Accuracy and ambiguity

Geometric reconstruction of a seventh century stone temple in Hanchey, Cambodia

Sambit Datta
Curtin University
Sambit.Datta@curtin.edu.au

Abstract. Modeling the fragmented and heavily eroded remains of early temple architecture poses several challenges in accurate reconstruction of shape and form from digitally acquired datasets. This paper describes a collection of stepwise ad-hoc modeling methods that can re-assemble ambiguous and fragmentary evidence to provide a robust and empirical platform for the reconstruction of ruined temples. The paper presents the results of the method and the degree of accuracy and ambiguity in the acquisition, processing and reconstruction phases. A key aspect of the method is the maintenance of multiple "ground truths" from plural sources of partial evidence. Key findings of the paper demonstrate early results from the manipulation of geometric modeling primitives based on point collections, an advance in extending the classical tools of architectural analysis and comparison. The problem of accuracy and ambiguity in these methods and their algorithmic implementation is the subject of further investigation.

Keywords: Digital data acquisition, flexible modeling, heritage reconstruction and visualization

1 Introduction

Digital reconstruction is a well-established methodology in the study of historical structures. Reconstructions have a wide number of applications in the scholarly study of past architecture, formulation of theoretical positions, conservation and physical restoration of monuments as well as virtual simulations for mass consumption in galleries and museums (Malpas, 2008). One area of work that has received relatively less attention is the virtual re-assembly of historic structures from deformed datasets. In particular, the assumptions of accuracy and ambiguity in recovering robust information from acquired datasets remain a significant problem (Affleck et al, 2005). This paper presents a digital workflow for modelling deformations in historic buildings. The elements of the workflow are illustrated through the analysis of a digital reconstruction of the structural geometry of a seventh century stone temple in Hanchey, Cambodia (Figure 1). Each step in the workflow and the problems associated with historical accuracy and the handling of ambiguity is described. The
aim of the paper is to identify these issues, particularly in the cases of temple architecture (heavily eroded surfaces, structural deformation and missing parts) encountered in South and Southeast Asia.

A crucial difficulty faced in digital reconstruction is the recovery of structural and architectonic details from digital datasets. This is further compounded in historic buildings, where missing information, fragmented and heavily eroded and loss of structural and formal integrity through the ravages of time render the process of establishing formal continuity between artifact and reconstruction difficult. In this context, computational techniques that can re-assemble fragmentary evidence, provide robust and empirical methods to fill in missing information and generate and test the accuracy and ambiguities in the digital reconstruction of geometry are necessary. This paper examines how digital modeling methods and workflows can extend the classical tools of model reconstruction from surface geometry of architectural scenes to structural information to the construction of solid parts-based models. The paper focuses on the need to mediate between accuracy and ambiguity in the interpretation of data provided by computational acquisition tools such as image-based techniques and point cloud sampling methods. In doing so, it relies on the conventional methods of architectural abstraction and analysis to provide guidance in the process of reconstruction through a series of stepwise incremental reconstructions.

2 Related Work

Computational means of acquisition such as photogrammetry, combined with parametric modelling and simulation become useful methods for projective reconstruction from multiple sources of partial evidence. Therefore, a wide range of methods, datasets, workflows and outputs has been proposed to fit these applications (Debevec et al, 1996; Streilen et al 1998). Datta and Beynon (2005) demonstrate the application of a hybrid computational approach to the problem of recovering the
surface geometry of early temple superstructures. The approach combines field measurements of temples with close-range architectural photogrammetry. The datasets are processed with rule-based generation and parametric modeling techniques. The extraction of higher order features from point sets is demonstrated in computational modeling (Daniels et al, 2008) with applications in recovery of complex curves from traditional buildings. The use of sophisticated techniques for the acquisition of historic sites has been developed for uncovering archeological landscapes (Evans et al, 2013).

The architecture of the temples of Southeast Asia owe their compositional characteristics to adherence to canonical treatises, the interpretation of priest-architects or the usage of earlier examples as architectural models for later ones (Smith, 1999; Dumarçay, 2004; Haendel et al, 2012). The fragmented discontinuity of textual accounts, lack of graphical representations and heavily eroded early remains render the process of establishing the lineage of formal continuity between canon and construction difficult. It has been speculated whether the architecture of these temples owe their compositional characteristics to adherence to treatises, the interpretation of priest-architects or the usage of earlier examples as architectural models for later ones (Meister, 1979; Indorf, 2006).

3 Overview

![Fig. 2. Kuk Preah Theit Temple, Hanchey, Cambodia. The present temple is physically reconstructed. (source: Adapted from Datta and Beynon, 2014)](image)

This paper extends previous findings on the reconstruction processes suitable for explaining historical building traditions in South and Southeast Asia. It forms part of a larger project on understanding the compositional and architectural linkages between the temple building traditions of South and Southeast Asia (Datta and Beynon, 2014). By focusing digital methods on analysis of plans, layout and proportion of wall ensembles, superstructure form and constructional and ornamental motifs, our work shows how the earliest Southeast Asian temples represent lineages that were constantly being adapted and refined from their genesis of the archetypal Brahmanic/Hindu temple.
The early temple architecture of Southeast Asia, presents a remarkable and intriguing body of evidence in support of inter-Asian connections. Seen as a collective corpus, these sites establish a consistent pattern of religious, cultural and technological ideas that transcend national or geographic boundaries (Chihara, 1996; Chapman, 2012).

In the absence of local textual records, the evidence embedded in the geometric and material composition of the surviving monuments is the main, and sometimes the only evidence by which a more conclusive understanding of the relation between theory and practice in these buildings might be developed (Meister, 1985; Datta, 2007). The motivations for the reconstruction and recovery of the three dimensional forms are to develop a digital dataset of early Indian antecedents, test new technologies for the acquisition of built heritage and develop new methods for comparative analysis of built form geometry.

4 The temple of Kuk Preah Thiet, Hanchey, Cambodia

4.1 Historical Background

The temple of Kuk Preah Thiet is located in Hanchey (Han Chei) about twenty kilometres north of Kompong Cham, occupying a prominent hilltop on the west bank of the Mekong river. While presently dominated by a modern wat, Hanchey is significant as the location of three pre-Angkor shrines, each in a distinctly different idiom, as well as the remains of several other buildings that have yet to be fully investigated (Datta and Beynon, 2014). There is a brick temple (original name unknown, now referred to as Hanchey A), a small cubic stone-slab cella known as Hanchey B (Indorf 2006), and the most unusual stone temple of Kuk Preah Thiet. Two inscriptions on the inner door pillars of Hanchey A were among the first discovered and were long considered as the most ancient in Cambodia. (Figure 2).

Historically, Hanchey seems to have been an area where different Khmer polities converged in the fifth to eighth centuries, though never a major centre of power itself. Down the hill and closer to the banks of the Mekong is the temple of Kuk Preah Thiet. Attributed to the ruler Bhavavarman (though dateable to well after his death) these inscriptions indicate that the site, if not the temples themselves, dates back to the second half of the sixth century. The pre-Angkorian shrine of Kuk Preah Thiet, therefore represents one of the earliest known stone temples in Southeast Asia. It is lithic in its conception, constructed of dressed stone (Figure 5) and has a storeyed pyramidal superstructure composed of tiers. The elements of this shrine can be traced to many antecedents in the Gupta period. However, the early date of the temple, its well developed superstructure and its proximity to known Gupta examples, makes it a crucial example of the pre-Angkorian temple corpus. Parmentier’s 1927 photograph of the temple ensemble (left), measured drawing of the plan of Kuk Preah Thiet Temple, Hanchey, Cambodia (centre) and conjectural drawing of the east facade (source: Parmentier, 1927:200) (Figure 3).
The cuboidal cella sits on a solid *jagati* (platform) with a distinctive *vedibandha* molding which is partially buried and yet to be excavated. The *jangha* or wall portion of the sanctuary is largely bare and simple. The distinctive *candrasala* motif appears on the superstructure tiers. The *Vamana* temple at *Marhia* and the *Siva* temple at *Bhumara* have similar bases, treatment of wall and motifs (Chandra, 1970). However, the most significant aspect of this sanctuary is the *Phamsana* ( tiered pyramidal) superstructure with a distinctive molding. In contrast to flat roofed temples, and the more developed superstructures at *Sambor Prei Kuk* and at *Phnom Kulen*, this temple has the tiered pyramidal form of superstructure, known from earlier wooden temples adopted in stone. The significance of the temple lies the early date of the architectural composition of its superstructure, a pyramidal composition in three tiers, known as *Phamsana* in the literature, predating the development of the majestic temple complexes of the Angkorian period (Datta and Beynon, 2014).

A cubic temple with a pyramidal roof, *Kuk Preah Thiet* is constructed of dressed basalt blocks. It has been partially stabilised and currently remains at risk of structural collapse. *Kuk Preah Thiet* is in its present state reconstructed, though at the time of the authors’ visit, so inadequately founded that the building is at risk of collapse. The ruinous state of the temple, in an advanced state of collapse, makes dimensional correlation very difficult. Structural deformation, missing elements, surface erosion of the soft volcanic basalt stone, contribute to the difficulties in establishing accurate measures.

To investigate the inherent ambiguity in establishing accurate measures, the virtual reconstructions, in particular the recovery of schematic profile information, can play a key role in establishing the architectonic ideas underlying the temple. Secondly, the reconstructions can be used to establish its relationship to earlier Indic, Javanese and Khmer temples as well as dimensional correlation with prescriptions in surviving temple construction manuals.

![Fig. 3. Parmentier’s 1927 photograph of the temple ensemble (left), measured drawing of the plan of Kuk Preah Thiet Temple, Hanchey, Cambodia (centre) and conjectural drawing of the east facade (source: Parmentier, 1927:200)](image-url)
5 Geometric Reconstruction Workflow

The Kuk Preah Thiet temple at Hanchey is heavily eroded, virtual reconstruction models play a key aspect in establishing the architectonic ideas underlying the earliest Indic, Javanese and Khmer temples and their relationships to canonical texts. To determine these connections, two and three-dimensional geometric dissections from the temple are analyzed and compared to measure and reconstruct their geometric properties. Fragments of evidence are brought together from field measurements, relating these to mathematical and geometric descriptions in canonical texts and proposing “best-fit” models. To recover the constructive principles underlying this temple, field measurements and close-range photogrammetry were combined with rule-based abstraction, and parameterized models.

The digital reconstruction process requires bringing together fragments of evidence from field measurements, relating these to mathematical and geometric descriptions in canonical geometry and proposing “best-fit” models (Figure 4). These digital methodologies permit the creation of the following types of 3D reconstruction models:

- Raw surface reconstruction. Datasets of the temple surface geometry recovered from point cloud data acquired through field measurements and close range photogrammetry;
- Recovery of Dissections. Close-fit planar dissections reconstructed by correlating raw surface reconstructions from point cloud data;
- Canonical Adaptations. Solid structural blocks and architectural elements are adapted from surface and dissection data to create extruded solid parts for simulation of conjectural reconstruction.

Fig. 4. Solid Reconstruction Workflow. Surface reconstruction is developed from field measurements and close range photogrammetry. A sparse point cloud is developed using Structure-from-Motion (SfM) technique. A set of horizontal and vertical dissections is developed from the raw point data. Extruded Profiles are used to generate solid elements of the temple geometry.
5.1 Accuracy and Ambiguity: Assumptions

The translation or “reverse” modeling of the temple from existing conditions to a conjectural reconstruction rests on a number of important assumptions. These assumptions are necessary to quantify the accuracy of the translation process as well as address the ambiguities involved in working with deformations and missing information. At one end of this spectrum is the raw model, a direct representation of the current temple as a dense point cloud or surface mesh with textures. The accuracy provided by such an approach is valid in cases where the veracity and integrity of the site is preserved and for visualization. At the other end of the spectrum is a conjectural representation as a three dimensional reconstruction based on primary or secondary sources. This approach is mostly used in cases of insufficient or missing information. Between the raw and speculative representations, lies a number of intermediate or hybrid strategies that seek to combine elements of both and develop a stepwise strategy based on well-founded assumptions. It is this third approach that is developed in this project.

- **Ground plane and orientation.** Establishing the ground plane and the vertical and horizontal axii of the temple using 3-point correlation.

- **Assumption of symmetry relations.** The basic symmetries of the temple are assumed to be regular around the axis. In the case of Kuk Preah Thiet, the entrance doorway and the wall extents are used to fit planar rectangular grids around both axes.

- **Assumptions of proportional relationships.** Manual field measurements are used to scale the proportions of parts and establish proportionate ratios for alignment and fitting of parts.

- **Structural integrity assumptions.** The deformation of the basalt block construction is assumed to be dry wall masonry with a nominal 2 mm joint. The blocks are assumed to be regular cuboids and aligned to fit the assumed orientations in both directions. Offsets are handled with proportionate ratios.

- **Simplification of element geometry.** Complex elemental geometry such as lintels, and doorframes are simplified to regular profile extrusions. Detailed carvings and relief motifs are abstracted to simple profile extrusions.

5.2 Raw surface reconstruction

Surface reconstruction is developed from field measurements and close range photogrammetry (left). The structural blocks are recovered by treating each block as a discrete surface (centre). A sparse point cloud of the object is generated using Structure-from-Motion (SfM) (right). (Figure 5)
Fig. 5. Raw Surface Reconstruction. Surface reconstruction is developed from field measurements and close range photogrammetry (left). The structural blocks are recovered by treating each block as a discrete surface (centre). A sparse point cloud of the object is generated using Structure-from-Motion (SfM) (right).

5.3 Recovery of Planar Oriented Dissections

Dissections are structured collections of planar two dimensional points, lines, curves and planes that are oriented in three-dimensional space. Drawing upon previous studies of geometry and mathematical schema, horizontal and vertical dissections are developed from an analysis of the sparse point clouds generated using structure from motion. (Figure 6). Dissections provide a new theoretical and methodological bridge to decimate the raw point cloud data and generate the planar, oriented control geometries underlying the construction of temple architecture. In Kuk Preah Thiet, dissections are used to bring together fragments of the raw surface reconstruction, relating these to mathematical and geometric descriptions in canonical texts and proposing “best-fit” constructive and parametric profiles.

Fig. 6. Planar oriented dissections. Raw structure from motion data provides point clouds. The point cloud dataset is oriented to the ground plane and a vertical plumb. A set of horizontal and vertical planes is used to cull the raw point set data. Points are projected using approximation with a threshold value for all points on or near the plane. Regular profile geometry is fitted to the planar points.
5.4 Canonical Adaptations

Fig. 7. Assumption of symmetry relations, fitting internal plan geometry into raw point cloud data (a). Discrete modeling of construction block profiles with dissection profiles for axial orientation and uniform block size (b). Rationalization of construction joints to 2mm in regular block geometry (c). Reconstruction proposition of structural blocks as a canonical model (d).

The setting up of parametric models means that formal relationships might be extrapolated beyond the evidence of deteriorated existing structures, and while this is necessarily speculative, it allows for virtual reconstruction of ancient sites (Figure 7).

6 Results

The digital reconstruction models of Kuk Preah Thiet present new possibilities for interpreting the formal and geometric basis of temple form. (Figure 8)

The computational approaches described in this paper present the creation of stepwise, partial three-dimensional models of geometry recovered from the existing condition survey of the Temple of Kuk Preah Thiet. These models demonstrate:

1. the recovery of the architectural geometry of ruined temples from digital datasets using sparse unstructured point cloud processing;
2. recording the genesis and evolution of the geometric, structural and ornamental techniques used in Kuk Preah Thiet; and
3. comparative analysis of the complex and problematic linkages between canonical prescriptions of ideal form with the analysis of data recovered from the surviving monument. In particular, the accuracy and ambiguity of geometric reconstruction is addressed in the analysis.

![Visual reconstruction of the geometric basis of the original temple form combining the planar oriented dissections and block fragments.](image)

**Fig. 8.** Visual reconstruction of the geometric basis of the original temple form combining the planar oriented dissections and block fragments.

The advantage of this process of stepwise reconstruction is partly a matter of speed, both of data collection and of making geometric comparisons, and partly a new experimental method for interrogating the architecture of the past, focusing on analysis of plans, layout and proportion of wall ensembles, superstructure form and constructional and ornamental motifs.

The results described in this paper recover the geometric basis of this architecture pieced together from diagrams and canonical descriptions, rule-based generation of idealized form models and close-range architectural photogrammetry of temple remains as published in previous work (15-20). The new advances presented in this paper develop early results in the field to identify how large unstructured point sets can be incorporated into the process of analysis and reconstruction following classical models of architectural analysis. As the reviewers of the paper have identified, many of the steps (e.g. Figure 7) remain ambiguous and uncertain, subject to manual and semi-automated and ad-hoc techniques. Formalizing these steps remains the subject of current investigation. For example, the recovery of geometric correlations by algorithmic means by comparing planar dissections will be reported in a forthcoming paper.
The paper attempts to communicate the complex relationships between cosmology, geometry and physical form using computational methods. The program of research is developing both Indian and Southeast Asian models. It is intended that the generative role of geometry within the architectural historiography of Brahminic temples can be clarified and more fully developed. Finally, promoting a better understanding of the potential of these new methodologies to domain experts can significantly enhance the uptake and adoption of computational tools in the rapidly developing area of architectural reconstruction.

7 Conclusion

This paper presents the architectural and compositional connections between Southeast Asian temple architecture using the digital reconstruction of a seventh century stone temple in Hanchey, Cambodia. The digital reconstruction of Kuk Preah Thiet presents new possibilities for interpreting the formal and geometric basis of temple form. This paper presents our research findings on the reconstruction of compositional and architectural linkages from digital datasets of temple geometry. Focusing on the earliest Southeast Asian temples, ongoing research (Datta, 2007; Beynon et al. 2013) is using geometric reconstruction for the comparative analysis of plans, layout and proportion of wall ensembles, superstructure form and constructional and ornamental motifs of the archetypal Brahmanic/Hindu temple. Much of the computational work on point cloud processing has been in the creation of surface meshes, texture mapping and establishing ground truths. To develop these experimental methods into a robust and reliable methodology for architectural analysis, the processing of sparse unstructured point clouds requires new and automated ways of developing plan and section schematics. We have presented one possible way of how this may be achieved in the case of reconstruction from partial information.

Acknowledgements. The author would like to acknowledge Co-investigator Dr David Beynon, Deakin University and the support of the Australian Research Council for supporting the Discovery Project: The influence of Indian antecedents on Southeast Asian Temples. The editorial team at Ashgate supported the subsequent publication of the research monograph, co-authored with Dr Beynon, Digital Archetypes: Adaptations of Early Temple Architecture in South and Southeast Asia. Stuart Hanafin, Michael Sharman and Greg Pitts, were research assistants for digital modelling and photogrammetry of the temples. We gratefully acknowledge the HIVE (Hub for Immersive Visualisation and eResearch at Curtin University. Dr US Moorti and Dr Vandana Gupta of the American Institute of Indian Studies (AIIS), Gurgaon provided crucial archival material on the Gupta temples. Dr. Olivier Cunin, and Dr Pinna Indorf of the Centre for Khmer Studies in Siem Reap offered many insights into pre-Angkorian temples of Cambodia. Ichita Shimoda, of the Sambor Prei Kuk
conservation project generously shared their reports, drawings and other research material on Sambor Prei Kuk.

References