Collective Pavilions

A Generative Architectural Modelling for Traditional Chinese Pagoda

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Abstract: This paper investigates generative architectural modelling for traditional Chinese architecture and aims to explore and extend the potential of adaptive computing for architectural design methods. The design manners analysis of traditional pagodas architectures is made in a holistic view and under historical perspective. We propose a descriptive model and generative system for the design of traditional Chinese pagodas, by which each pagoda is defined as a collection of style-matched and form-coordinated pavilions and described by both topological graphs and variant geometrical units.

Our approach models both of the building geometry and space organization/spatial patterns of pagodas separately. The generative mechanism consists of a framework of grammar-based design and parametric, recursive shape computation. Accordingly, the generative algorithm is also made of two levels, the topology of spatial patterns and the shape geometrical parameters that characterize pavilion variations. The algorithm for computing the former is based on GP (Genetic Programming) and the latter GA (Genetic Algorithms). To explore the collective behaviour of a group of pavilions, multi-agent modelling approach is incorporated in composition patterns search. A prototype system, '*glPagoda*', using the OpenGL graphics library for rendering and visualization, has been developed and implemented on PC windows platform.

1 INTRODUCTION

Nature is complex in its details and yet elegant overall. Human-made systems, including architectural structures, need to fit in harmoniously with its environment as in nature. To study how parts of a system give rise to the collective behaviours of the system, and how the system interacts with its environment, a relatively new field of science, called Complex Adaptive Systems (CAS), has emerged. The concepts of CAS originate from efforts to understand physical, biological and social systems that are ‘organized without organizer, coordinated without coordinator’ (Resnick 1994). Accordingly, the development of computational approaches based on CAS is inspired by ‘bio-logic’, and categorized into non-classic, connectionist and natural computation (Ballard 1997).

This paper investigates generative architectural modelling for traditional Chinese architecture and aims to explore and extend the potential of adaptive computing for architectural design methods. This paper is organized as follows. Section 2 provides the background review of the CAS theory and current application of CAS in formal and spatial design. A brief review of both the philosophy of the traditional Chinese architectural space design and pagoda is also given. Section 3 presents the proposed modelling and algorithm for implementation, followed by Section 4 with discussion and concluding remarks.

2 BACKGROUND REVIEW

The theory of CAS is based on relationships, emergence, patterns and iterations. Examples of its relevant computational approaches, for shape computation, architecture and urban morphology applications, include (i) formalization of natural form through fractal geometry, (ii) modelling of animal behaviour patterns, e.g., the *Boids* algorithm, (iii) biological growth processes, the L-systems, and (iv) evolution & adaptation phenomena, evolutionary computation: GA (Genetic Algorithms), GP (Genetic Programming), etc. (Ballard 1997).

From left to right: (a) The Kleiburg block of flats in Amsterdam's Bijlmer district project (b) Korean Presbyterian church of N.Y. (c) The 'Groningen Twister' project

Figure 1 A Sequence of Similar Modules with Iteration and Interaction

A good representative example of adaptive computing is found in the works of Greg Lynn. In their Amsterdam's Bijlmer District project, as shown in Figure 1a, the collective modules can be manipulated as a complex adaptive system with the stripes interacting with each other. By changing parameters of any one unit, entire structure changes as a sequence. Lynn named his idea and practice favouring the complexity of algorithmically generated form, as 'Intricacy', 'design based on time, topology, and parameters' (Lynn 2003). Figure 1b shows an iteratively/recursively form-generating idea for the Korean Church design. Other interesting works include the use of fractal line in different resolution in Eyebeam Museum of Art and Technology competition, and the use of genetic algorithms exploring solution space in the Embryological House project. The 'Groningen Twister' project in ETHZ provides another representative work along this line of generative design methods (Scheurer 2003). Multi-agent modelling simulation is used in the design process of column configuration, whereas each column acts as an autonomous agent of the complex system, shown in Figure 1c. A population of living columns survived in the environment through competition.

Examples in design computation research include recursive algorithms for shape computation, e.g., shape grammar (Knight and Stiny 2001), and fractals in architecture (Bovill 1996, Liao 1997) and urban structure (Batty and Longley 1997); evolutionary design for architecture (Ding and Gero 2001); artificial life for architectural design (O'Reilly et al. 2000); and 2D/3D Cellular Automata for building plan and mass/volume composition.

Despite of the profound influence of these works both in current avant-garde architectural practice and design computation research by CAS, we believe that the paradigm shift within the applications of architectural works is still not complete with respect to the following aspects: (a) unclear association to the architectural form & space concepts, and architectural space theories, (b) lack of an in-depth, systematic analysis of design manners that provides a holistic and connectionist view, and (c) insufficient development of aesthetic theory and historical perspective of the new paradigm. To address these issues, our research would associate architectural space concept to the new approach, from the spatial configuration and form making perspective to analyze design works based on historical heritage. First, the effort is to upgrade the concepts of architectural form and space based on 'bio-logic', self-organization and non-linear order. Our work attempts to develop a framework of generative architectural modelling that is applicable to design analysis & criticism, and formal & spatial design. Second, the basic shape components used as the basic entities for design modelling are integrated with architectural space concept, and spatial patterns in architectural settings. Lastly, we will study the generative architectural modelling for traditional Chinese architecture, and use ancient architectural structures, in particular, pagoda, as our study case. This would allow us to develop new aesthetic knowledge and historical research methods from investigating classic architectural works, and thus enriching our design manners & architectural vocabulary for current design practices.

Chinese tradition has 'a predominant view of a spontaneous, self-organizing world' (Prigogine and Stengers 1984, 22). Based on the philosophy of Yin-Yang and Feng-Shui theories, traditional Chinese architecture offers a certain kind of holistic, chaotic space concept, and non-linear order (Liao 1997). Examples of self-similarity phenomena are widely available in traditional Chinese artefacts, from the forms of lattices, to the spatial patterns of courtyard houses, pagodas, gardens, and city plans. These design patterns can be well interpreted by self-organization and fractal geometry concept, and generated by adaptive & recursive/iterated design methods, for instance, by 'parametric shape grammars' (Stiny 1977, Liao 1997).

From left to right: (a) Villa Capra in Vicenza by Andrea Palladio (b) A. Massively concentrating (Western) Vs. B. Quantitatively accumulating (Chinese) (c) Courtyard house model

Figure 2 Two Compositional Approaches for Building Mass/Volume

In terms of space organization, Chinese architecture tends not to show any consideration for integrating multiple elements into one mass. Buildings, although detached, are not isolated, but linked with covered paths or corridors. As shown in Figure 2, it seems like a certain kind of ‘Distributed Behaviour Models’, offering an organizational principle of plans that aims to pursue the integration of the whole with variations in groups or clusters (Li 1984, Liang 1984). By not emphasizing on any single form element, but concerning with the entire organizational relationship, every component in the architectural space design is important in creating and contributing new dynamic structures and functions at the different levels of the system, thus, playing a key role in maintaining the overall balance of the system. Like the strict organization of a set of chess pieces, each piece seems to be independent but yet all the pieces are tied up at a higher level, the chess board level, each configuration conveys a wealth of design ideas and meanings. Thus, conceptually in this strategy, any given design is far from being simply a ‘primitive’ plan or a naïve ‘quantitative accumulating’ pattern (Li 1984). Also, by ‘decomposing’ a whole into related pieces, it provides us an opportunity to introduce ‘multi-agent modelling’ approach into the generative design research for traditional Chinese architecture.

Chinese pagoda is a Buddhist temple erected as a memorial or to hold relics. Spreading with Buddhism from India to China, Korea, and Japan, pagodas gradually evolved from the original dome-shaped Indian stupa (Figure 3a), into high-rise tower forms (Figure 3b) that resemble the ancient Chinese indigenous multi-storeyed tower (Figure 3c; Liang 1984), with characteristic polygonal tower with roofs projecting from each of its many stories.

(a) Indian stupa **(b) Examples of Chinese pagoda** **(c) Multi-storeyed tower**

Figure 3 Evolutions of Pagoda Forms

Pagoda is made up of distinct components: steeple top, body, and base, each consisting of a variety of subcomponents. Normally, the body portion would contain many pavilion units, each formed with its own top, body, and base, Figure 4(a). Subset of pavilions may be combined as shown in Figure 4(b). Top may contain roof, eave, brackets, and steeple of tip, canopy/disc/ball, *sumeru* pedestal, top ridge, or hip type; body contains walls and/or columns, and optional veranda with its railing and banisters; and base contains platform and podium.

3 GENERATIVE MODEL AND EVOLUTION

We propose a two-level descriptive and generative model for traditional Chinese pagoda design, referring to combining both the graph-based architectural space descriptive method of Space Syntax (Hillier and Hanson 1984) and the recursive shape computational method of Shape Grammar into a unified frame, spatial pattern grammar-based design. With a framework of grammar-based design and parametric, recursive shape computation, our approach would be able to model the space organization/spatial patterns and the building geometry of pagodas separately, by topological graphs and variant geometrical units. We are also considering the generative architectural modelling approach to be extended to applications on diverse traditional Chinese artefacts and vernacular, e.g., courtyard housing design (Figure 2c), as well as current general architectural and urban space design.

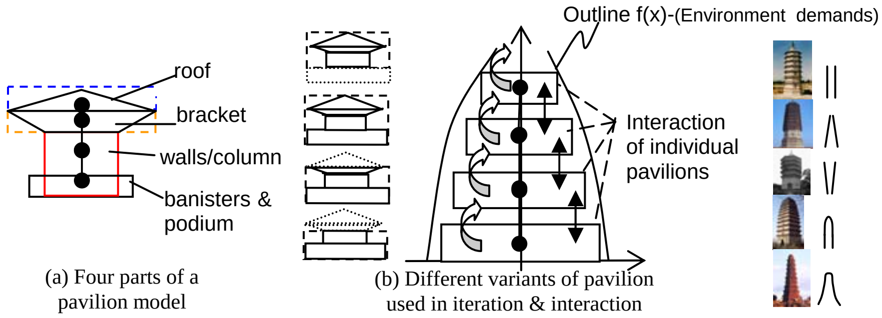

Figure 4 Diagrams for the Structural and Interaction Models

3.1 Descriptive Model

In the study of any complex adaptive system, one needs to identify the basic elements, the relation and interaction of the basic components, the general process of operations and formation, the properties and attributes that express the diversity and variability, the quantification of these attributes, and the behaviours and major activities. In describing traditional Chinese pagoda as a complex adaptive system, we first extract the basic units, pavilions. Pavilions are stacked up into a tower-shaped pagoda. There may be multiple pavilions at the same level. Figure 5 shows a

The properties of complex adaptive systems	
General	Pagoda
Elements	3 or 6 Pavilions (or Pavilion Parts)
Interactions	Adjacency Principles
Formation/Operation	Generative Constraints
Diversity/Variability	Variations by Form and Spatial Parameters
Environmental Demands	Visible (e.g. Style requirements for outline forms) & Canopy
Intended Activities	Gestalt/Emergent Rhythm Patterns for Worship & Memorial Purposes

Figure 5 A Sample Pagoda & Its Major Properties as a CAS

typical example of a pagoda and a table that summarizes these major properties that a designer would need to consider.

As pagoda shows a certain amount of symmetry, self-similarity and repetition, the interaction consists of placement constraints that define the layout or adjacency relation for the neighbouring pavilions. The basic operations consist of formation and concatenation of the pavilions, each of which has some variability in terms of the shape and form parameters, but yet in an overall effect, the entire collection of pavilions are style-matched and form-coordinated. Figure 6 shows several topological graphs of the spatial patterns of pagodas. Beside each picture is the diagram with bubble representing a distinct pavilion highlighting the two-dimensional layout of these structures that may include a set of pavilions; even only part of them is visible. Note that pagoda structure can be defined recursively and/or iteratively in graph-based grammar. There are several parameters/features that define the characteristic pavilion variations. Figure 7 shows the samples defined by the parameters of 'Eave Feature'.

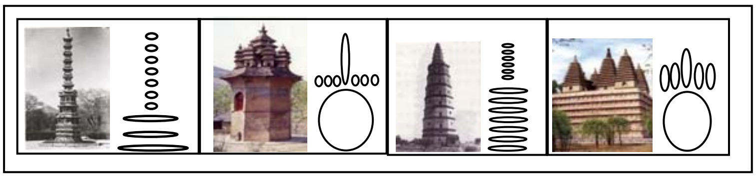

Figure 6 Samples of Pagoda Structure

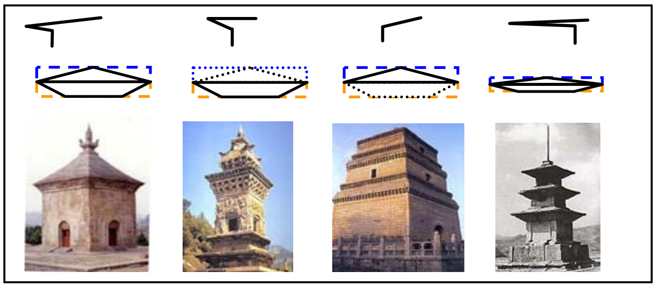

Figure 7 Variations by Eave Feature

Because pagoda is a public venue for people to view from afar and to visit, the demand of environment would be high visibility from public's view, both in terms of its overall external appearance and its prominent site location. As the main building functions may include worship and contemplate the displayed relics for remembrance of the past, both interior and exterior surrounding should permit visitors to roam and pause. From the perspective of spatial configuration and form generation, the emergence of Gestalt (e.g., rhythm patterns) is assured by the collective behaviour of a group of pavilions. To analyze pagoda works, we can indicate the relationships among pavilion individuals, so as to discover the adjacency principle between neighbouring pavilions, which lead to the emergent social structure of a pavilion group, i.e., formal pattern of pagoda design.

The major parameters include: (a) vertically, the height of the four parts: roof, brackets, body, and banisters & podiums, and (b) horizontally, the convex hull and the polygonal cross-section that characterize the planar layout. These parameters are easily represented in a graph form. The interrelationship of these parameters are constrained by the scale and ratios among the heights and the cross sectional dimensions. Figure 8 shows examples from fully extent, to half extent and half compacted, hybrid extent/compactness, gradually compressed, to fully compacted.

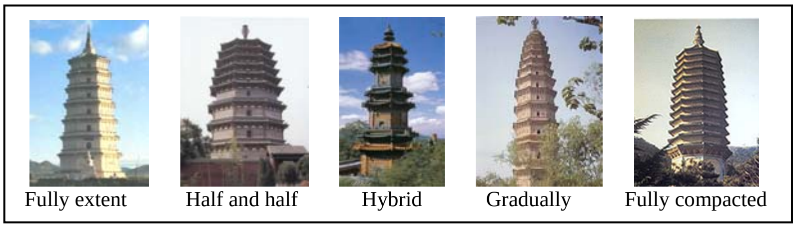

Figure 8 Samples of the Formal Patterns (Rhythm/Emergent Social Structure)

3.2 Generative Model

Our approach combines evolutionary search technique with the generative model. It consists of a framework for grammar-based design and parametric, recursive computation. Before the modelling of the interaction of pavilions, a set of assemblages of pavilions is generated (as predecessors of design populations) recursively. The parameters used for topologies of pavilion layouts include, i) graph-based spatial patterns of pagoda, ii) iteration number (since the number of levels in Chinese pagoda should always be odd). Along with the recursively generating simulation of variant pavilions, individual pavilion units, functioning as autonomous agents with distributed behaviours interact with each other by observing the given global constraints or principles (environment demands, e.g., pagoda's outline constraints, adjacency relations as shown in Figure 4b). As living behaviours, the pavilions and/or the parts (e.g., roof parts) can be interacting as: producing, moving, growing, and degenerating (shrinking and dying), as shown in Figure 9. Both of local spatial patterns (of pavilions) and global spatial pattern (of pagoda) can also be evolving concurrently.

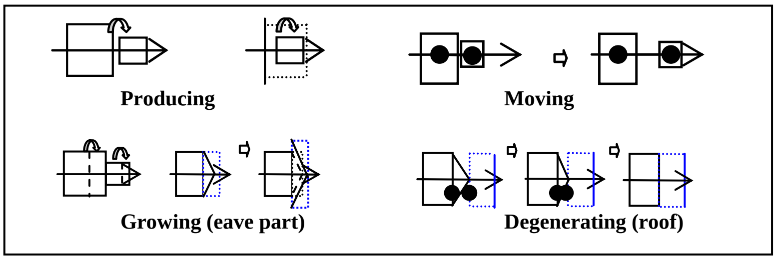

Figure 9 Adjacent Pavilions Interacting as Living Behaviours

3.3 Algorithms and Evolutionary Component

We introduce evolutionary computation technique for design space search, by adopting both the graph-based Genetic Programming (GP) for specification of the spatial patterns of pagodas, the topologies of pavilion layouts, and the pavilion parts layouts, and Genetic Algorithms (GA) for creating pavilion variations (Ballard 1997). The algorithm and flow-chart are given in Figure 10.

Algorithm

PhaseI. – Generate pavilions

1) Initialize design space for pavilion units
2) Randomly select one of the distinctive formal patterns of pavilion units and record its topographical graph
3) Randomly seed a set of pavilion units genotype (initial pavilion population)
4) Decoding the genotypes into phenotypes for evaluation of the fitness (subjective)
5) Put the genes of selected pavilions into the pool of evolved genes for the production of pavilion population

PhaseII. Generate spatial patterns

6) Initialize design space for the spatial patterns of pagodas / the topologies of pavilion layouts. This includes coding of the topologies of pavilion layouts, initialization of parameters, and creation of working environment
7) Randomly seed a set of graphs for the spatial patterns of pagodas / the topologies of pavilion assembling (initial pavilions topology population)
8) Decoding the genotypes into phenotypes for evaluation of the fitness (subjective)
9) Put the genes of selected pavilion layouts into the pool of evolved genes for the production of pavilion assembling population

PhaseIII. Generate assemblies of pavilions

10) Initialize design space for the assemblages of pavilions as the predecessors of design populations: selecting one of the genes of selected pavilions, and a set of the genes of selected pavilion layouts, and creation of working environment
11) Randomly specify one of the genes of selected pavilions and a set of the genes of selected pavilion layouts, so as seed a set of assemblages of pavilions as the predecessors of design populations, by recursive computation using the selected pavilion as axiom for graph-based grammar design

PhaseIV. Generate pagodas

12) Initialize design space; coding of the interactions between pavilions, parts of pavilion, coding of global and local constrains, initialization of geometrical parameters; and creation of working environment
13) Consider a pagoda as a collection of living pavilions: let individual pavilion move, grow, shrink, produce, die, and interact with others to generate a set of pagodas as design populations

PhaseV. Search pagoda design space

14) Specify the graph-based design grammars (genotypes) of desirable pagoda pairs for evolution from the viewpoint of subjective, aesthetic standards, and creation of working environment
15) Evolve genotypes: Crossover, mutate and reproduce. A set of evolved genotypes and their correspondent phenotypes are the generated pagodas.

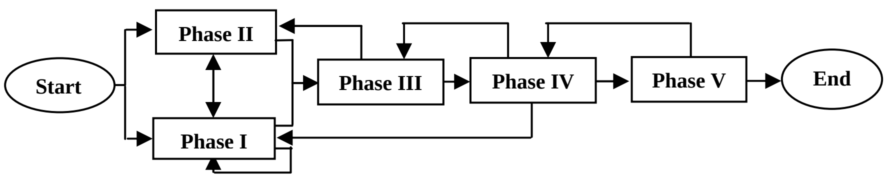

Figure 10 The Algorithm Steps and Its Flow-chart

GP typically starts with a population of randomly generated computer programs composed of the available programmatic ingredients. Then GP iteratively transforms a population of computer programs into a new generation of the population by applying analogues of naturally occurring genetic operations, which are applied to individual(s) selected from the population. The individuals are probabilistically selected to participate in the genetic operations based on their fitness (as measured by the fitness measure provided by the human user in the third preparatory step). The iterative transformation of the population is executed inside the main generational loop of the run of genetic programming. The GA is a probabilistic search algorithm that iteratively transforms a population (a set of mathematical objects, e.g., fixed-length binary character strings), each with an associated fitness value, into a new population of offspring objects using the natural selection principle and using operations such as crossover (sexual recombination) and mutation.

We have developed a prototype system, *glPagoda*, using OpenGL on PC windows platform, and conducted some preliminary experiments to test the effectiveness of the proposed system. Figure 11 shows some of the outcomes of *glPagoda*.

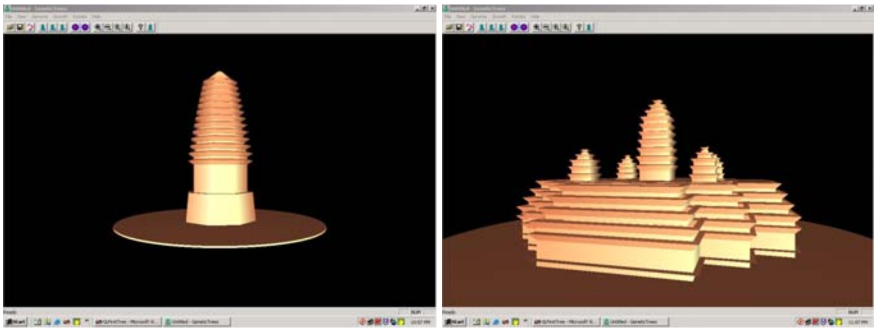

Figure 11 Screenshot Image with the Work Environment of *glPagoda*

4 DISCUSSIONS AND CONCLUDING REMARKS

'Space' is the crux of architectural design. However, the majority of current computational techniques, e.g., Shape Grammars, are only for shape manipulation, but not for space. Thus, in this paper our main contribution is to propose a two level (topological-geometrical) descriptive and generative model for space organization. By allowing interaction between adjacent pavilions, spatial patterns of both local pavilion(s) and of pagoda can grow, survive, degenerate, or reproduce in a dynamical procedure. This presents an opportunity to approach a multi-scale simulation of spatial pattern generation in the future.

In summary, this paper presented the works that explored the potential of complex adaptive systems application for architectural design, incorporated multi-agent modelling for generative design process, and introduced traditional Chinese pagoda design manners to design computation research.

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