Procedural Modelling of Traditional Balinese Settlements

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Abstract: Traditional Balinese Architecture is known for its extensive rules at both, the microscopic and the macroscopic level, ranging from the design of entire villages to single building elements. These rules are preserved in century old palm leaves, so-called lontars, and were put into practice by the Undagi (traditional "architect") according to the needs of the owner of the building who provides the bodily proportions to parameterize the building rules. These traditional rules lend themselves to the transformation for procedural modelling with design grammars. In architecture design grammars have been used in several examples (e.g. variations of possible Palladian villas, Chinese traditional architecture, historic reconstruction of Rome). Procedural urban modelling appeared more recently with software tools like the CityEngine which have expanded the idea of design grammars and allow for rapid generation of architectural models and entire urban structures of a specific contemporary or historical style. Typically, composition rules are derived by analysing the outer appearance of architectural representations, and lead to formalistic design patterns. The presented approach focuses on the underlying principles of Balinese architecture as well, and tries to formalize design rules reflecting the following concepts: hierarchy of space, cosmological orientation, balanced cosmology, human scale and proportion, open air "court" concept, clarity of structure, truth of materials. As these concepts are adaptable to location as well as the owner, a parametric, rule-based digital model seems well suited to aid this complex design process. A proof of concept was implemented in the CityEngine. This contribution is intended to be a prototypical 3D reconstruction of traditional Balinese settlements, thus helping to understand and preserve the architectural heritage of Bali.

Keywords: Procedural Modelling, Design Grammars, Traditional Balinese Architecture, Architectural Heritage.

Motivation for Procedural Modelling

In many cases archaeological urban reconstruction is based on the surveyed structures of an excavation site, typically containing only fragmented parts of building remains which does not even include a complete floor plan. Additional parts that are generated from the archaeological remains to form a complete building have to be derived using plausible interpretations based on extensive background knowledge about the architecture of underlying culture. Of great value to accomplish this task is the existence of reference objects, either in terms of comparable buildings that are better preserved or by means of widely acknowledged reconstructions. For this process a fundamental knowledge about the architectural style and building principles of the period of interest is necessary.

We focus on automated urban reconstruction based on prototypical lot sizes and urban design principles (like cardinal axes, central squares, typical placement of important sacred and secular buildings). This will be exemplified for traditional Balinese architecture, since its building principles have been preserved very well over several centuries. Moreover, these building principles are rule-based and rather strict, so they lend themselves perfectly for automated model generation. Procedural modelling is a technique for generative design with a certain set of rules that define how to generate a specific design. This technique can be applied to every scale, ranging from entire settlements to the creation of certain building typologies and even to specific architectural details. In our case the CityEngine seemed to be the most suitable tool for automated model generation to actually implement the Balinese building principles.

In this article we briefly summarize the principles of traditional Balinese architecture. Then we cover procedural modelling in architecture. Finally, we construct rules from the traditional Balinese building principles as basis for our procedural model of Balinese settlements. In order to visualize the approach the rules are implemented in the CityEngine and the results thereof are presented. In the final section a summary of the results is discussed.

Traditional Balinese Architecture

Traditional Balinese architecture is related to Bali-Hindu philosophy that is exhibited in traditional man built environments in Bali. The underlying ancient Balinese knowledge is preserved in lontars (palm leaf manuscripts). In figure 1 the left picture shows a typical lontar next to its engraving tool and traditional ink, the right picture shows the shelf of wooden boxes where the lontars are kept.


Fig. 1 – Lontar (palm leaf manuscript) with engraving tool and "ink", lontar library in Singaraja.

Contents on the lontars cover various aspects of human life including architecture, religion, healing, arts, history, and so on. Palm leaves are quite endurable and can be preserved for several hundred years. There have been efforts to translate the contents relating to architecture into Tulisan Bali (today's Balinese) and Indonesian (BIDJA 2000; DWIJENDRA 2010). Some of the basic principles of traditional Balinese Architecture can also be found in English publications (BUDIHARDJO 1995; EISEMAN 1996). The lontars themselves are kept in the Gedung Kirtya lontar library annex museum in Singaraja, a town in Northern Bali. Traditional Balinese architecture is based upon seven building principles (BUDIHARDJO 1995) as shown in figure 2 and described below. (1) Tri Angga (hierarchy of space) refers to the threefold quality of space, time, nature, man, and objects as laid out in Hindu-Balinese philosophy. (2) Nawa Sanga Mandala (cosmological orientation) is an orientation system consisting of the eight cardinal directions in combination with the centre created by the mountain sea-axis and the sun movement. (3) "Balanced cosmology" aims at expressing architecture as a harmonic unification of god, nature and man. (4) The principle of “human scale and proportion” bases dimensions of buildings on the body measurements of the owner. (5) According to the “open air, court concept” buildings usually are open towards nature or include open space and several pavilions within a surrounding wall. (6) “Clarity of structure” clearly display the building’s supporting structure. (7) In the same sense “truth of materials” exhibits the materials used in their natural appearance.

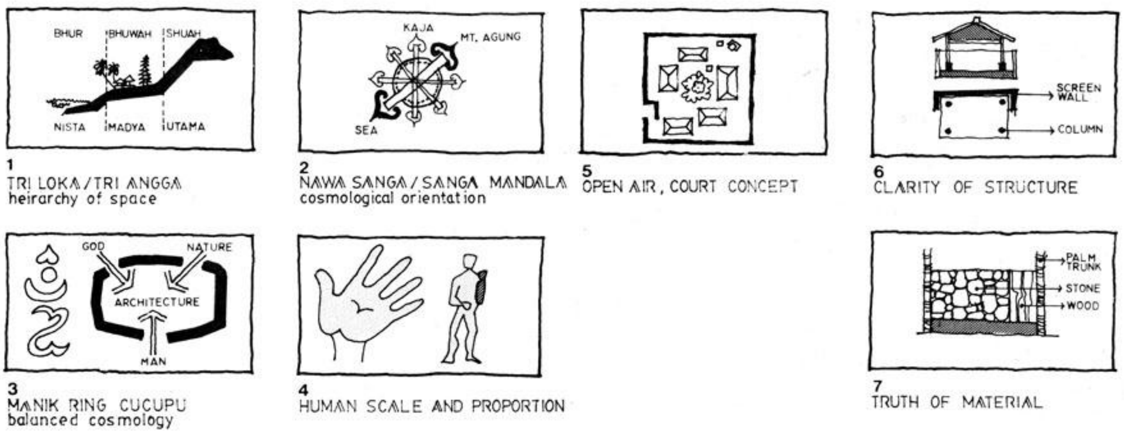

Fig. 2 – Balinese Building Principles, from (BUDIHARDJO 1995).

Typical Design of a Balinese Settlement

A typical village layout according to the traditional building principles is depicted in figure 3. There are three main temples arranged along the mountain-sea axis. The temple of origin (pura puseh) is placed in the part of the settlement that is closest to the predominant mountain in the area or Mt. Agung. The village temple (pura desa) is located in the village centre. The temple of the dead (pura dalem) is located towards the sea. The centre of the settlement is placed at the crossing of two main roads, where a banyan tree is planted as a symbol of life. The central area is used for public buildings, such as the village temple, the palace (if there is any), the market, the bell tower, and the assembly hall. Before bets on cockfights were forbidden, the cockfighting hall was also found in the village centre. Other areas are mainly used for housing.

Typical Layout of a House Compound

A traditional house consists of an open space and several pavilions (bale) that are arranged according to the “sanga mandala”. A typical example is shown in figure 4.

The family temple (structure A in fig. 4) will be built first. The other pavilions are placed at distances that are multiples of the main measuring unit (usually the owner’s foot length “tampak”). The multiples bear the qualities of the associated deities as indicated in figure 4 under the symbolized feet.

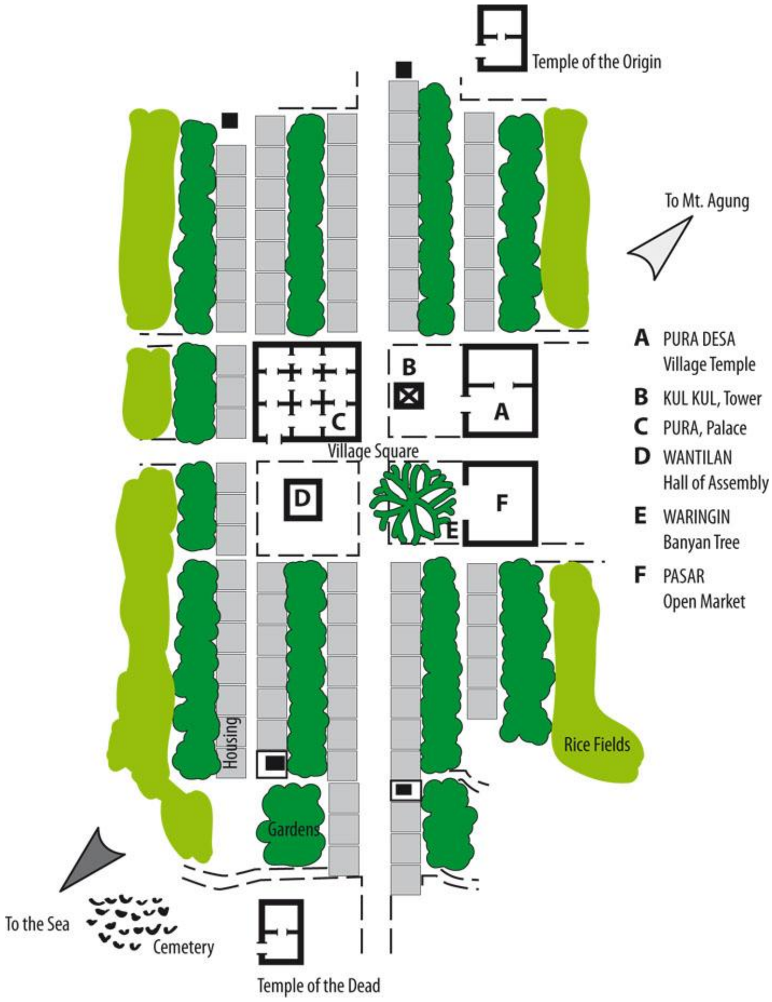

Fig. 3 – Typical settlement design, based on (BUDIHARDJO 1995).

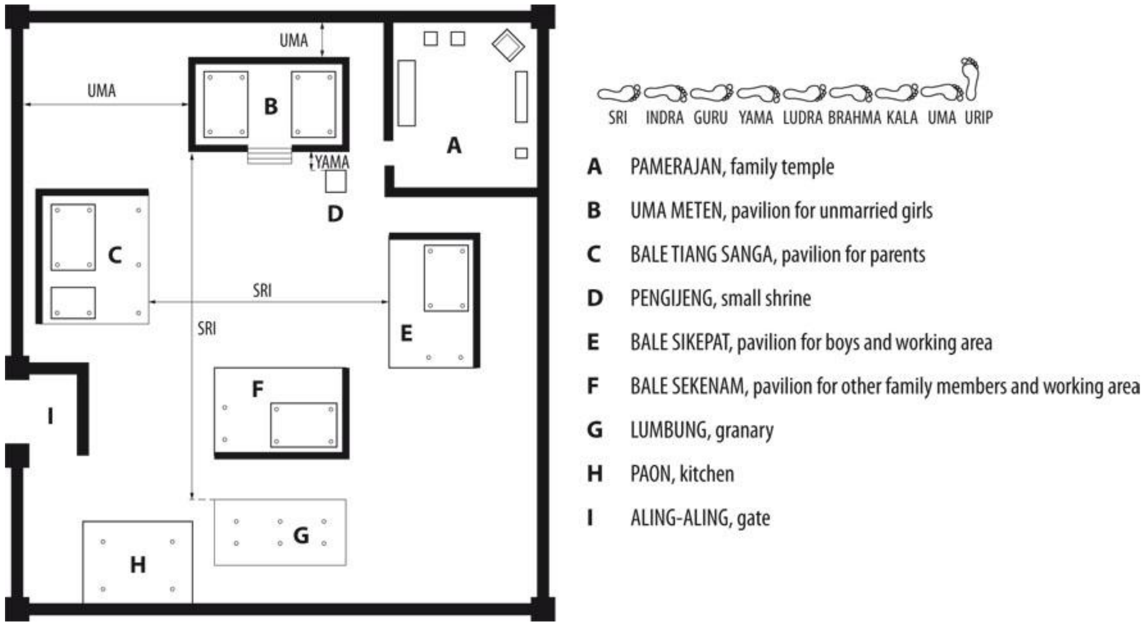

Fig. 4 – Typical house compound with distance qualities, based on (DWIJENDRA 2010).

Procedural Modelling in Architecture

"The key property of procedural generation is that it describes the entity, be it geometry, texture or effect, in terms of a sequence of generation instructions rather than as a static block of data. The instructions can then be called on when required to create instances of the asset and the description can be parameterized to allow the generation of instances with varying characteristics." (KELLY and McCABE 2006)

There are several approaches to procedural modelling in architecture. We will give a brief overview of the more common concepts.

Parametric building elements: typically common architectural object like doors, windows etc. that are used in many buildings are parameterized to cover the wide range of possible shapes. For example, typical parameters for a door are height, width, opening direction, number of wings. One example of such a system is Archicad (http://www.graphisoft.de/produkte/archicad/) together with GDL (Geometric Description Language).

CAD scripting languages: Hereby the commands of a CAD system that are usually given by a user are read from a script that controls the modelling software. Examples of this approach are VectorWorks (http://www.vectorworks.net/) or Rhino (http://www.rhino3d.com/) which both come with their own scripting language to serve that purpose (VectorScript, RhinoScript).

Visual Scripting Environments: Often this is an extension to an existing CAD package and provides a visual approach to scripting. Typically, graphical elements that represent certain functions or commands are connected by lines to indicate data flow. Examples of these systems are Rhino together with Grasshopper (http://www.grasshopper3d.com/) or Quest3D (http://quest3d.com/).

Programming environments: This approach is based on a general software development framework with specialized libraries to aid parametric design. Examples include Processing (http://processing.org/) and libraries such as anar+ (http://anar.ch).

Design Grammars: Shape or design grammars provide a formalism to create geometric shapes by a set of production rules. A production rule defines how a shape (or part thereof) can be transformed. A software package that implements this concept is the CityEngine (http://www.esri.com/software/cityengine/).

Procedural Modelling with the CityEngine

The software tool "CityEngine" is based on procedural modelling (PARISH and MÜLLER 2001) where geometry is not created all by hand, but largely through a set of rules. In the CityEngine a design grammar called CGA is employed to generate extensive 3D environments. Tools like the CityEngine allow for an efficient generation of architectural models and entire urban structures of a specific contemporary or historical style.

Typically, composition rules are derived by analysing the appearance of architectural representations from plans, drawings and photographs, which lead to formalistic design patterns. The final rule set contains a whole range of attributes which can be adjusted to appropriately set the appearance of the generated models. This "allows for the testing of several hypotheses by adjusting some of the parameters. This results in a powerful platform for archaeological discussion and exploration" (MÜLLER et al. 2006). Some examples of the use of the CityEngine can be found in (HAEGLER et al. 2009; WATSON et al. 2008), for the reconstruction of ancient Rome (DYLLA et al. 2009), for the procedural modelling of Mayan architecture (MÜLLER et al. 2006) and for variations of the Louvre with the use of the CityEngine see (CALOGERO and ARNOLD 2011).

Reconstructing Balinese Settlements with Procedural Modelling

To appropriately formalize traditional Balinese architecture, it is necessary to take into account both, appearance and ancient building principles. These principles are adaptable to location as well as the owner (cf. section Traditional Balinese Architecture). So a parametric, rule-based approach employing a design grammar seemed well suited to aid this complex design process. We used the parametric shape grammar technique which is supported by the CityEngine to implement and visualize the digital formalisation of traditional Balinese building principles. The creation of a typical traditional settlement served as a demonstration case for this purpose.

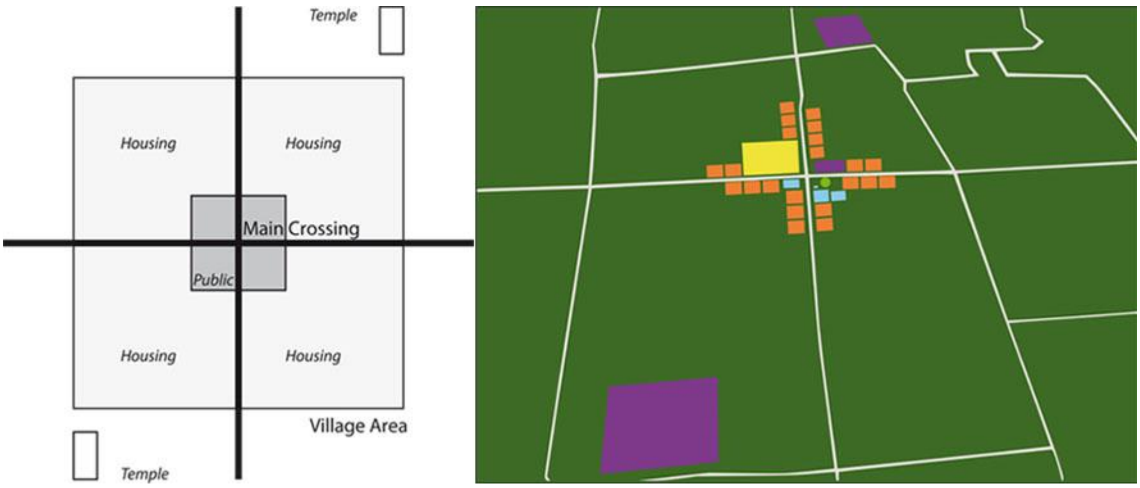

Fig. 5 – Typical village layout, schematic (left) and in the CityEngine (right).

Village Layout

In order to create a traditional Balinese village with a design grammar in the CityEngine, a street network from a Balinese village was imported from Open Street Maps (http://www.openstreetmap.org/). To this street network the typical layout of a Balinese village with coloured areas for each building type was added. The result of this process is shown in the right part of figure 5. The three temples are indicated in purple patches, house compound areas in orange. The public buildings are depicted in yellow for the palace, light green for the banyan tree, and light blue for the assembly hall, the market, the cockfighting hall and the bell tower. These diverse building areas serve as a start rule for the design grammar that was implemented. The design grammar to construct a typical village consists of a range of rules: several rules for building elements and one for each building type. To exemplify those rules, the construction of a house compound is demonstrated in detail.

House Compound

The rule for a house compound (rumah) is shown in figure 6. It starts with creating a basic layout with corner posts, the surrounding wall, placing the ground, and splitting the area into nine parts according to the building principles (1) hierarchy of space and (2) cosmological orientation. The house temple is placed in the area closest to the mountain, surrounded by its own wall with an entrance to the temple area. Then a suitable pavilion gets placed into each part of the compound and the entrance is placed at the road side closest to the sea. The creation of the respective pavilions is accomplished with a separate rule set (cf. section Pavilions below).

Applying these rules in the CityEngine to create a 3D model, results in a house compound as depicted in figure 7.

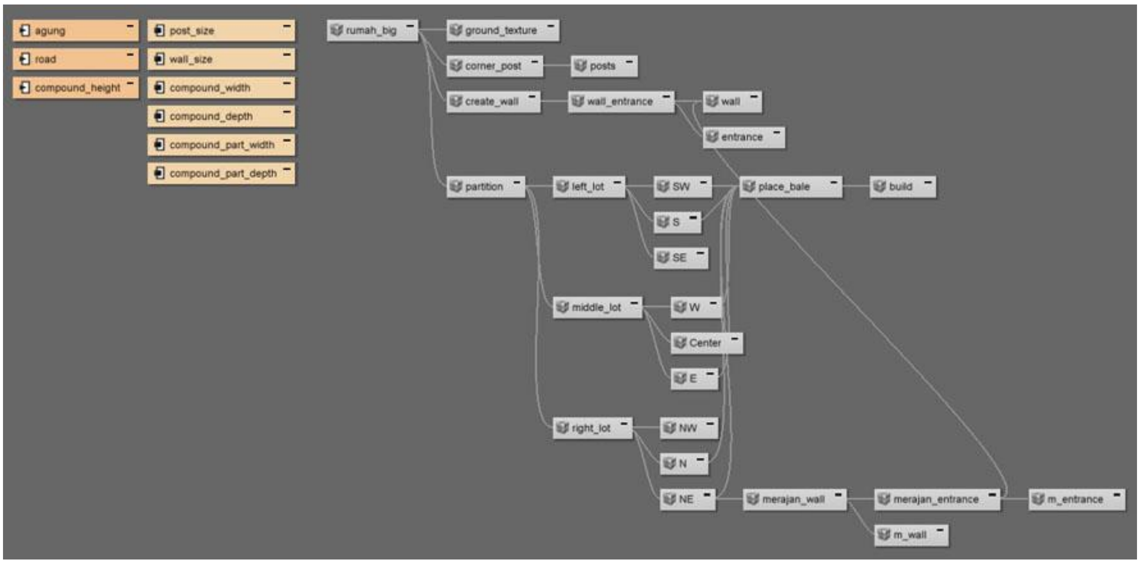

Fig. 6 – Rules for creating a typical house compound.

Fig. 7 – Traditional house created in the CityEngine according to these rules.

Pavilions (bale)

Pavilions are the main generalized form of structure within traditional Balinese architecture as most buildings consist of a collection of different types of pavilions. To demonstrate the power of rule-based model creation, different types of pavilions are created with one single rule set. Figure 8 displays a graphical overview of the rule set for the pavilion variation.

Variations for the construction of the pavilions are set to be randomly chosen at a certain percentage, e.g. the two available types of foundations are randomly chosen at 50% each, while the wooden platform will appear in 80% of the generated models. The central rule (bale) will construct the single pavilions and thereby split the structure into Base, Column and Roof.

Application of these rules in the CityEngine results in the pavilions which are depicted in figure 9 where the variation can readily be seen: The two bases in front are different from those in the back; the number of side walls varies between 0 and 2; some pavilions have a platform; there two different column bases are used.

Fig. 8 – Rule for pavilions.

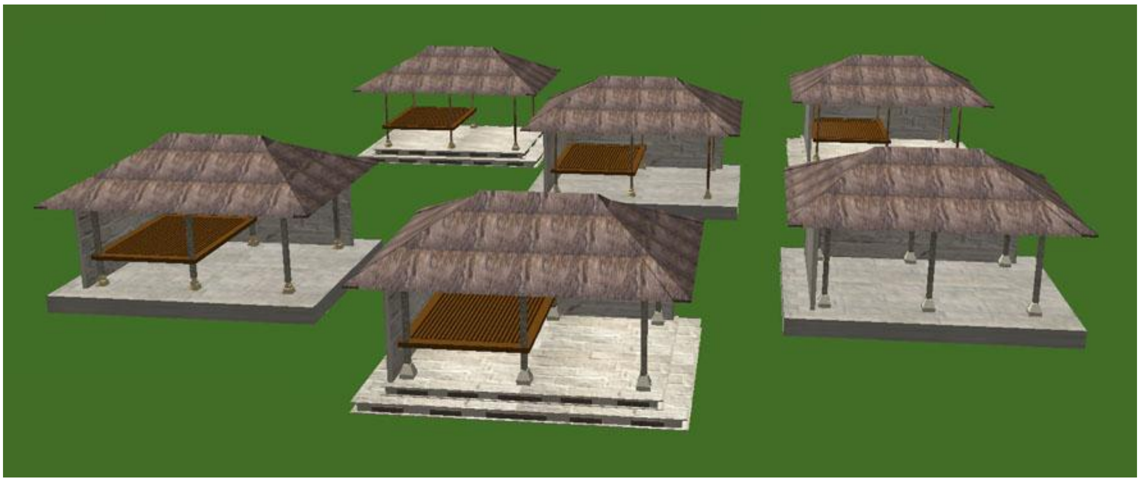

Fig. 9 – Different types of pavilions created with one parametric rule.

Village

To construct an entire village, rules for each type of building have to be developed. Putting all these rules together and applying them in the CityEngine results in the construction of the models for the village as shown in figure 10. It provides a view at the village centre with the village temple behind the banyan tree, the palace at the upper left, the assembly hall left in front of it, the bell tower next to the banyan tree, the open ground for the market and the cockfighting hall behind it. In front there are some house compounds.

Fig. 10 – Entire village, all rules combined.

Discussion

Since the principles of traditional Balinese architecture are kept as written instructions on ancient palm leaves (lontars) it turned out that this rule-based design is very well suited to be implemented as a set of shape grammar rules as it was done with the aid of the CityEngine. Shape grammars can be defined for each structure of typical Balinese settlements (entire villages, different building types and even diverse building elements). Parameterisation of the rules also allows for the integration of human proportions (in the form of actual dimensions of the body parts of the head of a building).

Concerning the preservation of Balinese architectural heritage, the exemplified translation of the ancient lontar scripts into digital shape grammar rules might be of great value. The main drawback of this approach is the intensive initial training required to learn rule based modelling.

Future work will be addressed to additional and more detailed translations of the ancient lontar scripts. Especially the complex distance rules as applied in the layout of a house compound require a better explanation.

Additionally, a more extensive parameterisation of building rules should be formalised and implemented to account for the great variety in building styles. Beside the detailed implementation of housing structures a similar approach should be undertaken for temples and other public buildings.

The demonstrated formalization and implementation of ancient Balinese building rules so far is only a first step. Additional studies of original literature as well as on locations in Bali itself are required to achieve a deeper understanding of this topic and to better preserve these valuable rules in the age of digital information technology.

Finally, it might also be of interest to adapt the traditional set of rules to modern Balinese architecture in order to meet the contemporary needs of living.

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