Chapter 1 Introduction

1.1 Research on historic architecture

Globalisation and its consequences have attracted the concerns of many researchers from many territories. This has also raised interest in the research of localisation, especially in the architectural field (Jin-Won Choi, Hyun_Soo Lee, Jie-Eun Hwang & Mi-Jung Kim, 2001). Architectural history is a branch of cultural history, which, like any other historical inquiry, involves asking and answering questions. The general aims for research in architectural history are:

- To investigate the architecture and design of a certain time and identify the major developments
- To consider the reason why these developments occurred and their importance
- To analyse and to understand the meaning and value of the works and hence to convert them to design knowledge in the present practice (Benton, T & Baker, G 1975).

Survey, research and report constitute a typical chain of essential work in historic architecture research (Cong, W. & Zhang Honng-Ran, 2001). Here, survey means on-site investigation and measurement, research stands for the documentation review of the appropriate historic building, and report indicates the way of representation. Historic architecture research involves the process of understanding the historic building's design concept and the representation of it. However, there are difficulties associated with this. For a historic site, the related information is often very limited. Normally, there are no original design drawings to reference and the historic building cannot be disassembled for further examination. Moreover, most historic sites are partly or entirely destroyed after hundreds of years of existence. There are also difficulties linked to the representation process. The current popular media for most architectural information are 2D images, drawings and photos. These are inadequate in representing 3D components, their complex joints and their relations, and it is often almost impossible to understand correctly the whole construction process (Jin-Won Choi, Hyun_Soo Lee, Jie-Eun Hwang & Mi-Jung Kim, 2001).

In such cases a common approach is to build a physical model (a traditional model) to examine the spatial layout, construction rules and other aspects, and hence to understand the building and the design concept. An extraordinary range of models has been and continues to be used for historic architecture research. Recently a new type of modelling became available: that is digital modelling.

1.2 Computerised model: an intelligent model

With the dramatic development of digital techniques, computer-based representation has experienced four phases:

- One-dimensional media: include words, texts and sounds
- Two-dimensional media: covers images, plans and maps
- Three-dimensional media: indicates lines in space, surfaces and renderings
- Multi-dimensional media, which includes motion models and animation (Mitchell, W. 1977)

This development enables a new category in architectural study – CAAD (Computer-aided architectural design). CAAD research and teaching has a long history going back to the 1960’s. However, in the last ten years, there has been a dramatic upsurge in activities brought about by factors such as the increasing use of CAD system in practice, the increase in computer literacy and the development and widespread use of the World Wide Web (Lewin, Ehrhardt & Gross, 1997). The most important influence has been rapid development in computer speed and power with software to exploit this.

Galli and Muhlhoff (2000) point out that the computerised model of a building is not just a 3D construction that offers infinite viewpoints, as does a physical model, but it is a dynamic model, one that is interlinked and can be changed. Its data are interrelated according to the accepted scientific definition of “model”, mathematical, financial, physical and statistical. By using simulation in the building environments, it is possible to examine spatial layout and construction, function and formal organisation, quantitative and economic aspects simultaneously. In this aspect, a computerised model is much more than a physical model, although its construction requires care, cognitive attention and intelligent interpretation in exactly the same way as the construction of a traditional model. They also state:

“A computerised model is a sort of intelligent model because it captures, condenses and organises information according to the cognitive and organisational structure of whoever builds it. The long hours taken to create it represent an important period of immersion: the lines and meaning of the project gradually take shape, the interrelations, the reasons, the structures become clear, hypotheses are thrown up in a constant interrogation between those involved: between the architect who designs the project and whoever is studying or reconstructing it.” (Galli, Muhlhoff, 2000 pp.6)

1.3 A brief background on Chinese architectural history development and research

1.3.1 The development of ancient Chinese architectural history

China has a written history of about four thousand years, but the history of Chinese architecture goes back much further into antiquity. For thousands of years, ancient

Chinese architecture has gone through a long and tortuous path. With its wise and diligent people, China created a resplendent ancient culture, which included an architecture of unique historic style with many superb examples, be it of individual buildings, of composition in building ensembles, or of city planning (Ancient Chinese Architecture, 1982).

The development of classical Chinese architecture is normally categorised into five stages:

- Architecture of the primitive society period

Primitive people, capable only of adaptation to natural conditions, chose to live in mountain caves close to water and hunting grounds. About 6,000 to 7,000 years ago, people began to make dwellings by digging pits that they covered with simple timber roofs. In such a way, the construction activities of human beings in ancient China began. About 5,000 years ago, dwellings started to be constructed in the form of three to five cubicles joined together in a row. Due to dissimilar geographical and climatic conditions, buildings of many diverse forms of construction appeared (Chinese Academy of Architecture, 1982).

- Architecture of the slave society period

This period lasted about 1,600 years, from the 21st century BC to 475BC. During that time a higher level of building techniques evolved. The construction of mausoleums became a major building activity. In addition, “rammed earth with framework construction was an innovation that was widely used in the construction of city walls, high terraces and podia for buildings”. The application of coloring, carving and other ornaments on buildings began (Chinese Academy of Architecture, 1982).

- Architecture of the early feudal society period

This period lasted about 1,000 years, from 475BC to 581AD. In this era, building activities on a large scale begun. The world famous Great Wall was started. The timber framing technique reached a higher level and began to be used in the multi-story buildings. Five basic roof elements emerged, namely the Wudian (hipped roof), Xuanshan (roof with gabled ends), Dunding (slightly vault shaped roof), Chuanjian (pointed roof) and Xieshan (half-hipped, half-gabled roof). Buddhism also made the road into China in this time. The extensive construction of Buddhist temples thus became a major building activity of this era apart from the building of towns and palaces. Some of the temples were built as tall and large wooden structures, which represent the high level of architectural technology in that period (Chinese Academy of Architecture, 1982).

- Architecture of the middle feudal society period

This period covers seven to eight hundred years, from 581AD to 1368AD. In this era, building technology matured further, methodical design for timber structure came into use, and the organisation and management of building construction became more developed. During the Song Dynasty, “artistry on buildings became richer and more polychromatic, with a higher level of workmanship in the artistic use of glazes, color painting and decorations” (Chinese Academy of Architecture, 1982). Colorful lacquer paints for wood frames also appeared. The achievements also includes one of the most important heritage documents in Chinese architecture history in the period of Northern Song Dynasty, Yingzao Fashi, a book devoted to building construction. It was a manual of building standards, containing detailed design principles of thirteen types of buildings, about their modular dimensions, construction methods, material quantities, and design patterns. It also outlined the rules and techniques for the construction of each building and each component (Chinese Academy of Architecture, 1982).

- Architecture of the late feudal society period

This period covers the Ming and Qing Dynasties, from 1368 to the Opium War in 1840. Architecture in this period continued to make progress, and achieved outstanding success, especially in garden making and architectural ornamentation. Fastening and jointing methods were used extensively in the timber construction technique to fabricate large structural members with small units. An alternative method of building large structures was introduced. During this period, "all sorts of refined arts and crafts which include gold plating, gilding, inlay work, carving and lacquering were applied along with silk tapestries and scroll paintings in architectural ornamentation" (Chinese Academy of Architecture, 1982). These techniques made the classical architecture more polychromatic, exquisite and stylish (Chinese Academy of Architecture, 1982)

After the Opium War in 1840, China was in a new era of semi-feudal semi-colonial society, and its architecture after that was under the influences of foreign models. Normally, the research of traditional Chinese architecture concentrates mainly on the architectural development before the 1840s.

1.3.2 The background of ancient Chinese architecture research

Regulated research on the history of Chinese architecture did not commerce until the 1930's due to the domestic conflict situation in Chinese history. In ancient China architectural construction skills and principles were transferred in a quite practical and oral way, so within the craftsmanship there is little written material left. Even those very rare written documents were hard to keep and to understand, and of course, could not cover all the ancient Chinese architectural literature. As stated in "A Pictorial History of Chinese Architecture" (1984):

"In China these architectural features had been developed by craftsmen over the centuries in response to basic needs, from simply providing shelter at one extreme to instilling religious piety or displaying imperial grandeur at the other. Slighted, for reasons still obscure, as the province of carpenters and masons, architecture did not evoke the intellectual curiosity that leads to scholarly analysis."

The development of Chinese ancient architecture followed an unbroken line. As the structural system matured through ages of development, a well-regulated set of rules governing design and execution emerged, which became "the grammars of ancient Chinese architecture" (Liang, 1984). It is necessary to have the knowledge of these rules for the study and understanding of Chinese Architectural history. Fortunately, there are two important books from two epochs of great building activities: the Ying-tsao fa-shin (Building Standards) of the Sung dynasty (960-1279) and the Kung-cheng tso-fa tse-li (Structural Regulations) of the Ching dynasty (1644-1912) – two "grammar books on ancient Chinese architecture (Liang, 1984). However, they are both filled with unfamiliar technical terms, which are extremely difficult for people today to understand.

Not until the twentieth century did the Chinese undertake the study of their own architectural history, and in this the pioneer was Liang Ssu-Ch'eng (pronounced Leong Sss-chunag). He and his group successfully built a basis of the history of Chinese architecture by the on-site investigation of historic sites and the guidance of old craftsmen, which enabled them to identify the various timbers and other structural parts, to observe the complex building methods, and to decipher the regulations cited in the manual. They owed to the historic "grammar books" all the technical terms which are understandable. As Liang (1984) announced, "the only reliable sources of information are the buildings themselves and the only available teachers are the craftsmen". Liang's first field trip was made in 1932. During the following years, they achieved dramatic accomplishment in the research of ancient Chinese architecture. He stated in 1940:

"For the last nine years, the institute for Research in Chinese Architecture of which I am a member has been dispatching twice every year, on trips of two or three months' duration, small teams of field workers headed by a research fellow to comb the country for ancient monuments. The ultimate aim is the compilation of a history of Chinese architecture, a subject that has been virtually untouched by scholars in the past. We could find little or no material in books: we have had to hunt for actual specimens

…

We have, up till today, covered more than 200 hsien or countries in fifteen provinces and have studied more than two thousand monuments. As head of the Section of Technical Studies, I was able to visit most of these places personally. We are very far from our goal yet, but we have found materials of great significance."

(Liang, 1940)

During their studies, they measured both large and small components of the structures, as well as their immediate settings. These measurements, and notebook sketches, were used in the subsequent productions of ground plans, elevations, and section drawings, and in very special cases for making three-dimensional models. Most research on Chinese architectural history thereafter have been based on these great achievements - the drawings, their documentations, and the two ancient official building standards that had been interpreted into an understandable language by them.

The uses of computer systems are not well developed in research into ancient Chinese architecture. Although computers were introduced into the work as early as in 1991

(Cong, W. & Zhang Honng-Ran, 2001), it has not become a popular method in the research practice, especially in database set up and computer modelling and simulation. Some researchers are now developing means of best using a CAD- based software CTA for the CAD drawings of ancient Chinese architecture for use in architectural education (Zhang, 2001).

1.4 New situations for ancient Chinese architecture research

As outlined above, ancient Chinese architecture had managed to follow an unbroken line of development. Boyd stated in his book "Chinese architecture and town planning" (1962): "Chinese civilisation, and with it Chinese architecture, are less remarkable for their antiquity than for their continuity". Chinese architecture experienced the development from the flowering of the Bronze Age in about 1500B.C. right up to the present, a completely continuous, individual and self-conscious civilisation of an extremely high level, as architecture was born at the very dawn of civilisation. It is this very continuity, independence and adaptability that constitute the characteristics of the classical tradition, and thus attracted the attentions of researchers form all over the world (given the idea that the research of traditional Chinese architecture concerns mainly architectural development before 1840).

There is no doubt about the importance of the study and understanding of ancient Chinese architecture today. With the development of globalisation, finding national identities from their traditional heritage has become a more important and meaningful research issue than before. It is an essential part of inheriting architectural wisdom and past experience and applying it now in the creation of a new architecture.

1.4.1 Digital techniques for ancient Chinese architectural research

As discussed above, the development of digital techniques has brought new approaches to historic architecture research. Accordingly, the study of ancient Chinese architecture has also been carried into a new era. By the impact of digital technique, the evolutionary and generative approach of ancient Chinese architecture may develop in parallel with the introduction of CAD in the research process. Computers enable some new research approaches such as site digitalisation, the animation of destroyed buildings, and the setting up of spatial information systems. The features like database analyses and information validation could greatly increase the reliability of the research. Moreover, digital virtualisations of historic architecture offer much flexibility and realistic effects.

Computers have turned out to be a useful preliminary tool for the assistance of historic architecture research, especially for ancient Chinese architecture, because:

- Chinese architecture history has experienced a completely continuous, individual and self-conscious civilization, which is tightly related; it is well suited to systematic study.
- The information source on ancient Chinese architecture is very limited. Therefore, a wide range of hypothesis and simulations as well as generative calculations have to be involved.
- Computers facilitate detailed and realistic representation of historic works.

Most uses of computers start from the digital reconstruction of the historic architecture, namely, the computational modeling process. A digital model could be the medium to link between the present and the historical past.

1.4.2 An intelligent model for ancient Chinese architecture

During the construction process of an ‘intelligent’ 3d digital model, clearer understandings of the building and design concept emerge. A 3d model is far more versatile than a photograph or 2d drawing. Computer techniques offer an easy method for managing large quantities of data, which can be modified infinitely. By using computers, we can define the relationships between data, structure them, and make them interdependent, in a way that is convenient for their intended use (Galli, & Muhlhoff, 2000).

In addition, simulation and animation makes the representation of design and construction techniques easily understandable. Decisions about viewpoint, light, framing, background, environment and so on, can shift from the creator of the information to the computer equipped user, who may have very different purposes and needs (Mitchell, W. 1998).

1.4.3 Application possibilities of computerised model for ancient Chinese architecture

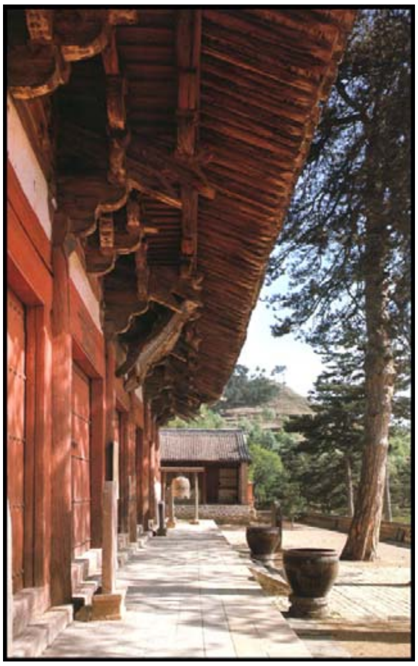
Ancient Chinese buildings, especially Chinese temples, are similar to Greek temples, in that they follow consistent rules and a have a common basic form. The structure of the temple has a logical assemblage of structural sections, and in turn, each structural section is a logical assemblage of pre-defined segments. There are basic rules for the locations and the shapes of each segment. From the basic dimensions through the detailed size, to the main dimensions of the whole structure, all these can be computed easily by use of digital media.

The important point is that the structural rules and features within ancient Chinese architecture enable the application of computational modelling of ancient Chinese architecture, providing the possibility of implementing the computational simulation and representation of Chinese historic buildings. This will be discussed later in this thesis.

1.5 The Foguang Temple

The research takes the ancient Chinese building the Foguang Temple (the main hall, in particular) as a case study. The temple was built in the Architecture of the middle feudal society period. In this era, building technology matured further. Methodical design for timber structure came into use, and the organisation and management of building construction became more developed.

Built in 874, the Foguang Temple was one of the most famous Buddhist temples in Wutai Mountain during the Tang Dynasty (Figure 1-1, Figure 1-2, Figure 1-3). Its main hall is divided into seven bays totalling 34 meters length, and eight portions wide wise totalling 17.7 meters. The roof is in the Wudian style (hipped roof), with single layer eaves. Columns inside and outside of the hall are of the same length. These columns, together with the architrave girders, corbel brackets and tie beams, form a strong structure which remains intact after more than one thousand and one hundred years. The corbel bracket and tie beams together also make a good artistic design.



(Figure 1-4, Figure 1-5, Figure 1-6: photos of the Main Hall of the Foguang temple)

The reasons for choosing this particular building as the case for research are considered from the following aspects:

- **Importance of the structural system:** The building has a typical timber structure framework of the building style of the Tang Dynasty. All the elements within the structure are structural rather than decorative. These structural components, most of which were prefabricated, have their own rules of dimensions and shapes. Moreover, the relationship between the components also followed certain construction rules. All these made the temple an ideal case for computational modelling.
- **The accessibility of the historic site:** After more than one thousand years, the building still exists. The historic site can be seen first hand, providing a valuable source of information and reference.
- **Availability of limited documentation:** Compared to other ancient Chinese historic sites, this temple is a very rare case that has attracted the attention of a few researchers. Therefore there are relatively limited documents done on this temple, which can be regarded as the necessary secondary information source and reference.
- **Historical significance:** The temple is one of the two existing earliest timber structural buildings in China. It is an important example in ancient Chinese architecture research, hence a commendable research subject for computational modelling. .

1.6 Research Scope & Approach

Considering the current needs of Chinese historic architecture research and the necessity of applying digital technique to this field, this thesis focuses on the understanding and modeling of the timber structure of the Foguang Temple (main hall). It does not cover the non-structural parts such as the inscriptions, murals and separations. Inevitably, it evokes some art, historic and cultural issues about Chinese architecture; however, they are not the main focus of the study. It is not meant to evaluate nor assess the achievements of ancient Chinese architecture.

The study explores a new approach to computer aided ancient Chinese architecture research by incorporating the experience from studies outside of China. There are two related research questions:

- Firstly, how to identify and represent the structural components, and the ways they are assembled. This is not covered in the few previous studies of the temple, which just offered brief introductions and general descriptions of the construction of the timber structure.
- Secondly, how to create a digital model for such a structure where there is insufficient or incompatible information. These are common issues that arise in the simulation and representation of historic architecture.

The thesis is organised in five chapters. Chapter 2 is a review of the literature on the digital modelling of the constructions of historic architecture. Chapter 3 is a discussion of the research methodology that is implemented for the digital modelling of the timber structure. Chapter 4 is a detailed record of the modelling process which includes hypothesising the “unknown” structural parts. Chapter 5 & 6 is a discussion and conclusion on the research process and outcomes.

Chapter 2 A Brief Review On Computer-Aided Historic Architecture Research: Cases & Theories

New technology has helped to generate new solutions for old problems. Computer graphics techniques are increasingly being used to visualise complex data in archaeological investigation. Computer-generated imagery dating back to the early 1980s has provided useful and fascinating reconstructions of ancient sites for archaeology and anthropology (Lewin, J.S. Ehrhardt, M. & Gross, M.K. 1997). Computers now not only play as tools for realistic visualisation, but also facilitate new methodologies for archaeological reconstruction and analysis. This chapter reviews a selection of different kinds of researches of computerised reconstruction of archaeological sites and focuses on those related to ancient Chinese architecture. At the end of this part is a brief record of cases that have involved digital techniques in database setup and data analysis in historic architecture research.

2.1 The reconstruction of historic site

The best-known examples of virtual reconstructions have improved modelling techniques and concepts in the re-creation of historical architecture. A large number of recent and ongoing projects have produced compelling views of various historic sites. The following section contains a simple list of some of these studies with a brief introduction to the background and research process for each case. The review is focused on those that involve some new theories and methodologies.

2.2 Kinds of model

The models that have been created for historic sites differ in terms of their purposes, ways of making, and levels of accuracy. They can be categorized as three basic types according to the modeling purpose and way of reconstruction.

2.2.1 Models of archaeological excavations

Many digital models were made for visualization purposes in archaeology study. Most of the studies are based on the archaeological excavations that record a vast amount of data. In recent years, several projects involving the creation of detailed virtual site reconstructions have been undertaken. Most of these digital models for archaeological excavations study were constructed in the studies of prehistoric sites, or destroyed historic sites. Being limited by the insufficient information from the survey of the site, it was always hard to offer a very real visualization effect. Moreover, the visualizations were not trying to represent the site as built, but to understand the site structure. Their basic concept was to build a virtual reconstruction of a site to help correlate the distribution of artifacts with the proximity to structural features.

A typical example is the virtual reconstruction of the Keatley Creek site in British Columbia, Canada, in 1995. The site contained many depressions, the majority of them being the remains of residential dwellings occupied over 2000 years ago. Based on the concept that *"the ability to visually relate the distribution of data to surface characteristics has proven useful in the identification of spatial correlations"* (Peterson, Fracchia & Hayden, 1995), a digital model was made from the survey data. In this study, the artifact data at this site was recorded as discrete counts within square regions. The site was sectioned by two meter-wide strips that were drawn vertically and horizontally. Artifact counts were recorded for each sub-square. In this way, a conventional 2D plot of artifact distribution of the site has been made which provides a tool to analyze the data. Based on this, the researchers used 3D computer graphics techniques to integrate the display of spatial data into a model of the prehistory pit-house. Under the assumption that certain artifacts have a strong association with a specific activity, this study has concentrated on creating a model of the major structural features of the site, hence to study how the inhabitants used the artifacts. Similar studies include:

- The digital modelling of the Saxon Minster of Winchester, UK, (Reilly, 1989) explores the way of application of constructive solid geometry (CSG).
- The 1989 model of Langcliffe Lime Kiln, UK, (Wood & Chapman, 1992) provided a means to check reconstruction ideas, simulate structural system and communicate results through images.
- A later project that modelled Furness Abbey, UK, expanded on the techniques pioneered in the early efforts and offered interactive viewing capabilities (Delooze &Wood, 1990).
- Attention to detail and accurate surface characteristics are also evident in the virtual reconstruction of the Visir tomb in Egypt (Palamidese, Betro & Muccioli, 1993).

2.2.2 Model for architectural visualization

A large number of digital models were constructed aiming to visualise historic architecture for analysis, teaching, or restoration. An example was done in 1997 in the US. A web site with photo-realistic animation and virtual reality walk had been developed to support study and teaching about household anthropology in sixth-century Meso-America (Lewin, J.S. Ehrhardt, M. & Gross, M.K. 1997). These researchers developed a series of computer-based images named “Computer Imagery” to represent the village life at Ceren, El Salvador 1,400 years ago. Here in this research, digital techniques and computer simulation have been used as media to represent history. In this way, people can easily make sense of the architecture and village life at that time; hence, it also offers support to teaching. An issue with such systems is that “without access to the site data and not having participated in the debate behind the renderings, outside viewers tend to be misled and see images as final and unquestionable views” (Lewin, J.S. Ehrhardt, M. & Gross, M.K. 1997). Here in this study, any possible illusion of reality during computer modeling and rendering was avoided by “allowing outside viewers to see the process engaged by the Ceren research team that extend the function of computer generated images beyond mere display, and enable them to play a more integrated role in the underlying intellectual argument”(Lewin, J.S. Ehrhardt, M. & Gross, M.K. 1997). It was a big jump since this study greatly encouraged individual examination and interpretation of the historical site data. It enabled the study and the enhanced understanding of the site with an objective approach. In an article titled “Not just another pretty face” (Lewin, J.S. Ehrhardt, M. & Gross, M.K. 1997), they claimed:

“seeing images in this context, viewers can formulate informed opinions about a rendering, perhaps developing their own arguments. A rendering is no longer viewed merely as a pretty picture, instead it serves as a visible argument”.

Digital techniques were also applied to assist the restoration of historic buildings, since its simulation enables the combination of views of the existing material and the proposed restored fabric.

Another example of a digital model for historic architectural restoration was conducted in Taiwan. After the Taiwan earthquake on 21st September in 2000, there was research on a historic architecture restoration project. It attempted to digitally simulate different combinations of new and existing roof tile layouts prior to the actual reconstruction. The computer simulation process assisted the professional and non-professional's analysis and evaluation to achieve a visually harmonious and ready for construction solution (Tang, Liu, Lin, Shin, Chang & Chiu, 2001).

Many of the most famous models can be found in a fine collection of computer-simulated buildings edited by Novistski (1998) who is a regular contributor to Architectural Record. The book is named "Render real and imagined buildings" and contains 27 digitized models of lost, un-built and imagined well-known buildings and designs.

With the development of computer techniques, the models for architectural visualizations are becoming more effective. The construction of these digital models also involved a wide range of computer graphic techniques. However, The main purpose of these models is to provide general visualization effects. They were intended to represent broad architectural design concepts and knowledge rather than detailed architectural data. They still stay at a "looks like" level. Few of these models gave much concern for the construction details. From the historic architecture research approach, this kind of model helps to make a sense of the design but is not enough for further research to be carried on it due to the weakness in details and accuracy in dimension and shapes.

2.2.3 Model for detailed historic architecture research and teaching

Based on the model for architectural visualization effects, the research of historic architecture demands more detailed and accurate digital models to be built. This kind of model can be treated as a real size digital copy of the physical reality. It contains all the valid assessable information of the studied site. During the construction process, considerations are not only given to the design concepts and general appearance, but also to the in-depth construction details and structural relations. To some extent, it can be regarded as an additional reference for the study of the historic site. Not surprisingly, this also poses a high requirement on the sources of information and clear understanding of the site. Accordingly, the models of this kind are quite few. One of the successful attempts was made in 2001. This was an in-depth study that explored a computer's role in disseminating construction knowledge and building information for Korean traditional architecture. It was a clear and meaningful case study that also contributed to the field of applying digital techniques in ancient Chinese architecture research. From an architectural approach, ancient Korean architecture and ancient Chinese architecture are similar, in terms of material, structure style and ornamentations. Therefore, it offers a perfect example for further studies of ancient Chinese buildings.

In their research, a well-known old temple building (Buseoksa Muryangsujun) was selected as a study subject. The researchers first built an accurate 3D model of the building, categorized its building components, and then analyzed their connectivity, the connectivity patterns and rules. Based on this, a web-based tutorial system of Korean traditional architecture was to be developed (Choi, J. Lee, H. Hwang J. & Kim M. 2001). The web-based tutorial system of Korean traditional architecture is named Kota View. The idea is to develop a robust data model which represents building components, connectivity between components and their connectivity rules. The conceptual interface of the web-based system is composed of five main parts:

- A main menu to contain the subjects of the whole system
- A sub-menu bar to contain complete categories to classify the main menu items
- An embedded viewer to show the real-time simulation of the construction (the key module of Kota View)

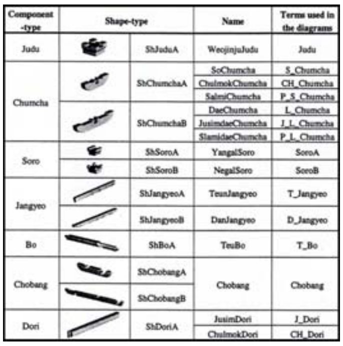
- A movie player to show interactive movies including the information of construction
- A prompt window to show messages

(Choi, J. Lee, H. Hwang J. & Kim M. 2001).

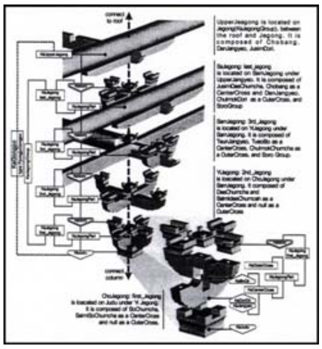
During the modelling and simulation process, the researchers built a construction data model of the traditional building from the following aspects (Figure 2-1,Figure 2-2):

- The analysis of the building structure
- Types of component shapes
- Types of connection rules related to the order of assembly
- The classification of components

(Choi, J. Lee, H. Hwang J. & Kim M. 2001).



Component -type	Shape-type		Name	Terms used in the diagrams
Judu		ShJuduA	WeojinjuJudu	Judu
Chumcha		ShChumchaA	SoChumcha	S_Chumcha
			ChulmokChumcha	CH_Chumcha
			SalmiChumcha	P_S_Chumcha
		ShChumchaB	DaeChumcha	L_Chumcha
			JusimdaeChumcha	J_L_Chumcha
			SlamidaeChumcha	P_L_Chumcha
Soro		ShSoroA	YangalSoro	SoroA
		ShSoroB	NegalSoro	SoroB
Jangyeo		ShJangyeoA	TeunJangyeo	T_Jangyeo
		ShJangyeoB	DanJangyeo	D_Jangyeo
Bo		ShBoA	TeuBo	T_Bo
Chobang		ShChobangA	Chobang	Chobang
		ShChobangB		
Dori		ShDoriA	JusimDori	J_Dori
			ChulmokDori	CH_Dori



(Figure 2-3,Figure 2-4: the shape-type list and the whole features of the structure, “The wooden construction data modeling of Korean traditional architecture, CAADRIA Conference”)

By the application of digital techniques in this manner, this study offered a new method to understand traditional architecture from the computational approach. The table of the shape-type list indicates the concept of the database for this building.

It needs to be emphasised that ancient Chinese wooden structure is quite similar to ancient Korean Wooden structure, with certain basic prefabricated structural elements which were assembled following some certain rules. The concept of using a shape-type list and structural features table that was outlined in this study explored a new and efficient way to understand, represent and reconstruct the complicated assembly of an ancient wooden structure.

2.3 Method Used for Digital modeling and representation of historic site

The modelling and representation of historic architecture is a complex process that involves many architectural and technical issues. Due to the particular circumstances, features and the simulation purposes of each individual case, there is not a methodology that has been commonly recognised. The following part is a review that focuses on the methodologies which have been applied in the digital modelling and representation of historic sites. Some useful knowledge and methods are derived for the modelling of the Foguang temple in this study.

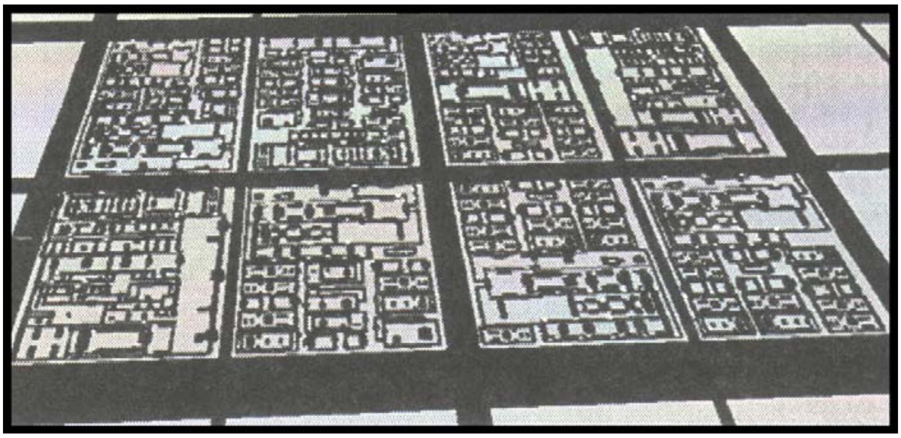
2.3.1 strategies and structures of modelling

One of the most critical issues for historic architecture modelling is how to organise and structure the information of the site, hence, to figure out the steps of modelling. This issue becomes increasingly important that most of the historic sites can only provide limited original information. In 1995, Singapore scholars completed a study on the use of computer simulation for medieval Chinese cities Chnag'an and Suzhou, two of the most important cities of the Tang and Song periods (Heng, 1995). The research was based on an ongoing project to reconstruct their cityscapes. It attempted to provide visual, formal and spatial information critical to the understanding of the development of these Chinese cities. During the research and simulation process of the Chang'an city, the researchers faced the following difficulties, which are common in historic architectural research:

- Accuracy: this involved the availability or lack of source materials. Information came not only from the pictorial and on-site, but also from textual sources.
- The reconstruction of the urban components: the architecture in the model needs to be like that of the Tang Dynasty. However, there was little information to rely on. Besides the existing Buddhist architecture, the study also consulted contemporary religious complexes in Korea and Japan.
- Determining the layout of the walled wards: the larger wards were divided into quarters and further subdivided into 16 smaller neighbours. Large religious compounds or even aristocratic residences in the wards disrupted this pattern.
- The precision of cities of the period: the simulation could not hope to recreate the city at any specific point in time, as there was not enough information. The attempt could only suggest a generic view of what the city could have been.

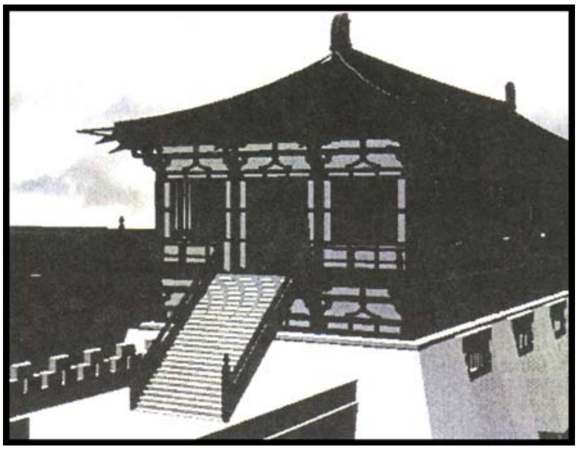
In the study, it was decided that the urban components were constructed at three levels:

- City level: simple mass models of individual urban structure were created and later combined to form wards (Figure 2-3)



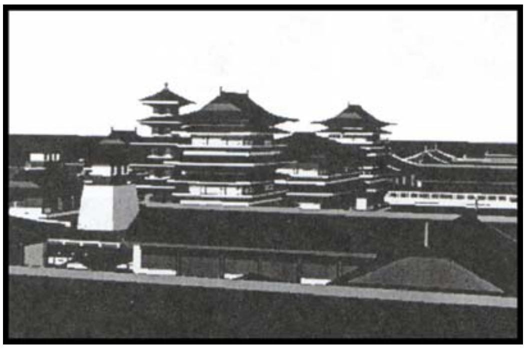
(Figure 2-5: City level, “Digital reconstruction of medieval Chinese cities, the global design studio, CADA”)

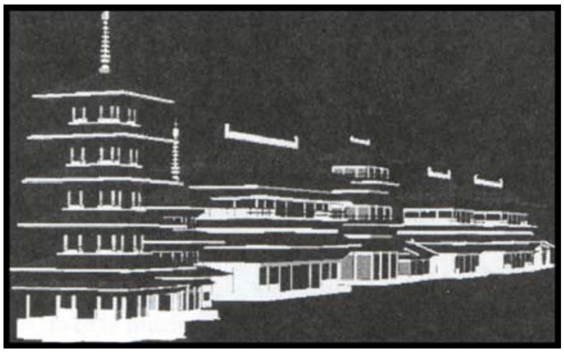
* Compound level: selected urban massing should be rendered in detail to show the buildings in the city (Figure 2-4).



(Figure 2-6: Compound level, “Digital reconstruction of medieval Chinese cities, the global design studio, CADA”)

* Ward level: they were constructed at an intermediate visualization quality between that of the city level and the compound level. For each building type, a wide range of variations was made (Figure 2-5, Figure 2-6).





(Figure 2-7, Figure 2-8: Ward level, “Digital reconstruction of medieval Chinese cities, The global design studio, CADA”)

From the above graphics, it is easy make a sense about the Chang’an city at that time. The study was a successful one, although the quality of the draft and the way of representation was still unrefined. The idea of subdivision, however, enhanced the legibility of the study.

A more recent study by Galli and Muhlhoff in 2000 developed this idea of disassembly. In their research, a number of digital models of famous architectures and designs were constructed (Figure 2-7, 2-8).

(Figure 2-9: digital model of “Artist’s holiday house on the lake”, designed by Terragni 1933, Galli & Muhlhoff, 2000)

(Figure 2-10: digital model of “Horticulturist’s house”, designed by Terragni 1935, Galli & Muhlhoff, 2000)

The methodology they used demonstrates a concept of strategic analysis of the historic architecture and modelling structure. They introduced the modelling process that:

"It is important to clarify the purpose of the analysis in order to define the most suitable hierarchical structure. Starting with the most basic primitive solids, the computerised models should allow the reconstruction of the project elements, the analysis of the material used and, most important, the attribution of a composition meaning to the elements. The structure of the model would therefore allow the identification of those elements (or group of elements) that fulfilled an important role in the composition…in the simplest situation, each element of the model is a reference to an initial cube, whose parameters have been set to give the right shape and size…the elements are referenced to a higher class in other objects, the key groups of the project. These are then referenced in the end model…"

(Galli & Muhlhoff, 2000)

The concepts outlined in the above studies provide an efficient way to understand and control the large quantity of information of historic sites. For the modelling of a complex historic building such as the Foguang temple, the idea of disassembly and representing the hierarchical structure seems to be extremely efficient and effective for the understanding and management of the complexities of structural features and relations. This structure allowed the model to be broken down with ease and material qualities could be attributed to the various parts.

The Foguang temple is in the format of a prefabricated wooden structure. Most of the structural components are prefabricated and then assembled to make the structural segments (group of components), then to make the whole structure. Some of the components are highly duplicated within the structure. The large variety of structure components and the complexity of the connection relations make the structure extremely difficult to understand and organise. The method of disassembly, hierarchical structure of information and modelling based on catalogue components outlined in the above studies offers a possible solution for this difficulty. This concept has been adopted for the understanding and structure of the construction information of the Foguang temple and for the modelling practice later in this thesis.

2.3.2 Representations associated with computer database

Methods of representation that have been used by researchers include animation, reconstruction simulation, and interactive effects. However, all focus on a visualisation effect approach. For complicated structures such as the wooden structure of the Foguang temple, the computer model is not only for visualisation purpose, but also for the demonstration of:

- The construction features,
- The connection relations of the structure,
- The detailed information of each component, and
- The hierarchical relations.

Digital model does not seem to be enough for all the above needs.

As introduced in section 2.2.3, in the modelling of the Korean traditional building, a shape-type list that contains structural features was employed to show the detailed properties of each components and their hierarchical position within this structure. This shape-type list can be regarded as a simple database for intensive representations. This idea of using a database to demonstrate the inside relations and regulated information for each component provides more availabilities for the representation of historic architecture.

The structure of the Foguang temple is even more complex than the Korean temple. It is hard to demonstrate the structure well and intensively solely based on the 3D model and computer simulations. For this purpose, the concepts of building a database associated with the digital model have been adapted to this study. More details about the possibilities and the methodology for doing this are explained in Chapter 3.

2.4 Digital Model for Chinese Historic Sites

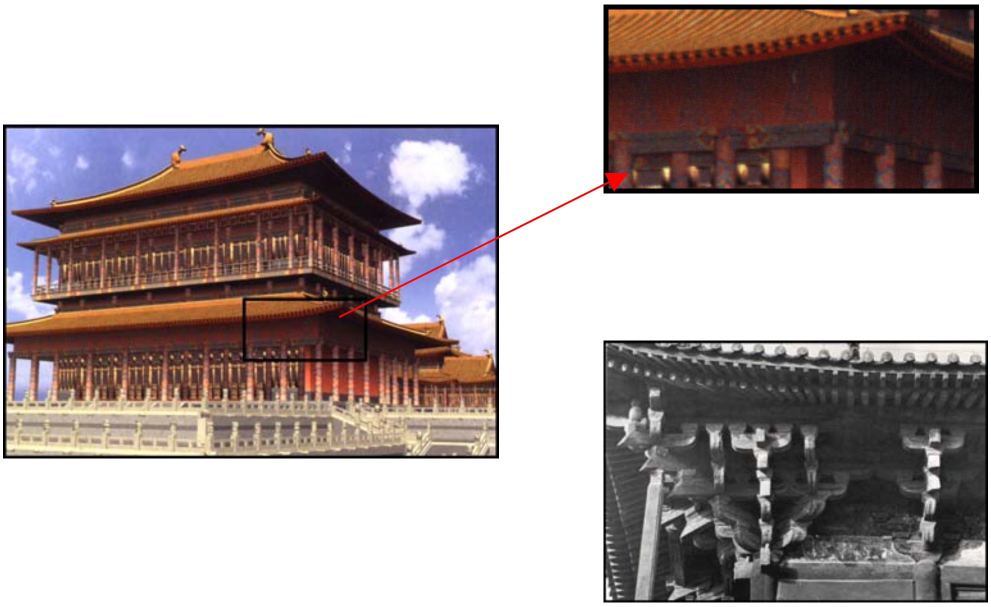
2.4.1 The limitation of current works of Ancient Chinese architecture

The use of digital techniques for ancient Chinese architecture research also has a long history dating back to the 1980's. In 1986, the Xerox Palo Alto Research Center explored a computer-based design environment that can represent process through an example of composing façades of Chinese temples.

In this study, "temple compositions are constructed by generating tessellated vocabulary elements, relating vocabulary elements in a topological mosaic, and integrating the mosaic into temple facades" (Makkuni, 1986). The research explored a fresh concept of how to apply digital techniques to the ancient Chinese architecture research; however, it was still an application at the two-dimension level.

Ever since, studies related to Chinese historic architecture have continued to evolve. A CAD-based software called CTA for the drawing of ancient Chinese architecture was developed in 2000 in the University of TianJin for architectural education purposes (Cong & Hongran, 2001). There has also been one book published on computerised modelling for ancient Chinese architecture: Tang Ren Jie Jing (Wang, 2002), which is a brief record of the digital modelling process of some Chinese traditional architectural elements. However, lack of academic discussions makes it just a reading for amateurs. In short, due to the complexity of ancient Chinese structural style and the shortage of construction data, few of these sources could serve as a basis for reliable and realistic visualizations; even collectively, they may not be sufficient to support further detailed studies.

There have been commendable attempts in computer modeling, simulation and animation of ancient Chinese buildings. In Novistski's (1998) collection of computer models, there was a Simulation of the lost Mongolian Palace (Figure 2-9).



(Figure 2-11: computer simulation of the Mongolian Palace comparing with the photo of ancient Chinese building)

It provides a sense of the building of the time. However, this does not provide enough information for clear architecture research. The timber structure of ancient Chinese buildings is one of the most important areas of research of architectural heritage. Here the example used only a mapping function for this structure without showing its three-dimensional details.

This is the common problem for ancient Chinese architecture modeling. This is due to the lack of information or lack of careful investigation of the structure. To avoid this and achieve a valid and reliable outcome, the modeling in this study has to be based on in-depth information collection and an intensive understanding of the wooden structure of the Foguang temple.

2.4.2 Appropriate situation for the modeling in this study

The problem of insufficient information is the common difficulty for historic architecture modeling. For the sites that have been destroyed, such as the case of the dwelling of the Keatley Creek site, the most acceptable way is to make hypotheses based on the existing references and to try to give the most reasonable solutions. However, the Foguang temple is a special case. The wooden structure still exists and is well preserved after more than one thousand years. It is the most valuable reference for the digital modeling process. But for some critical parts of the structure (the corner part of the eave bracket system), detailed visual investigations are required to ensure understanding of the structural details. That means the structure has to be disassembled. This seems impossible at the current situation since no one can ensure the structure can be reassembled back with the original components after being disassembled.

The modeling is therefore based on sufficient information for most of the structure and limited information for some certain parts. The challenge is that for visualization and research purposes, this digital model ought to present the real effect of the structure although it cannot be proven now, or at least the most reasonable and possible solution. The task is to facilitate the relations from known information to unknown information based on the construction knowledge and rules within the structure. No existing studies can be found to provide a guidance to deal with this issue. Therefore, an appropriate modeling framework has to be developed according to the particular circumstance of the Foguang temple.

Chapter 3 Research Methodology

The research described in this thesis has two aspects:

- A contribution to the research of ancient Chinese architecture;
- A demonstration of an approach to the computer modelling of ancient Chinese architecture where there is incomplete or incompatible information.

This chapter begins with a review of the methodology for interpretive historical research and how this work fits within the research of ancient Chinese architecture. It then discusses the possibility of making a computer database for Chinese historic architecture and the methodology for doing this. It finally describes the methodology for the computer modelling of the Foguang temple in the case study, and for the hypothesising of the parts of the structure where there is insufficient information.

3.1 Interpretive historic research and a case study approach

According to the definition given by Groat and Wang (2002),

"*interpretive research is the research activity of investigations into social-physical phenomena within complex contexts, with a view towards explaining those phenomena in narrative form and in a holistic fashion. The researchers attempt to collect as much evidence as possible concerning the complex phenomena and seek to provide an account of those phenomena. This requires searching for evidence, collecting and organizing that evidence, evaluating it, and constructing a narrative from the evidence that is holistic and believable…architectural history research is part of the larger domain of interpretive research. The emphasis for interpretive historical research is assessing evidence from the past. Tactically, it entails fact-finding, fact-evaluation, fact-organization and fact analysis. It entails an interpretive imagination that nevertheless does not spill over into fiction, but is rather guided by mind. It* *entails being aware of different kinds of judgments that can be made once enough evidence has been garnered. It entails the imaginative identification and use of specific tactics to access the object under study. During the process, a computer can be used as a tactical tool in interpretive research."*

The research of Chinese historic architecture, which has very limited sources of information, is an aspect of interpretive historic research. Led by the concept of the methodology of interpretive research, my research work described in this thesis is a case study which has to assemble all of the original and secondary information that is available and then interpret them into the making of the digital model of the Foguang temple. In the interpretation of the data, it is necessary to make hypotheses about the form of the structure that is based on the grammatical concepts of vocabulary and rules. The theory of shape and shape grammar provides a basis for identifying and understanding vocabulary and rules (Stiny, 1980).

3.2 A theoretical basis for digital modelling of historic architecture

3.2.1 The development of shape grammar theory

Shape grammars are a formal expression of a long tradition in Western art and architecture of seeking to understand underlying and recurring patterns of form and space, and means for the generation of desired forms and spaces.

Alberti made a significant contribution to this subject by separating the conceptual design of an object from its material expression. He called "design a firm and graceful pre-ordering of lines and angles, conceived in the mind, and contrived by an ingenious artist" (Alberti, 1955). Leonardo Da Vinci explored the configurational possibilities of central-plan churches, and in so doing he identified two broad equivalence classes – the cyclic and dihedral forms. In Germany Albrecht Dürer searched for the ideal human model, a "wire camera" that provided an objective description of a human face (Durer, 1528).

In the 19th Century there were more formal attempts to identify the grammar and language of design. In France, Viollet Le Duc in 1876 stated "The first condition of design is to know what we have to do; to know what we have to do is to have an idea; to express this idea we must have principles and forms; that is grammar and language"(Viollet, 1876). The German educationalist Friedrich Froebel took these ideas into the kindergarten by dealing with the arrangement of some comprised elemental building blocks. The notion of a fundamental cellule constituting a crystal had been formulated to describe many different crystalline forms. In France, Durand and his colleagues developed a systematic approach for architectural design teaching in the same elemental way as Froebel's. Frank Lloyd Wright in the 20th Century wrote that

"for each designer or architect, he must speak a kind of language in his design work. If he does not have one, he must adopt one" (Wright, 1954).

Under this statement, every building contains at least one language.

In England, four men represent different aspects of these activities:

- Jones, who completed his volume "the grammar of ornament" in 1856 which encourages designers to take Goethe's approach seriously: study the principles not the superficialities, and generate new original forms.
- Dresser, who was a designer and lecturer in botanical works, evolution and morphology,
- Semper, who wrote a major theoretical tract on design during his stay in London,
- And Babbage, who was working on the analytical engine – precursor of the modern computer.

At the turn of the century some of the most innovative artists, including: Frank Lloyd Wright, Kandinsky and Le Corbusier, spoke of grammar and language of design in their works. There were still a lot more thought and discussions by others at that time about the concept that design is a mode of computation, and that such computation explicitly exercises both imagination and reason (March & Stiny, 1985). Their efforts greatly contributed to the idea of the development and connections of spatial arrangement throughout the design process.

In the 1980s a powerful descriptive generative approach to shape and spatial system was developed in parallel with the introduction of computer aids in the design process (March & Stiny, 1985). George Stiny and his colleagues successfully built a formal, mathematical system and identified some spatial relations and generative approaches based on this arithmetic. Here shapes were defined as "spatial individuals made up of lines in two or three dimensions which are specified without reference to any definite scheme of decomposition". Their arithmetic involves:

"the sub-shape relation (<=) which partially orders shapes; three Boolean-like operations: shape union (+), shape intersection (.), and shape difference (-); and the similarity transformations. The operations and transformations are defined on the universe of shape U, which is the least set containing the empty shape and a single straight line that is closed under shape union and the transformations. Every shape in U except the empty shape has a proper sub-shape, and every shape in U is a proper sub-shape of another shape."

In other words, "simple shapes can be combined in arithmetic expressions to build up complicated shapes representing designs". Shape grammars are spatial generalisations of spatial systems. Each shape grammar determines a proper subset of the universe of shape U. The shape grammar formalism allows for algorithms to be defined in terms of parameterised shapes. Each such algorithm defines a language of shape (Stiny, 1980). As stated by Stiny and March (1985):

"Shape grammars are algorithms that perform arithmetic calculations with shapes. These calculations can be controlled to generate shapes with special structure and properties and thus allow for designs to be constructed according to definite compositional ideas".

This is the major content of the shape and shape grammar theory for design. Its terms are taken from natural language. Grammar governs the way in which words are modified and combined in human language to convey complex concept beyond the simplicities of individual words. For generative grammarians in linguistics, grammar refers to the entire system of structural relationships in a language, viewed as a set of rules for the generation of sentences. This term may also be used as metaphors in architectural design and study (Bruton & Radford, 2003). An artistic grammar may be regarded as a summary of an artist's current knowledge of the elements available to create artwork and of how to make appropriate use of them for that purpose (Bruton & Radford, 2003).

3.2.2 Shape grammar theory as an approach to study Chinese traditional structural

According to the shape grammar theory, a spatial relation is specified by a set of shapes in designs. And designs can be constructed according to spatial relations defined in a given vocabulary of shapes (March & Stiny, 1985). Shape grammars are used to define languages of designs in two ways:

- First, to create new designs: it begins with a limited number of compositional ideas (known as spatial relations) with a given vocabulary of shapes to examine the possibilities for constructing designs with these shapes according to the spatial relations.

- Second, to find the shape grammar: it begins with a limited number of existing designs in a given style, and proceeds to find a shape grammar that generates these designs and new ones in the same style. (March & Stiny, 1985)

In simple words, a shape grammar can be used to define new languages, but also can be used to define a language for known designs. Every design or design style can be represented by a shape grammar. As Stiny stated, "Architecture requires the delineation of one part of space from another. Such delineation, a configuration of lines, characterise shape. The organisation of a system of shape gives spaces an architecture" (Stiny, 1980).

This is one of the most valuable contributions of the theory. It offers a new approach for the understanding of existing buildings and designs. A number of designs have been reviewed from the shape grammar approach, include the prairie-style houses of Frank Lloyd Wright (by Koning & Eizenberg, 1981), Terragni (Flemming, 1981), Japanese tearoom plans (Knight, 1981), Mughul gardens (Stiny & Mitchell, 1980), Chinese lattice designs (Stiny, 1977), and Hepplewhite style chair-back designs (Knight, 1980). It can be seen that a study of shape and shape grammar is a useful approach to historic architectural research.

This approach has been conducted by Andrew I-Kang Li, who has been studying the language of Chinese traditional architecture of the 12th century since 1990s. Li based his research on *Yingzhao fashi*, the valuable ancient building standards of the wooden architecture of the Song Dynasty centuries late than the Foguang Temple. The aim was to: *"demonstrate how the parameters and their constraints are related. Here he* *undertook to characterise rigorously and in an unified way the language of design defined by the structure carpentry system of the Yingzhao fashi…"* (Li, 2001)

He has formulated a shape grammar for the generation of design in seven steps of sub-designs: *"stage A: plan diagram sub-design, B: section diagram sub-design, C: plan sub-design, D: partial elevation sub-design, E: roof section, F: section, & G: complete elevation sub-design"* (Li, 2001). Li demonstrated the feasibility using the shape grammar formalises as a way of expressing the vocabulary and rules of Chinese timber architecture.

With the introduction of computer aids in the design process, given a vocabulary of shapes and the spatial relations, the development and calculation of designs is possible based on computer models. On the other hand, it is also possible for computer techniques to be involved in the inverse way: in getting the spatial relations and vocabulary from the designs in order to understand the design concept.

Chinese traditional structural system was always under certain rules, grammars and languages, during thousand years of development. The study of Chinese architecture history largely involves the study of the traditional timber structural system. In addition, it should also investigate the design rules and language 'spoken' during different eras, to understand the development and evolution of Chinese traditional architecture.

For the application of the shape and shape grammar theory, the construction of Chinese traditional buildings is of a typical style. Rules, orders, grammars, and language can be seen throughout the structural system. Each ancient Chinese building has similar construction elements and is speaking a language of construction in a similar way to the others. There might be slight differences according to varying eras and physical conditions, but in general, the Chinese traditional structural system was strictly following some kind of construction rules. With the development of construction skills, the rules and orders were also amended accordingly. Verifying the evolution of the construction rules for the traditional structural system is the essential step for Chinese ancient architecture study. In this thesis the concepts of consistent vocabulary and rules that are found in shape grammar theory are used in the reconstruction of the form of the timber structure of the Foguang temple.

3.3 Methodology for reconstructing a digital model of the Foguang temple (main hall)

3.3.1 Data collection and validation

The validity and reliability of data and information are important factors for the success of academic research.

To ensure the accuracy of this research, there are two main ways for data collection:

On site investigation

In order to make sure the validity and reliability of the research, much preliminary data is required. On site investigation will focus on information about:

- The natural environment
- The artificial environment
- The structure and components (dimensions, joints and connections)
- The ornamentations (including materials & colours)

Methodologies applicable:

- Survey and measurement
- Photographic documentation

The objectives are to produce and work out the details of:

- The plan, partitions & columns

- The architrave girders, corbel brackets and tie beams
- The ceiling & roof

Documentation review

Available documentation is another important media in understanding the building. The following information is taken into consideration:

- Background
- Historic development
- Structural features
- Construction skills
- Original situation
- Analysis by others

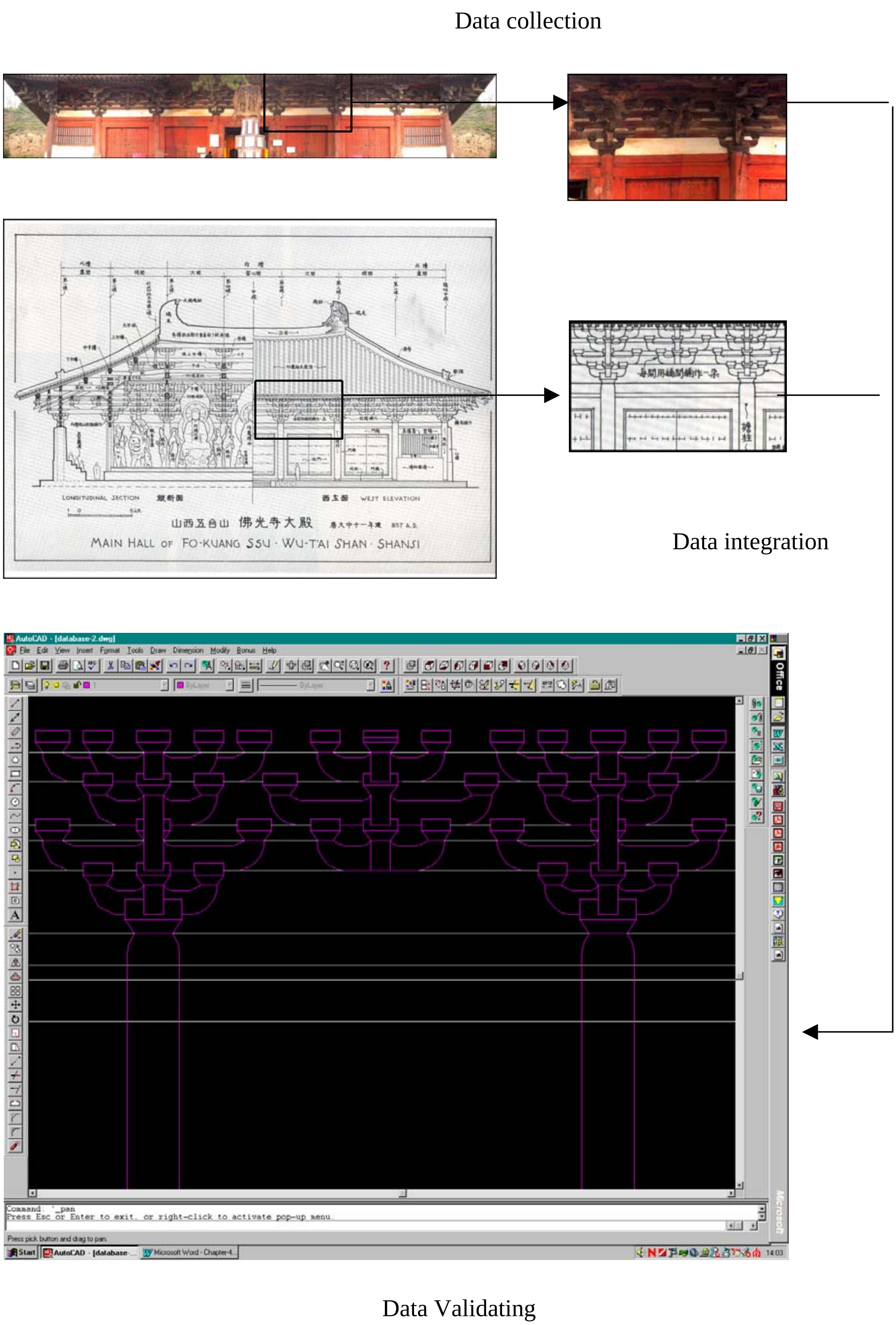
Sources:

- The survey drafts and drawings of the building
- *Yingzao Fashi* – the ancient building construction standard
- Documents about ancient Chinese wooden structure (related to the building)
- Documents about ancient Chinese Buddhist buildings
- Documents about ancient Chinese architecture
- Local literature of the building
- Government reports about the building

After the data collection process, it is an essential step to validate the data and information achieved. In this research, this step includes two parts:

- Data evaluation: selecting the valid relevant data from the sources of information.
- Data integration: integrate the first hand data from the on-site investigation and second hand data from the documentation review.

The following graph shows the basic idea of the methodologies at this stage:

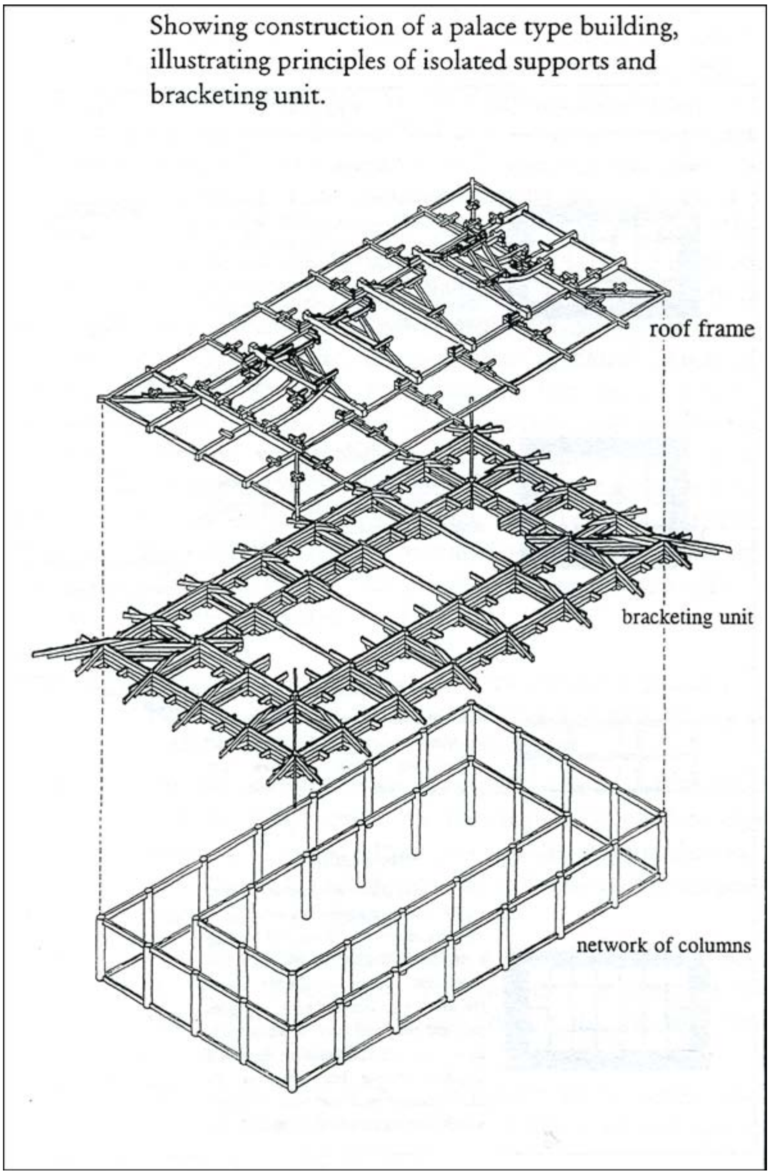


(Figure 3-1: methodologies for data validation)

3.3.2 A grammatical understanding of the Foguang temple

As Liang (1985) stated, the Chinese have always employed an indigenous system of construction that has retained its principal characteristics from prehistoric time to the present day. The basic characteristic of this system constitutes a raised platform, forming the base for a structure with timber post-and-lintel skeleton, which in turn supports a pitched roof with overhanging eaves. This is the basic construction rule for the structural system. More rules are specified to govern the module, connectivity, and assembling of components due to various conditions. Liang (1985) also pointed out, “The basic bracket set plays the leading role, a role so important that no study of Chinese architecture is feasible without a thorough understanding of this element, the governing feature of the Chinese order.”

As a traditional Chinese timber structure, the Foguang temple is a typical example with certain construction rules and vocabulary of components. This therefore supports the idea of interpreting the original and secondary data for the modeling of the structure. For a clear organization of the large quantity of information, the first step for making the digital model of the structure is to achieve a grammatical understanding of it. According to Guo’s study (Guo, 1999) the timber structure of the main hall of the Foguang temple is categorized into three basic groups of segments based on their structural functions and locations: network of columns, bracket system and the roof frame (Figure 3-2). In turn, each segment can be sub-divided into the basic structural elements.



(Figure 3-2: disassembling to structure to three segments, “Guo, 1999, The structure of Chinese timber architecture”)

The understanding of the timber structure of the Foguang temple includes the study of two aspects:

- Construction rules: which is the logic relations between each component and how they are assembled to make the structural segments, and how the segments are combined to make the whole structure.

- Vocabulary of components: the structure is made up of about 40 components with different structural functions and locations. The shapes and dimensions of these components are related following certain rules.

The basic methodology for making the model is to find out these grammatical rules of the structure, then build the model according to these rules. This process is detailed later in this thesis.

3.3.3 Build a database for the representation of the wooden structure of the Foguang temple

Although the idea of setting up databases for historic buildings sounds plausible, only a few attempts have been tried. Galli and Muhihoff (2000) showed that until then, historical research and architectural criticism had only occasionally used the possibilities offered by the digital techniques and the related organisational concepts. Computers had often been used in a way that was secondary to the aims of the research, being limited to the creation of simple databases or the presentation and diffusion of results. They argued that they should not merely be used as a means of producing images or storing data, but should act as the researchers' privileged partner, supporting the process of analysing, interpreting, understanding and illustrating the project studied.

Database for information management & representation

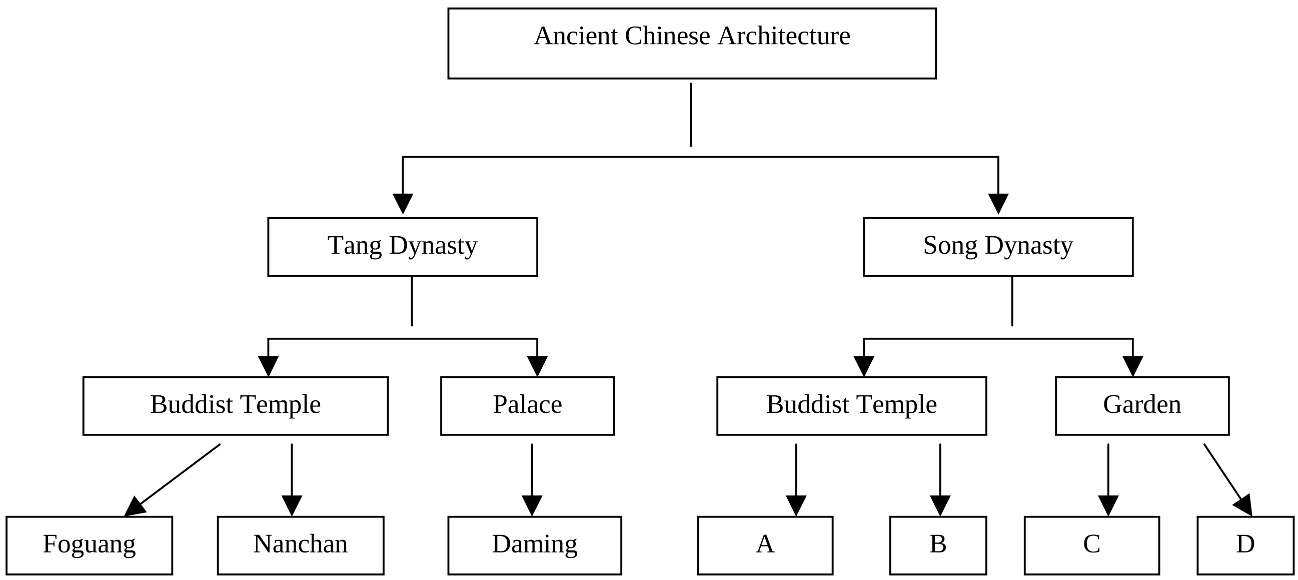
A database is a collection of data, which are shared and used for multiple purposes (Martin, 1981). The data are stored in such a way that they are independent of the programs that use them. The computer programs or software that create, manipulate, and use the database are called database management systems.

In terms of historic building research, a database can contain a mass of information related to a particular building. It is organised in a way to permit easy extraction and accessibility of data items. The database management system is a computer-based software set up to access, evaluate and analyse the database of the historic building. The organization of the data allows the logical association of one item of data to another item or to multiple items. Data structure has implications regarding the rules for data manipulation and stems from two sources:

- Structure that is inherent in the data itself and that expresses logical associations determined by the phenomena described,
- Structures of convenience, which arise by virtue of the tools used to express and store data.

  (Rumble & Hampel, 1984)

The following diagram shows a basic database structure (Figure 3-3):



(Figure 3-3: a basic database structure)

This is an example of a rigid structure. The following shows the tabular format in the placement of the data (Figure 3-4):

ID	Name	Architectural Style	Dynasty	Culture
01	Foguang	Buddhist Temple	Tang	Ancient Chinese
02	Nanchan	Buddhist Temple	Tang	Ancient Chinese
03	Daming	Palace	Tang	Ancient Chinese
04	A	Buddhist Temple	Song	Ancient Chinese
05	B	Buddhist Temple	Song	Ancient Chinese
06	C	Garden	Song	Ancient Chinese
07	D	Garden	Song	Ancient Chinese

(Figure 3-4: tabular format database)

Comparing the two diagrams here, we can easily find the logical association between the data fields. It is this logical association of the data structure that allows the efficient and accurate computational management of the database.

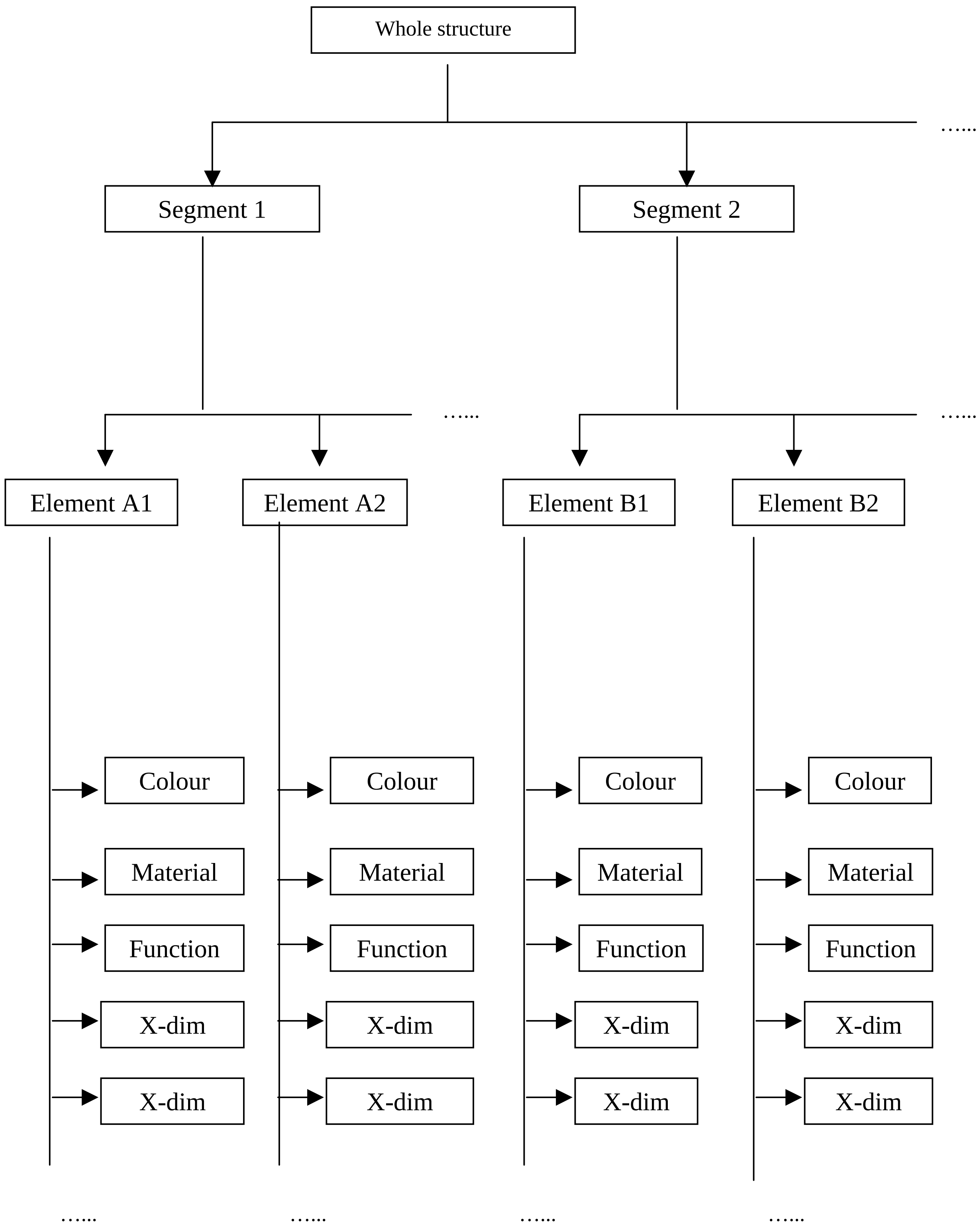
Database for the structure of The Foguang temple

Data processing of design project information differs from data processing for other applications. For instance, an automated billing system for a department store will contain a large volume of data, but all of it can be represented in a short list of accounting categories. Accounting data is predominantly number and titles: numbers are combined with rules defining how they are assembled into reports such as income statement, balance sheets, and invoices. Procedures used with this type of information are highly repetitive. The system may include thousands of account receivables, yet each one is entered, processed and output much like all the others. An architectural design project also includes a large volume of data. In contrast to accounting, it is distributed into a diverse array of data types, including numeric, text, and graphic. The variety, both of functions performed and of documents created is much broader than that required for accounting data (Schilling, 1987).

There are two basic requirements for the set up and management of a computer database for ancient Chinese architecture:

First, in the database, each data item has to be computer readable. Therefore, for the large quantity of graphic information of the historic building, they must first be converted to digital formats. Second, to achieve the effective and efficient working on the database, there must exist logical associations between these data items.

Ancient Chinese building is suitable for such digital representation. First, the entire available information about the building could be digitalised, even though the information covers a wide range, of graphic and text data. Secondly, there exists a logical association in ancient Chinese architecture in that the timber structure is assembly by a set of construction segments. Accordingly, each segments is made up of some certain elements. The elements are in standard size and shape, most of which are prefabricated. The connection of elements and components follows some construction rules. Therefore, all the data from the ancient Chinese buildings are related. Construction and connective rules link them together. The following example shows a simple database of the ancient Chinese building (figure 3-5).



(Figure 3-5: a database structure for ancient Chinese buildings)

Computers offer an easy method for managing large quantities of data of ancient buildings, which can be modified infinitely. The digital database will contain all the valid data that are derived from the modelling process. The database will include information on the shape and size of each element, the connection language of different structural segments, the material and colours. Such an information database is also necessary to facilitate further studies and researches of ancient building. The automation allows efficient and effective management of information by enabling the quick search and review of database.

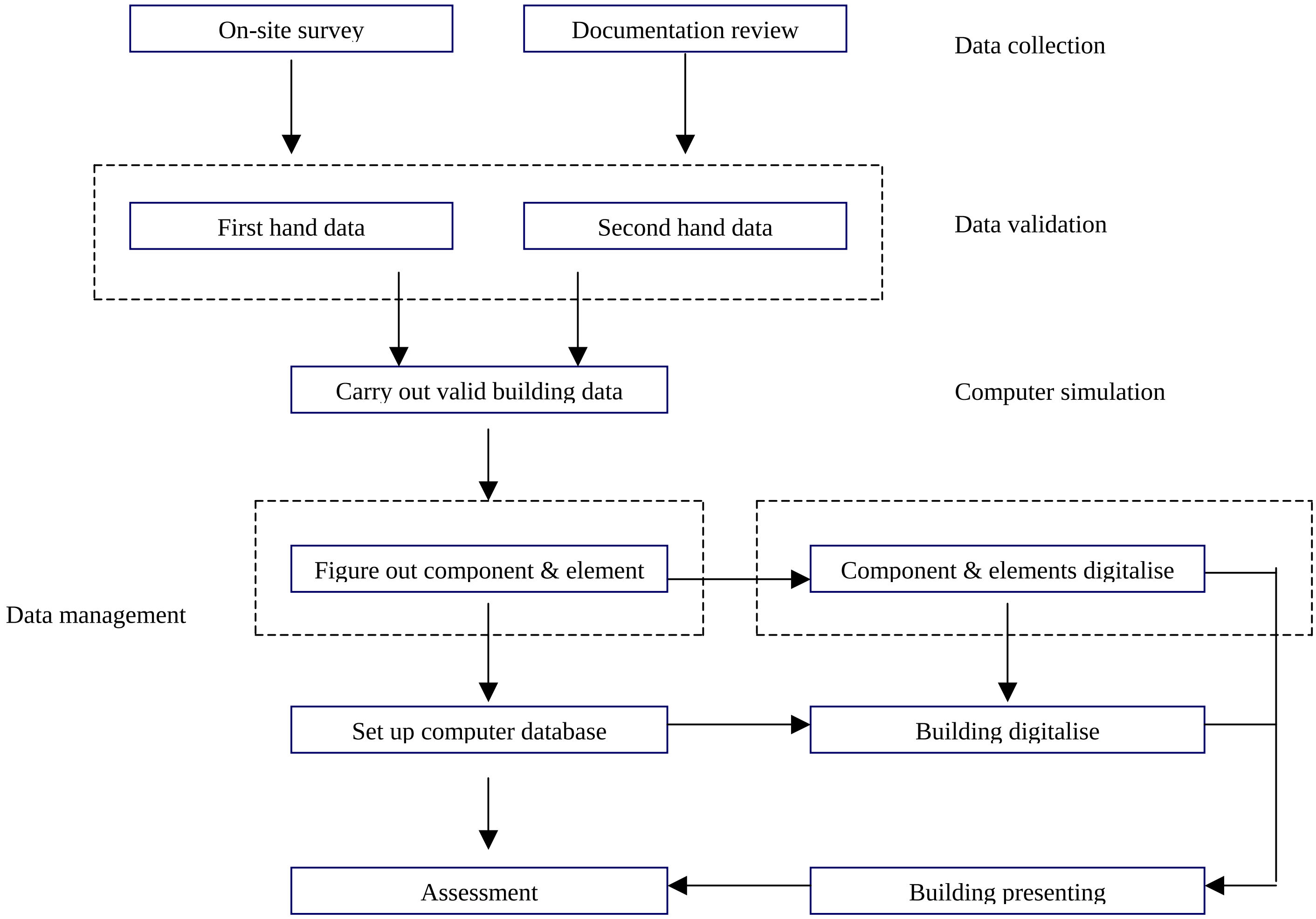
In this study, the database is based on a tabular component vocabulary which contains all the detailed information of each component in terms of spatial data and structural properties. For each component, there is a sub form describing its features with images providing a detailed visualization. The data offered in the database is a summary of the information of each structural component that is derived during the modeling process. It is an alternative valuable source of information that is easy to manage, organize and develop.

It is important that the database be open for review, revision and further development by others. Therefore, other scholars can add their research findings to it and the database will continue to grow.

The information may start only with the data from one single building of a certain period in Chinese history. With other research works on ancient Chinese architecture added to the database, the database will develop and be revised constantly. It can be grown to contain the data of hundreds of ancient buildings in different architectural styles of various time periods. It is hoped the database would one day become an efficient information resource of ancient Chinese architecture for people working on their researches.

3.3.4 The methodology framework for the practical process of modelling

The following is a chart of the framework carried out for this research:



(Figure 3-6: the implementation framework)

Based on the theoretical model mentioned above, the following section explains the implementation process in more detail:

1. Studying the building based on the information at hand

Making sense of the basic logic of the timber structure system based on the previous researches, structural drafts and the photos. Carrying out a brief structural model, to identify:

- The basic components that make up the structure as well as their structural functions

- The relationships between each segment
- The structural components that make up each segment
- The connectivity between each component.

2. Carrying out the basic shapes and rules by considering the related grammar book of system construction

As introduced in early chapters, there were two official books left about the construction rules of Chinese traditional timber structure: Yingzao Fasi of Song dynasty and Gongbu Gongcheng Zheli of Qing dynasty "two grammar books from two epochs of great building activities" (Liang, 1984). This study will take the Yingzao Fasi as the main reference since the structural features of the Foguang temple, which was built in the Tang dynasty, are more related to those of the Song style. It will review the construction rules and grammars mainly from the aspects of modules, bracket sets, beams, columns, and the roof style.

3. Testing and revising these shapes and rules

For each construction rule and shape, which has been adapted from the references, it will be tested whether it still works in the Foguang Temple by fitting it back to the computer model; this spells out by what standards or levels do the rules or shapes fit the structure.

4. Computer modelling of the building based on these shapes and rules

'Architecture Desktop' will be the application software for the computer modelling process. To make the modelling process applicable and clear, the construction structure is disassembled digitally. The modelling process follows a procedure of constructing the basic elements to build the segments, which are then assembled to create the whole structure. The shapes and connection rules will be tested during this process.

5. Reviewing the model

After the model has been reconstructed, it has to be reviewed in several ways:

- By comparing it to the physical reality
- By verifying the interior relations and connectivity
- By comparing the structural rules of the model to the rules from other references.

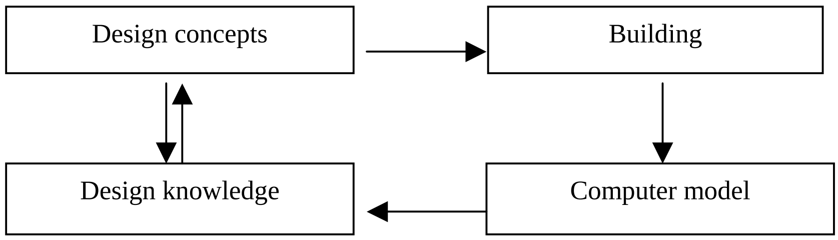
3.4 Methodology for dealing with contingencies and insufficient information

3.4.1 The concept of an "ideal model"

The grammars and language within the temple is the key, which will lead us to the ideal model. It needs to be clarified that there could and would be differences between the model and the real structure. In 'real' building it is impossible to follow the rules exactly due to unforeseen contingencies during the implementation process.. The modelling process needs to follow the rules rather than the fact. However, rules are rarely fixed and definitive (Bruton & Radford, 2003). Therefore, information analysis, rules summarizing and rules testing made up of the central part to carry out the shapes and grammars. Reviewing and revising ought to be carried out during the whole modelling process.

In this research the Foguang Temple is chosen as a case study subject to assess the relationship between computer and ancient Chinese architecture research. Like others, it could be seen as a record or collection of the ideas of the designer or architect. However, it is a challenge for researchers to derive the design concept and development process from it.

The idea is to initially build up a computational model of the building, which contains as much construction details as the original one, while at the same time, not seeking to represent the discrepancies caused by contingency factors during construction. In this study, the computer model is not a representation of the now existing temple, but a model of what it 'ought' to be like - the 'ideal model'. It is based on the physical reality, has all the reasonable factors and terms, and discards the occasional inaccuracy. The following diagram shows the main idea of the modelling process (Figure 3-7):



(Figure 3-7: idea of the modelling process)

Mitchell (1990) stated "Once we have established the space, shapes, primitive, properties, functions, and relations that will concern us in a world, we can go a step further and axiomatic that world. That is, we can state necessary relationship between shapes that exists within it". The simulation purpose of this research is to build such a world, in digital format.

3.4.2 The concept of minimal adaptation

The hardest challenge for modelling is the simulation of the 'unknown' part. For the Foguang Temple this is the bracket and purlin system on the corner column which is not shown in drawings or visible on site. The means of modelling this part is by making hypotheses. Here, a hypothesis is achieved by dealing with the factual data (information sources) and theory (grammars and rules). From a research approach, the factual data are derived from the physical reality; the theory is a conceptual framework that explains existing observations and predicts new ones; a hypothesis is a working assumption. Typically, researchers devise a hypothesis and then test it against available data obtained from previous experiment and observations (the facts).

A number of hypotheses will be made based on the current shapes and rules. Probably, there will be more than one hypothesis that fit the situation, whereas the solution should ideally be singular. In order to choose among these possible hypotheses, a very useful principle called Ockham's razor has to come into use.

Ockham's Razor is the principle proposed by William of Ockham in the fourteenth century: “Pluralitas non est ponenda sine neccesitate", which translates as “entities should not be multiplied unnecessarily".

In this case it indicates that the simplest hypothesis is likely to be the most correct one.

Led by this idea, the following procedures are designed to deal with the task:

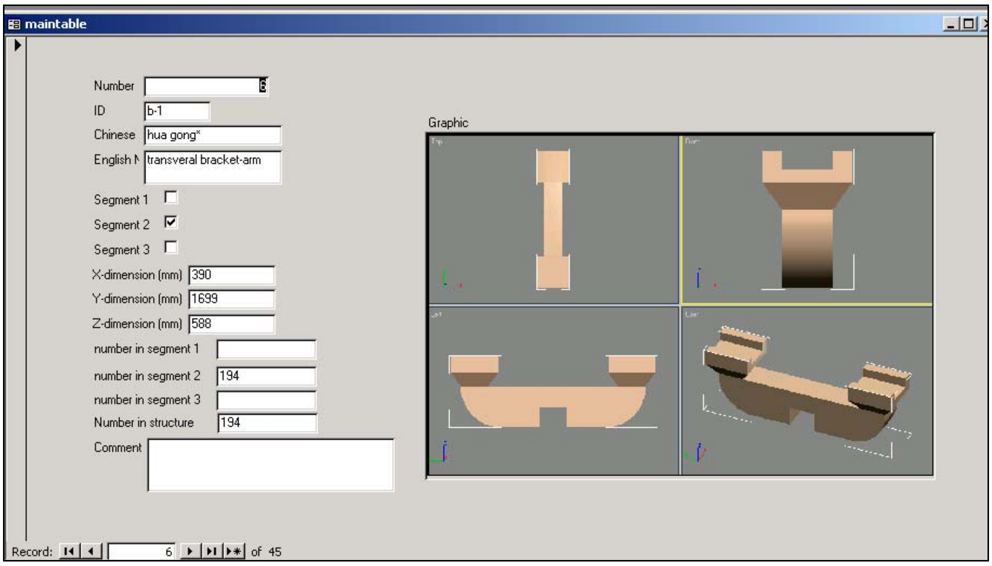
1. Look for existing vocabulary elements and rules that will fit in the situation.
2. If none is available, make a hypothesis of the vocabulary elements and the rules that are closest fitting.
3. If still not available, modify the hypothesis in the minimal way and test until it works.
4. Add the modified shapes (vocabulary elements) and modified rules to the grammar for possible further use and modification.
5. Test the result as the modelling process goes.
6. If it does not seems to be reasonable, start from the second closest possible hypothesis, and go through the procedure again until the ‘right’ one is found.

3.5 Methodologies for representation

3.5.1 Representing the database

A series of database forms will be employed to represent the structural database of the building. The representation will focus on the following points:

- The physical constitution of each element: shape, dimension, material
- The structural functions and connections for each element
- The hierarchical relations of the elements



(Figure 3-8: the computer layout of the database on single element)

3.5.2 Representing the building

The representation of the building will be recorded on a CD. The methodology for the representation of the building will be applied in an object-oriented way. The production CD needs to contain the following subjects and processing upon request:

- An auto-run starting (research background, target, terms of period….)
- Introduction of the research and objectives
- Animations of the building (with various views and conditions)

- Animations of each segments depicting their functions & positions
- Animations of the elements for each segment showing their connections and properties, which link to the database of the elements
- Assessment of the simulation by comparing it to the original documentations