figure 2. The form of a superstructure is determined by a rule-based generation of its major horizontal and vertical control components (left). From these components, the global form can be computed (right).

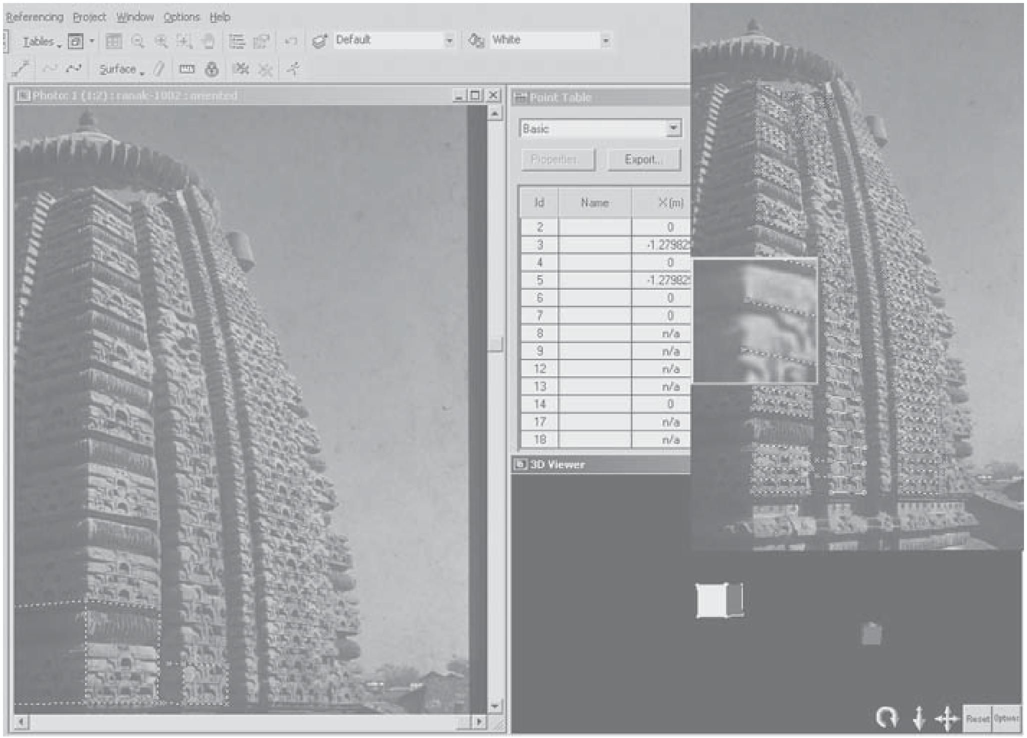

Figure 3. Models of individual elements of superstructures are generated using close-range architectural photogrammetry, supported by control points from field measurements.

Facade (Debevec et al, 1996) system combines model-based geometry with image-based rendering to reconstruct architectural scenes from photographs.

In our approach, models of individual elements of superstructures are generated using close-range architectural photogrammetry supported by control points from field measurements of temples (Datta, 1994). The surface information is extracted from photographs using standard close range photogrammetric techniques. This process recovers the elemental geometric information in vector form. Control points from field surveys are used to add accuracy to the model information. The elemental geometry (points, lines, curves) are then converted into closed profiles in a CAD modeling environment to generate the constructive geometry (surfaces and solids) of the motifs.

Computation of the tiling geometry

To explain the superstructure form of Latina temples, the specific instances of superstructure motifs are augmented by comparison with archetypal generation. The computing of the final geometry is broken into three parts, a global model governing the overall form of the superstructure, local models governing the geometry of individual motifs and finally a parametric model of the surface geometry combining the global and local models (Datta, 2005). A parametric model is then developed using the global model as a skeletal surface and this skeletal surface is tiled with a sequence of scaled units using the local geometry of the motif (Figure 3).

The shape and appearance of model entities are derived by parameterization to support multiple variations from the same model geometry. The recovered tile geometry is then combined into a single model that forms the basis for the repetitive tiling of the surface. The tiling function is based on the sequential subdivision of the curved surface. A parametric model comprises the three dimensional surface and a collection of scaled repetitions of the original motif sequences measured from the example shown in Figure 2.

In practice, each of the offsets have a separate sequence of units forming their latas. This change in the number of tiling motifs, and hence in the proportional series, imbues the lata with a complex rhythm. The three dimensional models together with the series formulation of proportional relations defines the tiling geometry for a Latina superstructure.

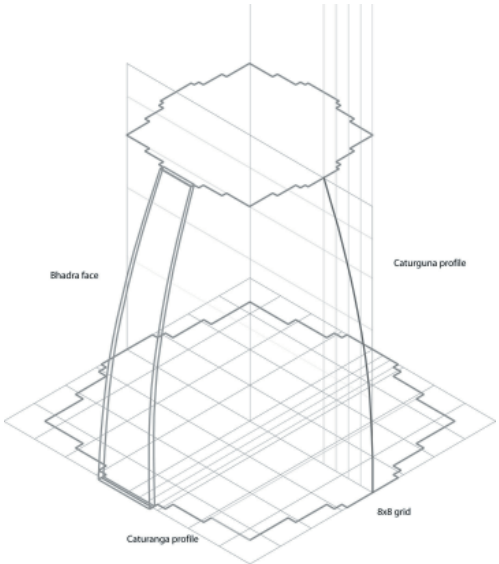

Figure 4. The superstructure of the temple is controlled by two horizontal control profiles in plan and a curved profile in section. The horizontal profiles are offset into four faces. Each offset is extruded in the vertical direction along the curved profile.

Illustrative Example

Using the computing approach described in the previous section, three dimensional models of superstructure geometry that follow the profile of the offsets (angas) in plan, a specific curve (rekha) in section and are made up of a given number of repeated motifs (jala, lata). This process is explained through the reconstruction of the superstructure geometry of a tenth century latina temple, the temple of Ranakdevi at Wadhwan.

Superstructure geometry

The horizontal profile of the temple of Ranakdevi is determined by recursive subdivision of the ritual grid of 64 squares. The basic module of the ritual grid (mulasutra), determined from field measurements, is a=660mm. Following the method reported by Meister (1979). a, the offsets of the profile are determined based on the mulasutra. The horizontal profile has three offsets (caturanga form) and these are sub measures of the basic module, a, a/4, a/4 and a/6 respectively. The width of the offsets in terms of the basic module are 5a/4, 7a/8, a/4 and 7a/4 respectively. Using these figures, the plan profile of the temple is computed (Figure 4).

Computation of motif geometries

The form of the Ranakdevi superstructure is based on the extrusion of the caturanga plan profile following the vertical curve profile (caturguna rekha). The central offset of the superstructure (mulapanjara, madhyalata) is tiled with the single unit of carving that progressively diminishes

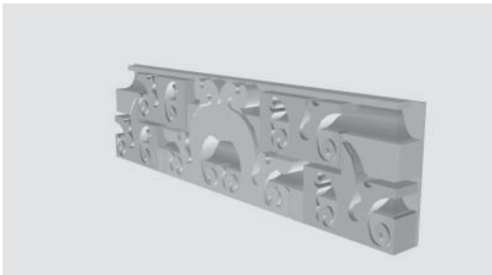

Figure 5: The local geometry of the central spine is computed into a three dimensional tile made of a bounding box and two interlaced segments, a band model and units composed of carved pattern (gavaska patterns).

through a scalar reduction of size. The geometry of this motif is derived using a combination of control points determined from field measurements and digital photogrammetry. The motif geometry is described using three models. First, a global bounding box model based on measurements of the control points of the motif is established. This bounding box information is necessary from two perspectives, to accurately apply metric information to the photogrammetric process and to provide a suitable handle for creating scaled copies of the unit. Second, the bounding box is subdivided into horizontal bands. The third model comprises the units of carving that are superimposed onto the horizontal band model. The computation of the motif geometry as shown in Figure 5.

Computation of the tiling geometry

The tiling geometry of the central offset of the superstructure in this temple comprises 27 units. The first (lowest) unit is enclosed in a bounding box of size, 4a/3 x a/3 and the last unit has a bounding box of 4a/7 x a/7, with the remaining 25 units falling within these limits in a series progression. The tiling of the central spine is computed by recursive subdivision of the global geometry using a series progression. The bounding box of each unit is computed from a set of parameters that control the global model such as the initial starting unit, number of units, scale factor and type of progression. These are then tiled within the enclosing geometry of the central (bhadra) spine (Figure 6). This process rationalizes the degree of curvature derived from the rule-based curve generation into planar facets that approximate the curvature. Thus the explicit derivation of the curvature of the form as shown in Figure 4 in now replaced by a family of polygonal tiles related by a function of the underlying series mathematics.

It is now possible to derive the motif geometry directly from this model by a simple substitution rule that maps the bounding box of each unit to the specific geometric size of the tile shown in Figure 5.The resultant model gives the final superstructure geometry where each tile in the series is a self similar scaled version of the motif model geometry (Figure 6).

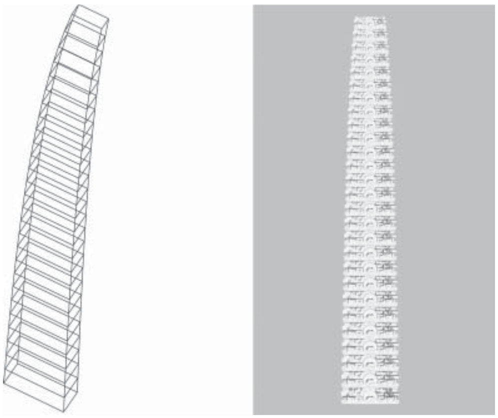

Figure 6: The tiling of the central spine is computed by recursive subdivision of the global geometry using a series progression (left). Each tile in the series is a self similar scaled version of the motif model geometry (right).

Discussion

The paper describes a hybrid approach for recovering the constructive geometry governing the superstructure of latina temples and explaining their formal and compositional relationships. The approach is termed hybrid as it combines three established methods, rule-based generation, close-range architectural photogrammetry and parameterised models to address the problem.

The advantage of the hybrid approach is that changes in assumptions and testing of geometric alternatives can be easily simulated from multiple sources of information, such as texts, sacred diagrams and individual temples. Further, since the superstructure geometry is based on formal rules, they can be easily transferred to other, similar classes of form (e.g. a related but different school of temple building). Finally, the use of this approach allows researchers to study the evolution of temple form over time, as a series of related instances arising out of similar techniques.

The computation of motif geometry using

photogrammetry is particularly tedious and time consuming to reconstruct manually due to the complexity of the shapes. Increased automation in this process will enhance the overall efficiency of the approach. One mechanism may be to use auto-markers or use more sophisticated scanning methods.

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