13 Using virtual models to teach traditional Chinese wood construction[1]

Andrew I-kang Li and Jin-Yeu Tsou[2]

Chinese University of Hong Kong, Shatin, N.T., Hong Kong

In this paper we discuss our experience in using virtual models to teach traditional Chinese wood construction. Although our approach is technically simple – we use a kit of model parts made with the Solid Modeler of AutoCAD, Release 12 (now Release 13), and customized commands in AutoLISP – we have had excellent results. This is because of the remarkable match between the modelling medium and the highly systematized nature of traditional Chinese wood construction. It is this crucial – and interesting – characteristic that we want students to understand and appreciate.

In our first teaching experience, in the fall term, 1994–95, despite unexpected drawbacks, our approach succeeded. In fact, our students, all Hong Kong Chinese, were surprisingly enthusiastic and even took pride in the sophistication of this uniquely Chinese construction system. In 1995–96, we have used the same kit of parts in two courses: a introduction to Chinese architecture (spring term) and an advanced course in Song dynasty wood construction (fall term).

We first discuss briefly the theoretical basis for our approach. We then describe the assignments, the kit of parts, and supporting materials used in our teaching experiences. Finally, we discuss our findings and consider directions for the future development and improvement of our approach.

INTRODUCTION

Since 1993, we have been developing a technically simple but innovative approach to teaching traditional Chinese wood construction. Our approach uses virtual models to demonstrate the most interesting and significant aspect of this subject, namely its rule-based nature. We have used this approach in a variety of assignments and courses and have found that, despite unforeseen shortcomings, it is highly effective in communicating the principles of the rule-based system. In addition, our students were unexpectedly enthusiastic about Chinese architecture as a result of these assignments. In this paper, we discuss the theoretical basis for our approach, the teaching tool and how we have used it in our teaching, our findings, and our plans for future development.

1.0 THE APPROACH

1.1 Theoretical background: Why virtual models?

We use virtual models to avoid the disadvantages of physical models and to highlight the conceptual framework of traditional Chinese wood construction. We see two disadvantages with physical models. First, they are usually detail models, which emphasize subassemblies and their constituent components. This makes it difficult to communicate a comprehensive conceptual framework for understanding the functions and relations of the components. Worse, it gives the impression that traditional Chinese architecture is nothing more than an arbitrary collection of building parts with strange names. Second, physical models are difficult and time-consuming to make: a complete model can have hundreds of pieces that must be individually formed. This is a further disincentive against exploring the capacity for variation inherent in the rule-based system of traditional Chinese wood construction.

This rule-based system, however, is exactly what we wish to emphasize. It establishes a large set of sanctioned building designs by defining two small sets. One is a set of prototypical building components, like columns and beams, which are repeated individually and in groups throughout the structural frame. The other is a set of rules for assembling those components. Not only is this rule-based approach more elegant and sophisticated than simply listing each possible building, but it also demonstrates that Chinese architecture is as developed and intellectually stimulating as any other. It is to teach this rule-based system that we use virtual models.

Our source is the *Yingzao fashi,* or *Building standards,* an official building manual from the Song dynasty (960–1127), published in 1103. It has been a critical document in Chinese architecture for the simple reason that it is one of only two books on architecture surviving from the imperial era. (The other is the Qing manual *Gongbu gongcheng zuofa zeli,* published in 1733.) In fact, the "discovery" in 1919 and subsequent reprintings of the *Yingzao fashi* led directly to the establishment of the field of architectural history in China, and the manual has remained an important object of research.[3]

1.2 Teaching materials

In our teaching, we have been using two types of materials: the virtual model kit and supporting materials. The virtual model kit is a set of prefabricated prototypical components, like columns and beams; in virtual modelling terms, these are *primitives.* Students copy the prototypical components as required; that is, they instantiate the primitives to obtain *instances.* They then construct models of buildings by assembling the copied components (the instances) according to the rules of assembly and composition. Virtual modelling expedites the required large-scale repetition of components, which frees students to grapple with the rules, which we believe are the most meaningful and interesting aspect of a rule-based system.

The kit presently contains thirty-eight primitives, from columns and beams to *dou* and *gong* (blocks and bracket arms). These are sufficient to make a simple three-bay building composed of 310 instances. In 1995, we implemented customized AutoLISP graphical menus and commands for inserting components and placing them into position. This eliminated much time-consuming manipulation in AutoCAD, reducing the average time for constructing a standard model from one and a half weeks to one hour.

In addition to the model kit, we have supporting materials ranging from a cardboard model of a bracket set, to readings in English and Chinese, to on-line materials, including instructions, historical examples, a glossary, and a construction animation.

2.0 THE ASSIGNMENTS

We have used the virtual model kit in a number of different ways and at different levels, from a one-session exercise in an introductory CAD course to a term-long research project in an advanced course in Song wood construction. Here we discuss the two assignments that we gave in required second-year courses in the undergraduate architecture programme at the Chinese University of Hong Kong. The first was a four-week assignment in the introductory CAD course in 1994–95 (49 students), and used an early version of the model kit. The second assignment, two weeks long, was given in the Chinese architecture survey course in 1995–96 (44 students). By this time, we had improved the kit according to our experience with the first assignment.

2.1 Design and construction of a complete building (1994–95)

The assignment was to design and construct a virtual model of the structural frame of an official Song building, according to the rules of the *Yingzao fashi.* Thus it encompassed the complete process, from design through construction. Students had had no courses in Chinese architecture, but were taking a twentieth-century architecture survey concurrently. We gave the assignment in the required introductory CAD course, which it served as an exercise in three-dimensional modelling. In terms of architectural history, however, our goal was to introduce the students to the systematic basis of Song wood construction.

We divided the assignment into two stages. In the first stage, the students were each to build one bay of a sample model, which used, unaltered, the parts provided in the model kit. This was to give them practice in manipulating the components and to introduce them to the parameters governing the overall dimensions of the building (e.g., building width and bay width, building depth and bay depth, and column height). This stage was long – one and a half weeks – because we had not yet developed the customized commands.

In the second stage, lasting two and a half weeks, the students worked in groups of three or four. Each group proposed and, after our approval, designed and constructed a complete model of a different building and prepared a report. Most groups focussed on one or more of the parameters listed above; a few groups investigated parameters that we had simplified or eliminated, such as the sources of curvature. Students were required to conform with the rules governing the values and interrelationships of the parameters.

2.2 Rule-based façade design (1995–96)

We gave this assignment in the required Chinese architecture survey course. There were forty-four students, all of whom had had a one-term introductory CAD course, a one-term survey course in twentieth-century architecture, and a field trip to China.

This assignment differed from the earlier one in that it examined only two parameters: the width and height of the central bay. Students constructed thirty variations of the same sample model as the year before. They then printed out the façades at the same scale, and pinned them on the wall in a six-by-five matrix (six widths by five heights).

Of these thirty façades, only fourteen were sanctioned; sixteen were not. Students studied the matrix and wrote a short essay on the relation between the three rules and the boundary between the sanctioned and the unsanctioned façades. This boundary is determined by the three rules governing the height and width of the central bay. The first rule limits the width (200 to 450 *fen,*[4] or 2.560 to 5.760 m), the second limits the height (up to 375 *fen,* or 4.800 m, with no minimum given), and the third limits the relation between the width and the height (the height may not exceed the width).

3.0 FINDINGS AND DISCUSSION

3.1 The advantages of virtual models

The outcomes of these two assignments support our starting assumptions about the benefits of virtual models. Our first assumption was that this approach would make possible the otherwise impossible task of constructing complete models. Both the 1994–95 and the 1995–96 classes finished the standard sample model of 310 instances. The first class, doing the building assignment, took a week and a half; the second class, doing the façade assignment, used the improved version of the kit and finished the same models in one hour.

The first class, with no background in Chinese architecture, went on to design and construct sixteen complete models in two and a half weeks. This was possible *only* because they were working with virtual models; it would have been impossible with physical models. The models had as many 900 instances, and if students had had to form each one individually, they would have abandoned the task in short order.

In addition, the advantages of virtual models are meaningful precisely because the system is rule-based. It is a simple job to provide students with a small set of primitives (a kit of parts) which they duplicate as necessary. Their attention is then focussed on the conceptual underpinning of the system: the rules. We had assumed that our approach would make the rule-based system obvious and prevent students from getting bogged down in details. It is clear from the products and students' comments that this was the case. One student wrote:

> *Before this assignment, I think Chinese building is very mysterious as it seems to be very complex and [to] have a lot of small elements. When we open a book about this, it is full of complex diagrams and ... unknown Chinese terms.*

> *However, ... in this project ... [t]he [building] process is simple. ... I think that I can read some references more easily with this experience of handling this project.* (Desmond Tse Kwok Cheung, 1995–96)

Our second assumption was that using virtual models would make possible not only single models, but also sets of comparison models. In the building assignment, one group took the initiative to do a small set of comparison models, showing that they recognized this possibility and thought it useful. In fact, at a larger scale, the whole group of sixteen models demonstrates how one set of rules and one set of building parts can lead to varied results.

The façade assignment was an explicit comparison of results produced by varying the values of two parameters. The value to students is clear.

> *From the project, we can see that the way of Chinese building according to* Yingzao fashi *is really a modulated building system. Once we know the rules ..., we can build a large variety of buildings, ... from a small village house ... to a large palace for the emperor. ... This is really an amazing building technology.* (Victor Fung Chi Hang, 1995–96)

Students commented that assignments with the virtual model kit are more effective as part of a history course. In fact, the assignment and the course seem to be complementary. A history course provides the background knowledge against which students can verify their observations during the assigment.

> *We have done similar assignment using the Yingzao fashi in the first term [in the CAD course]. However, we knew nothing about traditional Chinese building structure at that time. It seemed to me that I did something that I was totally unfamiliar with. As a result, I learnt nothing. For this time, it is fruitful to do this exercise as we have already obtained basic knowledge about the construction of traditional houses during history courses. We are clear about [the] content of this exercise.* (Pery Ho Kin Yun, 1995–96)

Conversely, many students felt that the assignments give them the experience of building a building, an experience which they do not otherwise have, either in lectures or field trips.

> *I think the programme contributes to my deeper understanding of the basic Chinese building system, especially the roof structure. It is because I have the chance to assemble a whole building myself. And different components can be seen from a more three-dimensional view on the computer.* (Rosetta Kwong Mei Ying, 1995–96)

3.2 The disadvantages of virtual models

Notwithstanding the evident advantages mentioned above, there were equally evident disadvantages. However, we believe that as long as we recognize them, they do not outweigh the advantages. The virtual models were less correct than physical ones would have been – *assuming that the students had been able to complete physical ones* –

because the mistakes were possible only with virtual models; they would simply have been impossible with physical ones. In other words, the mistakes are attributable to our use of virtual models. This should be a caution that the virtual model is only a complement to the physical model; it is not a replacement. In fact, the virtual model opens up new possibilities not only for learning, but also for error.

Students made two kinds of mistakes. The first appeared as impossible connections among structural members. This is serious, as the interlocking of members is a key feature of Song construction. Our cardboard model makes this type of error physically impossible, but our virtual model lacks this kinesthetic feedback. This mistake is especially easy to make with members which are otherwise easy to confuse. Clearly, the cardboard model is still indispensable, as one group of students wrote:

> *[D]uring this project, the cardboard model help[ed] us a lot in understanding the connections of different pieces and whenever we [had] problems in constructing the virtual model, we [had] to turn to that model.* (Florence Chan Lai Shan et al., 1994–95)

This points out a technical limitation, the lack of collision detection. When the model kit does not have an efficient algorithm for this capability, students manipulating the building elements can not only overlap them in three-dimensional space, but can also violate the construction sequence.

The second kind of mistake stemmed from the lack of gravity (which one could say is actually another form of intangibility). As the same students wrote,

> *the absence of ... gravity in the virtual model can create some illogical situation, for example, one can place a rafter onto the correct position before constructing the columns or purlins.* (Florence Chan Lai Shan et al., 1994–95)

3.3 Representation of the virtual model

In the building assignment (1994–95), students found it difficult to manipulate the elements of the model; they found it especially difficult to select individual points, lines, and other elements. This resulted from the inconsistency between the *three*-dimensional virtual model and the *two*-dimensional representation of that model on the screen. We, the instructors, tended to think in terms solely of the *three*-dimensional model, but in fact what the students saw and manipulated was its *two*-dimensional representation: the interface mechanism between the user and the virtual model consists of a two-dimensional monitor display and a two-dimensional pointing device.

We propose two approaches to investigate this question of the interface of the virtual model. The first approach is to redesign the existing interface to support the required operations. The present version of the model kit, used in the façade assignment (1995–96), incorporates such an improved interface: it includes self-aligning functions and a graphical menu template.

The second, more radical, approach is to transfer the model kit to a virtual reality simulation environment. In another project, we are currently developing the virtual reality interface technology, including stereographic eyeglasses with head tracking and a three-dimensional mouse with object manipulation commands. In the virtual reality environment, students will be able, by means of a stereographic display and eyeglasses, to enter the three-dimensional virtual space containing the model kit and to manipulate the model parts directly. This would eliminate the problem of manipulating two-dimensional representations of three-dimensional objects.

3.4 The philosophy of the modelling environment: an observation

In the building assignment, it appears that the students were reacting to the philosophy of the modelling environment, which, by attributes like its characterization of three-dimensional space and the commands it provides, makes some tasks easy and others difficult.

Most students chose variants which could be constructed easily and avoided those that could not. Students constructed the "easy" variants by first forming a single bay and then applying commands like *copy, array,* and *mirror* to form the complete structural frame. These models were generally large and repetitive.

Only a few students opted for the "difficult" variants, which required intensive manipulation of individual components. These models were small, but involved subtle issues, like the structural frame's deviations from orthogonality, for which the *Yingzao fashi* has explicit provisions. (We had omitted these provisions from the assignment for the sake of simplicity.)

3.5 Students' reaction: an observation

Students reacted enthusiastically to the assignments, much more so than we had expected, and were keen to learn more about Chinese architecture. Some of the attraction appeared to be that the learning was self-guided.

> *[T]his is an interesting assignment for it really gives us the chance of "building a building" and lets us explore on our own.* (Ben Poon Ho Sing, 1995–96)

Another reason for enthusiasm seemed to be the intellectual appeal of the construction system itself.

> *We find this project very interesting because we have learnt [not] only [about] ACAD but also the construction of Chinese architecture. We find the topic –* shengqi *[a way of introducing curvature by varying the column heights] – that we are doing is very interesting and has great research value. Since the time for this project is too short for us to explore more about* shengqi, *our group has much interest to carry out the research in the latter time.* (Lesley Choi Lai Chun et al., 1994–95)

But the assignment also seems to have struck a chord in our students, all Hong Kong Chinese. They were excited to have discovered the sophistication of this uniquely Chinese construction system, and were proud of their "ancestors" who had developed it.

One thing we find interesting is the underlying principle behind this 'seem to be simple' structure. One will find that it is entirely different from Western architectural construction. We get inspired to a new aspect and stunned to explore it in the foreseeable future. (Wong Yin et al., 1994–95)

In the whole project we find it very interesting to get to know more about the Chinese architecture and construction. We are surprised by the very detailed guidelines of [the] Yingzao fashi *and [by] our ancestors who had thought so carefully and wisely about the buildings. We admired the compositions of the buildings which contain thousands of small components [which] fit very well to form a large building.* (Chan Kei et al., 1994–95)

The assignments appeared to alter students' preconceived ideas. They often think that Chinese architecture is quaint, arbitrary, and irrelevant, and so when they discover that it is in fact beautiful, logical, and sophisticated, they are pleasantly surprised, even thrilled. To Chinese students following a primarily Western curriculum, this revelation affirms their own heritage, and they identify with it personally.

[Our] interest [in] Chinese architecture is cultivated through the assignment. It is wonderful to see various tiny pieces forming an elegant and beautiful building. There is great logic and thought behind [it].

In our own Song dynasty building, we are fascinated to discover a few things ... which make us feel that the structure is very elegant and [that the] Chinese [are] very clever. (Gabriel Chan et al., 1994–95)

I have not only learned the manual, I [am] also ... proud of the traditional culture of my own country. (Leung Wai Yin, 1995–96)

CONCLUSION

There are both advantages and disadvantages to this teaching method. It has subtle limitations that we must understand in order to anticipate and avoid error. Nevertheless, it is technically simple and truly helps students to apprehend quickly the most remarkable aspect of Song construction, namely its systematized nature. Moreover, it generates enthusiasm among our students.

We have compiled the model kit and the supporting materials into a CD-ROM for limited distribution and trial. These are still under development, and we intend to continue work in the following directions.

First, we will make more parts. The present kit of thirty-eight primitives is limited. We will construct more primitives, particularly of the bracket sets, to make the kit more complete.

Second, we will implement customized commands for parametric design. That is, allow the user to input values for parameters like column height. The model kit will then produce modified instances accordingly. Currently, the commands are optimized for a single building; implementing parametric commands will allow users to produce many variations with equal ease.

Third, we will provide more complete on-line supporting materials. Students have made many suggestions for improvement in this area. In addition, we plan to produce a bilingual (Chinese–English) version of the materials and reorganize them in Macromind Director.

Readers will find current information on this project on our department's web page (URL: http://www.arch.cuhk.hk). We welcome all comments and suggestions.

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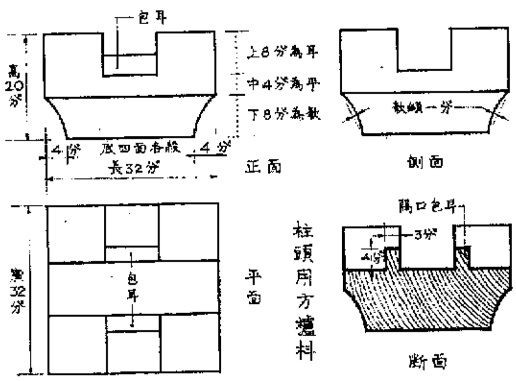
ILLUSTRATIONS



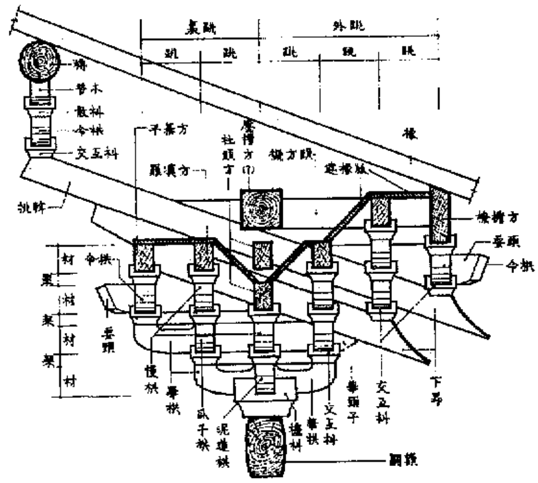


Figure 1 (left). A typical prototypical component: the *lu dou*, or cap block. Its dimensions are given not in absolute units but in *fen*, a modular unit which has one of eight values from 19.2 to 9.6 mm, according to the rank of the building. Thus its height, defined as 20 *fen*, can range from 384 to 192 mm. The *lu dou* is the bottom-most component in the bracket set (see figure 2).

Figure 2 (right). A bracket set. It is composed of individual components and is repeated as a group throughout the structural frame. The *lu dou*, or cap block, sits on the beam.

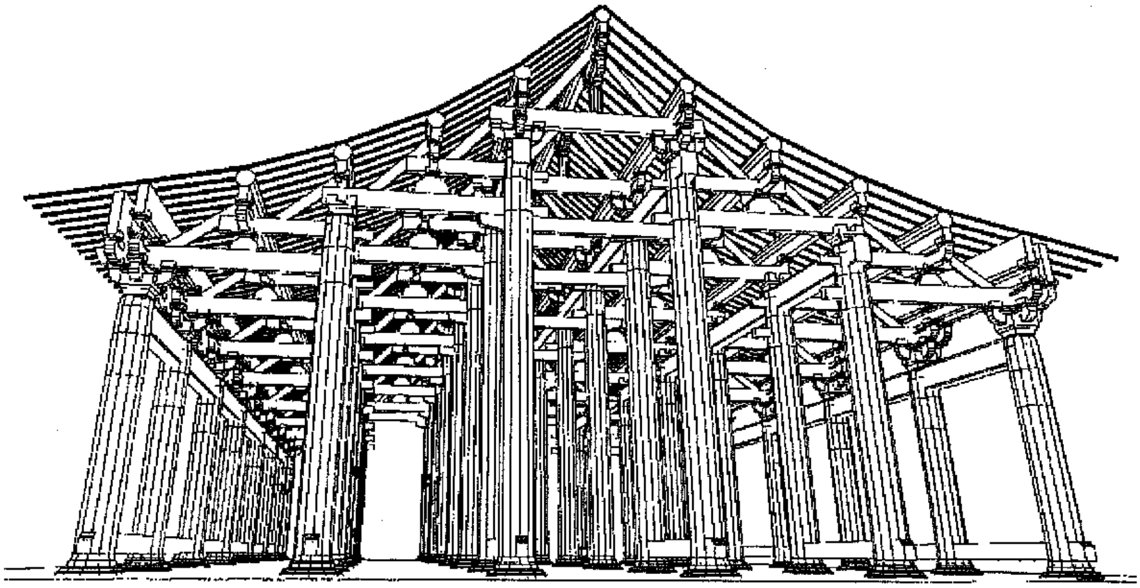
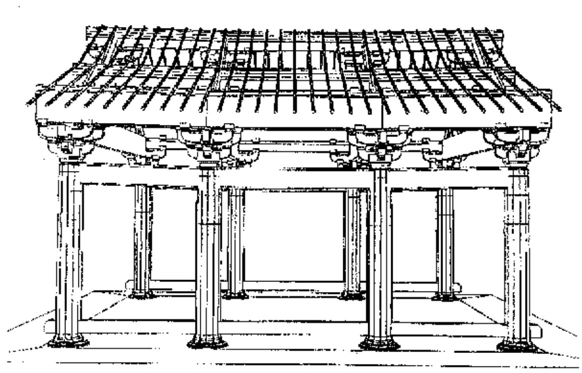


Figure 3. The building assignment (1995–95). This is an "easy" variation, produced largely by duplicating components. It exhibits a mistake unique to virtual models: it defies gravity. Above the second column from either end in the perspective, there is a small block (*dou*) suspended in mid-air. The bracket arm (*gong*) supporting it is missing. (Gabriel Chan et al.)



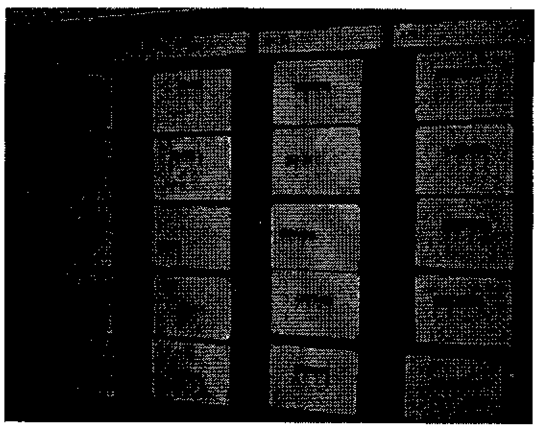


Figure 4 (left). The building assignment (1995–95). This is a "difficult" variation, produced by manipulating individual components according to rules of curvature: columns are of different heights and slope inwards in both front and side elevations. (Wong Sau Kin et al.)

Figure 5 (right). The façade assignment (1995–96). Students produced a matrix of thirty variations (six widths by five heights). Two columns at the right of the matrix are not shown.

NOTES

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2 Both of the Department of Architecture, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong. Phone: +852 2609 6515 (Li), +852 2609 6558 (Tsou). Fax: +852 2603 5267. E-mail: andrewili@cuhk.edu.hk (Li), b137787@mailserv.cuhk.edu.hk (Tsou).

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3 For a general introduction to the *Yingzao fashi,* see Glahn (1984) or Liang (1984). For the rule-based system, we follow Liang (1983) and Chen (1981). For a more extended discussion of the rule-based system and virtual models, see Li and Tsou (1995).

4 The *fen* is a modular unit, ranging from 19.2 mm to 9.6 mm. In this assignment, we assumed the sixth of eight possible grades; at the sixth grade, 1 *fen* = 12.8 mm.