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The Conference Convenors received a total of 44 abstracts. Abstracts underwent a double-blind peer review by two members of the Conference Organising Committee. Authors of accepted abstracts (32) were invited to submit a full paper. All submitted full papers (18) were again double-blind peer reviewed by two reviewers. Papers were matched as closely as possible to referees in a related field and with similar interests to the authors. Sixteen full papers were accepted for presentation at the conference and a further 6 papers were invited to present based on submitted abstracts and work-in-progress. Revised papers underwent a final post-conference review before notification of acceptance for publication in these conference proceedings.

Please note that papers displayed as abstracts only in the proceedings are currently being developed for submission to a digital cultural heritage special edition of an academic journal.

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Digitised connections: reflections on the image analysis and spatial modelling of Southeast Asian temples

Abstract

Following the arrival of Brahmanic/Hindu/Buddhist culture, a great number of temples were constructed across Southeast Asia. Epigraphic evidence, along with the architectural and stylistic similarities between temples in these regions, is strongly indicative of historic cross-cultural links that evolved through a process of long experimentation with philosophies, world-views and architectonic methods. A wide-ranging analysis of the canonical geometry and compositional form of temples in India, Cambodia and Java, with reference to Indic texts, local antecedents and archetypal South Asian temple forms has previously been undertaken. In comparing the relationships between canonical geometry and the form of temples, the bases for the architectural composition of these temples have been reconstructed by the authors, using spatial information modelling (e.g. parametric models, rule-based design and mathematical development of rule-based surfaces). These reconstructions augment the fragmentary written or epigraphic evidence available for these temples and gradually establish the range of early South and Southeast Asian temple forms and geometric characteristics. Presently, these comparisons between geometry and form are being extended through a combination of photogrammetry and image-based analysis methods with flexible graphical simulation and visual immersion techniques. These methods serve to reassemble evidence of the architectonic links between different temple sites across South and Southeast Asia. This paper reflects on the use of these methods in developing 'reverse-architected' geometric/architectonic models to mediate historical and formal propositions about lineages of historical architecture.

Keywords: Projection; photogrammetry; visualisation; spatial modelling; 'reverse-architecting'; temple architecture

Introduction

Projection operates on the intervals between things. It is always transitive (Evans 1990, 366).

Photo-based modelling provides a robust methodology for researching temple architecture in South and Southeast Asia. Using photogrammetric methods, fragmentary physical evidence of connections between different temple sites can be pieced together to create three-dimensional reconstructions. These reconstructions constitute the empirical basis for the study of linkages (or lack thereof) in the genesis and development of these temples. Our research has examined the extent to which digital temple typologies can be related directly to Indic canons or historic architectural sequences determined by archaeological or historiographical methods (Datta and Beynon 2014, 2005). The affordances of digital methods make these questions prescient as they impact the very meaning of the represented artefact and the parallel histories of subject and method: firstly, the history of the subject – understanding the origins, evolution, development and geographic spread of ancient temples in South and Southeast Asia; secondly, the history of the method, of how these buildings have been recorded and interpreted, and more precisely how the method of their recording has influenced and been influenced by their interpretations.

We are interested in the role of representation as an active constituent in the evolution of how these buildings are understood. Changing methods of representation means changing ways of seeing and new means of representation indicate new possibilities for interpretation. Affleck and Kvan (2005, 169) observe that the majority of virtual heritage projects attempt to create a realistic computer representation of their subject. The emergence of digital technologies provides powerful tools for the acquisition, representation and archiving of historic architecture. Digital acquisition techniques such as photogrammetry, combined with rapid prototyping technologies such as 3D printing, compose a digitally driven method for researching the genesis

and evolution of temples. Contemporary scanning techniques can capture the emergent form to a greater degree of detail than is perceptible to the human eye, but in an indiscriminate manner. A digitally scanned model can be interpreted as capturing a series of instructions for particular lengths, widths, and heights, recorded to a much greater degree of accuracy than in a traditional model; for instance, minute changes in surface definition due to weathering may be detected and measured – but this exactitude is of a very specific kind related to the object as found, rather than the object as conceived or created. Variations from the ideal geometry of a temple can be put down to a number of possible factors: inaccuracies in initial construction, on-site contingencies, expediencies in craft, and then weathering, indifferent, hostile of inadvertent human interaction, subsidence, insect infestation. The combination of such factors can render a complete, observed building different to its conceptualised state even without serious erosion or destruction of its parts. It is the human eye that has to detect patterns within the scanned image or model and then make informed assumptions as to which parts are important, which are redundant, as well as about the alignment, proportion, and disposition of important parts in relation to the whole. It is this judgement that is critical in its incorporation into the model – as the resultant information alters what is measured from the observable in a profound manner. From a myriad of points, a few are chosen as significant and their relationships with each other prioritised and codified. The ability to represent temples in plan and section or in three-dimensional form endows the researcher with new tools of spatial and temporal presence as well as degrees of abstraction. This freedom permits new interpretations, experimentation and contestability not afforded in other media.

However, this is not the primary intent of this study. While our methods allow for the accurate and realistic development of digital replicas of individual artefacts, ranging in scale from architectural elements, through buildings to entire cities, our concern in

reconstruction is the degree of accuracy, realism and reproduction of the underlying composition of the original artefact that can be attained. Therefore, when data is missing or eroded or the artefact is partially destroyed due to the ravages of time, other means of filling in the missing data are required. Key missing data consists not only of the embedded geometric information in the artefact itself, but also of its evolutionary lineage over time; that is, missing objects of similar use and appearance that precede or follow it. This method of investigating the underlying geometries of temples as a means of understanding the connections between them, differs from archaeological, art historical and architectural methods of study of physical elements and details. The process of measurement and computation in order to discover aspects of the underlying geometry of temples requires a certain suspension of the vision-based sensibility that practices based on photography of artifacts and buildings naturally bring to scholarly fieldwork. This does not mean that photographs have no visual importance, but their primary functions are as conceptual aids in our aim to trace the genesis and evolution of temples in India and Southeast Asia from early experimentation (400 CE) to the beginnings of the mature expression (c 900 CE). Each reconstruction is a point in the design space of possible temple adaptions.

As noted back in the 1990s (Mitchell 1994, p. 6), the value of 3D computer graphics techniques is that they mathematically construct perspectival views, applying projection and shading procedures in a way that both continues and redefines traditions of perspectival construction that began in the Renaissance. In our work, there is a series of ontological translations from actual temples as considered geometrically in terms of lines, surfaces and solids, to reproductions of these lines, surfaces and solids in virtual environments. These translations become a useful means for reconstructing reality from multiple sources of partial evidence. The geometry generated from temples is projective in the sense that it projects a geometrical representation of cosmology into three dimensions, but it is not projective in the sense of an image.

However, before continuing with this methodological speculation, the following section will give a brief account of the architectural/historical basis of our project.

Historical connections between South and Southeast Asia

It has long been speculated whether the architecture of ancient South and Southeast Asian temples owes its compositional characteristics to adherence to treatises, the interpretation of priest-architects or the usage of earlier examples as architectural models for later ones. The fragmented discontinuity of textual accounts, lack of graphical representations and heavily eroded early remains, make the process of establishing the lineage of formal continuity difficult. To further develop our understanding of these buildings, traditional methods of architectural analysis need supplementation by the innovative application of digital techniques.

It is known that Indian contact with Southeast Asia is of considerably greater antiquity than the earliest extant temples. There are the remains of extensive settlements in the Mekong Delta dating back to at least 2000 BCE (Higham 2002, p. 86) and to the origin of polities in the region between 300 BCE and 300 CE. The earliest brick or stone architecture in Southeast Asia (other than that of plinths and footings) has been dated to around 650-700 CE. This is considerably later than the earliest evidence of brick or stone architecture in India, and about 500 years after the beginnings of Indian influence in the region (Brown 1996, p. 263). The increasing strength of local polities across Southeast Asia happened alongside the increasing adoption of Indic cultural traits by Southeast Asian peoples. Around this time in Southeast Asia, there is also the first appearance of images of Indian deities, inscriptions in Sanskrit (and even of local languages in Indian-derived scripts – there being no indigenous Southeast Asian writing found), and monumental architecture based on the Indic *cella*.

Possible connections between Indian architecture and that of Java and Cambodia have been both promoted and contested by different scholars. Sometimes stated connections are not really explained, such has how the *rathas* of Mamallapuram were prototypes for Southeast Asian temples (Chihara 1996, p. 79), though connections have been postulated based on structural or technical similarities, such as the relationship between load-bearing structure and architectural expression (Dumarçay and Royère 2001, p. 110). For much of the nineteenth and twentieth centuries, it was assumed by most scholars that early Southeast Asian states were heavily dependent on Indic culture for their development. The question was how this dependency had occurred, and to this end, theories of Indian conquest, colonisation or migration were postulated. The problem with these theories was their lack of evidence, except for occasional parallels in myths of origin. However, more definite clues lie in the physical form of the temples, and the basis of this form in sacred geometry.

Temple geometry

The physical form of the temple is fundamental to its purpose. As Coomaraswamy points out, in the Hindu cosmic structure, 'The human frame, the constructed temple, and the universe being analogical equivalents, the parts of the temple correspond to those of the human body no less than to those of the universe itself' (1997, p. 178). Each is a microcosm of the other. The temple does not just symbolise this sacred geometry. It 'is', immanently, the universe. The temple makes manifest the connection between the everyday world of the senses and the world of divinity, but more than this, makes them one. Scholars have explained the use of geometry in temple plans by tracing their basis in canonical text, sacred diagrams and cosmogony (Chandra 1975; Chihara 1996). Specifically, the constructive and implicit relationships between geometric canon and individual monuments are explained through studies of temple geometry. The morphology of the Indian temple and its progressive geometric complexity can thus be followed from the

earliest extant *cellae* in the fifth century to entire thirteenth century complexes and temple cities across India and Southeast Asia (Meister et al. 1983). Textual and graphic descriptions of mathematical and geometric constructions governing the form of temples are described in the literature.

Embedded in the plan of most temples is a ritual grid diagram of 8 x 8 = 64 squares (the mandala), prescribed for temple building in the *Bṛhatsaṁhitā* (Bhatt 1981) and later texts (Kramrisch 1946). This grid is used to generate the ground plan and control measure in the configuration of stone temples (Meister 1976). Working from an understanding of temple construction sequence as well as the ritual underpinnings of temple composition, Meister found the sixty-four square mandala's dimensions correlate closely to the constructed dimensions at the level of the vedībandha, which corresponds with the level of the sanctuary threshold.

After testing this premise on a number of examples, Meister concluded that the horizontal dimensions of the *vedībandha* provide for a set of proportional relationships that relate to śāstra prescriptions. Furthermore, he shows how the horizontal profile of the *cella* depends on the number of offsets and the proportional relationships between each offset based on the proportional subdivision of the 8 x 8 grid (Meister 1979, p. 206). In addition to the ground plans, the profile geometry of the superstructures exhibits an intricate mathematical and geometric expression attributable to canonical precepts (Kramrisch 1946; Meister 1979). Our work applies digital techniques to Meister's method.

Visualisation methods

Utilising the different methods of data analysis and visualisation available to us, we are able to show different representations of the data that has been collected both from photogrammetric and manual modelling. As noted previously, there is a tendency of viewers to add their own context to the structure. When focusing on the raw structure of the temples, this is undesirable. In addition to this, the point clouds

generated from photogrammetry contain noise that may also add an element of subjectivity to the interpretation.

In order to combat these effects, we have developed a voxelisation strategy that allows visualisation of the abstracted shapes without the viewer needing to comprehend the noise. Using this technique, we can generate a solid representation of a temple once the 'up axis' has been found. In this case, we create a cubic bounding box around the point cloud and recursively divide each cube into eight sub-cubes until we reach a predefined minimum size. We then create a visible cube for each sub-cube if the number of points it contains exceeds some threshold (Datta, Chang, Hollick 2016). This collection of cubes will form a 3D model of the structure that we can include in 3D environments and use to perform further analysis.

One of the effects of this technique is that slightly

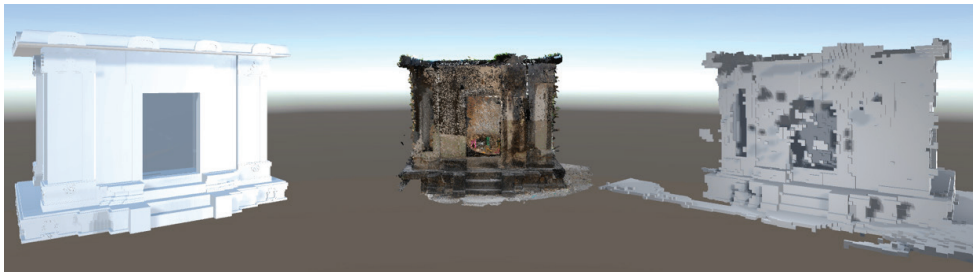

Figure 1. From left to right: manual reconstruction, point cloud, automated voxel reconstruction. (Source: authors).

slanted lines are 'straightened'. Depending on the situation, this may either be a hindrance or a help, as knowledge of the original data is still required. One of the analyses we can perform using voxelisation is to split the model along any of the voxel lines to create a series of 'slices', allowing us to visualise the geometry of the structure and look for symmetry or other familiar structures.

Using the representations shown in Figure 1 (above) we can place the 3D data inside virtual environments, within which the viewer can immerse themselves to

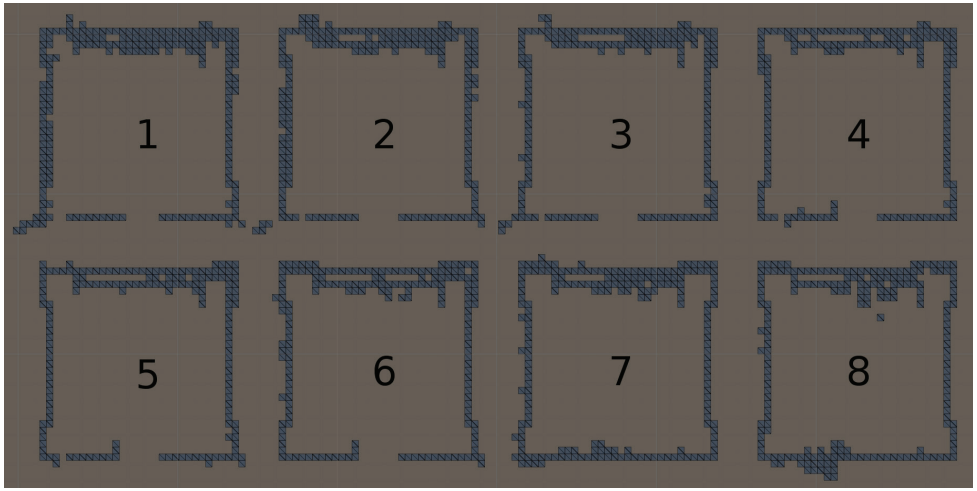

Figure 2. Temple split into voxel slices. Here we have a selection of slices from the centre part of the above temple, numbered 1-8 from top to bottom. This clearly shows the door and structure of the temple, abstracting away some of the noisiness of the point cloud and allowing us to focus on the overarching geometric elements. (Source: authors).

explore the temple structure. This immersion may take the form of large scale displays such as those at the Curtin HIVE (Woods et al. 2017) and at other visualisation facilities, or smaller displays such as those for desktop monitors or various head mounted displays. These display options may allow the viewer to see the scale and layout of the temples in a way that would not be possible on simple paper. Furthermore, the different representations of the temple, revealing otherwise non-obvious features, allow the viewer to focus on different aspects of the structure.

Projection, the visual and the architectural: affordances of digital methods

As the brief summary of visual methods in the previous section shows, reconstruction of temple forms involves using the digital information generated by acquisition methods to create three-dimensional surface and solid models that can be enhanced by textures and materials when necessary. The imagining here still requires some human intervention, whether in the algorithmic manner of machine recognition, or

in the judgement of the individual who manipulates the photogrammetric software until it correlates with their knowledge/recognition of the subject. The image is thus mobilised. What can be recognised here is not only the apparent veracity of the photographic image, but also the indexical nature of a series of photos. This makes them a medium through which it can be possible to go beyond conventions of projection and representation to 'see' the actual object directly. However, this sense of 'looking through' requires a certain predisposition and understanding of context and frame that involves mentally stitching together the 'index' of photographs to more fully see the represented object.

The virtual models created via photogrammetry share with photographs (and sometimes with traditional physical models) a particular state of being. When we look at a photograph we are viewing an image separated from its referent. In a 3D print/virtual model, we are looking at a result of a series of such separations, now also of form from form. However, as we are viewing temples as applied research in themselves – as applications of theory (*sastras*, geometry etc.) to materials, form, composition and aesthetics, then our series of separations are in some way an attempt to simulate a return to these sources (or at least provide clues towards them). In this sense, digital practice has become a useful means for re-construction of reality from multiple sources of partial evidence. Buildings may be represented in apparent three dimensions via drawings but are more directly experienced via models. A 3D model (whether printed or visualised in virtual space) becomes more than a photograph: an object in itself, which, like the original building, can propagate images of itself, these images being once removed from the original building, but still recognisable as such, having, as Robin Evans might put it 'a kind of permanent identity' derived from its multiple images (Evans, 1990). Representation of an overall composition in a model is also provided, in contrast to a drawing, as the viewer is not confined to a fixed position or series of positions in relation to the subject. The ability of the viewer to move around the

model affords a multivalency of experience in relation to it. Unlike the analogue photographic image, the traditional model, whether it is made of simulated 'real' materials (stone, plaster, timber) or deliberately abstracted ones (card, paper, Perspex), is limited in its potential to reveal detail.

Here it needs to be stressed that the modelling process is not a realistic representation of the temple but an ideal 'adaptation' of the rules underlying its architectonic composition. This departure from 'accuracy' and 'authenticity' is a necessary step of abstraction that permits all records to be mapped into an ideal laboratory of digital forms. The rule based model generation can be used to derive, compare and overlay the ground plan and superstructure geometry of related monuments. This rule-based generation of profiles allows us to conjecture on the range of possible measures, based on texts as well as field measurements. The models as 3D prints look deceptively finite and object-like, but their objecthood should be better read as a snapshot of the processes of which they are a part. The models themselves are a kind of language – readily translatable, as people are used to looking at miniature models of buildings (both as designs and as three-dimensional representations of actual buildings). At the moment this language looks deceptively simple, as many of our subject buildings are mostly complete (though many have been restored, some more speculatively than others).

Seeing these models as representative of the 'real' is a little misleading in the same way that viewing photographs used to be (particularly in the pre-digital age). 'In conferring on photography a guarantee of realism, society is merely confirming itself in the tautological certainty that an image of the real which is true to its representation of objectivity is really objective.' (Bourdieu 1990, p.70, quoted in Mitchell 1994, p. 59). In a way that could equally apply to our models: where we have been using the tools, operations, and media of photography to serve our pictorial ends, these instruments and techniques have simultaneously been constructing us as perceiving subjects. The primacy of the visual, of trying to

comprehend a building through consideration of its visual characteristics, needs to be suspended in favour of what Robin Evans might refer to as other means of projection (Evans 1990). In this regard, the digital approach may be compared in a propositional sense to Evans' theories on geometry in architectural making. Evans described a series of translations to track the development of architectural form through projective geometry, the building as an object being cast through a series of drawings to the finished product, a projection informed by the subjective experience of buildings. And so, he developed a proposition about how architecture develops through the translation of drawing into building, of representation into actuality. Our particular challenge is the opposite, the translation of a building through the geometric and proportional clues present in its form, back to its description. Evans also discusses, following art historian Rudolf Wittkower's method of relating architectural characteristics to music theory (Wittkower 1949), the way in which European Renaissance architecture was an architecture of symbolic rather than pure form. Here, the issue of meaning's relation to form is highlighted, in particular the way that forms do not intrinsically have meaning, but are instead *charged* with meaning by their contextualisation within a cultural/philosophical system (Evans 1990, p. 4). Thus, what is important about the geometry of a building is what is held to be important by the cultural/philosophical system that created it, what is *projected* onto it (Evans 1990, p. xxxi). Thus, it is the nature of this projection, and the ability to abstract it by some means, that underlies our processes and methods.

This is, in a sense, a form of 'reverse engineering' or 'reverse architecting' in that it 'concerns all activities for making existing architectures explicit, and the main goal of reverse engineering is to increase comprehensibility of the system' (Krikhaar 1997)– although in the case of our work, we are of course using the term 'architecture' in its traditional and literal sense. It is a process of examination that can be considered, adapting Borches and Bonnema's analysis, to have three phases: information extraction,

parametric speculation/application/abstraction and (re)presentation (Borches and Bonnema 2010, p. 356). These three phases are continually repeated. This iterative process is important as the information extracted can be abstracted and (re)presented in multiple ways, with each form of representation offering different insights into the nature of the architectural subject under study. So the models are not so much end products, but vehicles for thoughts. They are both the media and the outcomes of a method, involving physical measurement and photogrammetry. They provide a series of projection procedures that both simulate the form of the subject building, and frame its salient measurements as a series of parameters based on reference to numerical geometries and compositional arrangements as found in ancient texts. As noted by Dumarçay in his construction studies of Southeast Asian temples, parallels between architectural models and architecture as a model provide a theoretical basis for the drift from original geometric sources, where this can be plausibly established, towards variations in form and proportion (Dumarçay 2003). Digital tools for data processing (such as photogrammetry) permit the systematic capture and reconstruction of existing temple remains, and so develop Dumarçay's process of piecing together the genesis and evolution over time of the geometric experimentation within specific schools of temple building. Furthermore, 'ideal' models of temples can be constructed by combining textual descriptions from textual canon (śāstras) with graphic diagrams (rule-based generation, parametric models), supporting the comparative analysis of early temples from related temple building traditions within South and Southeast Asia. The digital models of this architectural diaspora are therefore neither real nor authentic in a traditional sense.

The role of the virtual: visual/conceptual

In summary, virtual representations of temples do not masquerade as replicas of the original object. Instead, they are re-representations that allow hidden elements and aspects of the temple or site

to be examined. Further, virtual models permit and provide a mode of presence for collections of artefacts and abstractions. Just as close-ups or slow motion in film permits seeing reality in a deeper way, digital models provide such a mode in the case of understanding architecture. Skeletal models of geometry, dissections and sectional renders, allow the viewer to be immersed in the otherwise hidden and unavailable aspects of architecture, which are not experienced through direct perception of the original. However, the processes that we are developing are intended to provide the basis for informed speculation about future subject buildings that are less complete, this basis being grounded in a shared geometric/architectonic compositional schema where measurement is possible (which in some subject buildings, may only be the base of the original structure).

From this codification comes the application of principles that can be applied both to other observable parts (so realigning them according to the same informed assumptions) and by extension, to parts that cannot be observed because they no longer exist, or are in such an eroded state that their original form is no longer recognisable. Such generative methods are useful for describing a class of artefacts with similar characteristics. By observing a family of similar objects, rules and constraint relationships between common elements can be identified. The knowledge embedded in the photographic architectural record can be 'read' through computational means, such as the science of Photogrammetry, to inform, posit or refute positions on their formal derivation and architectural lineage. Using the information we may gain from discovering the evolutionary lineage, preceeding and proceeding objects and family membership of artefacts when geometry is missing or eroded we may be able to fill in this missing information to create a more complete representation.

Our purpose in using digital methods is, therefore, not to challenge or displace the authenticity of the physical object or the faithful accuracy of the

photographic record. Instead, the aim is to develop 'unobtrusive mediations' that permit connections and interpretations that permit scholars and the public to assess and experience the significance of historical architecture. If the evolutionary lineage of a class of artefacts can be captured by identifying similarities and differences in their geometry, this information can be used to aid in the reconstruction of eroded or destroyed artefacts.

Three-dimensional digital and physical models' conjectural reconstructions enable the comparison of temple sites spread over time, geography and culture, which, with the analysis of data recovered from surviving monuments, explain the complex and problematic linkages between canonical prescriptions of ideal form. The data collected, and then analysed via photogrammetric methods, establishes an empirical ground to study the linkages (or lack thereof) in the development of temple architecture across South and Southeast Asia. Using spatial information modelling, the fragmentary evidence from diverse sources can be pieced together first to conjecture and then to establish a comprehensive picture of a whole corpus of temples across space and time.

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