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ICA^{3}D – Intelligent computer-aided ancient Chinese architecture design

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ABSTRACT

Ancient Chinese architecture represents a unique contribution to the world's architectural heritage. However, there has been a serious lack of computer supported tools for representing, modeling and designing different forms of ancient Chinese buildings. We present ICA^{3}D, an intelligent computer-aided system for designing ancient Chinese-style architecture. With ICA^{3}D, the user has multiple choices of interaction from interactive menus to Chinese natural language description. The Semantic Web technologies are used to represent the domain knowledge including complex rules for composing complete timber structures from individual pieces of wood and rules for inferring construction sequences. Compared with other CAD technologies, the approaches presented in this paper feature a combination of user interaction and automation, a text-to-scene pipeline, and a scalable knowledge infrastructure supported by automated reasoning.

1. Introduction

Ancient Chinese architecture [1] represents a unique contribution to the world's architectural heritage, with respect to both technology and art. The complex of ancient Chinese architecture is a grand system incorporating politics, religion, art, culture, techniques, and craftsmanship. It is one of the three major schools of world architectural systems, while the other two being European and Islamic architecture. The uniqueness of ancient Chinese architecture lies in its wooden structures. The number of Chinese buildings with a history of more than 300 years that are worth of protection has amounted to 80,000. Among them, about 2500 have been declared by the Chinese government as national historical relics.

In spite of the great efforts in preserving the ancient architectures and techniques, more and more ancient buildings were damaged or even destroyed either by natural forces such as lightning strikes, fires, and floods, or due to human factors such as city construction and water reservoir building [2]. The protection of ancient architecture, including its theory, arts and techniques, has become an urgent task, of which digitization is imperative [3]. Nevertheless, there has been a serious lack of computer supported tools for representing, modeling and designing different forms of ancient Chinese buildings. It was with this background that the Chinese Ministry of Science and Technology initiated in 2006 a project called "Study on the virtual restoration and Web representation techniques of ancient architectures". Our research team was responsible for one of its subprojects called "computer assisted ancient architecture animation generation system based on semantic understanding". Here, 'semantic understanding' means the system to be built should be able to understand the semantics of the user's natural language input in terms of the type and scale of the desired building and to further show its construction process. This was the background that we proposed and developed ICA^{3}D, an intelligent computer-aided ancient Chinese architecture design system. Currently ICA^{3}D can support the design work of more than 180 different ancient Chinese architectures ranging from wooden structures, pagodas, Dougong [4] to joinery [5].

Our motivation is to provide an intelligent platform for computer-aided ancient architecture design. With the rapid development of China's economy, more and more attention of the country has been directed to the cultural aspects. The purpose is not only to conserve, but also to make use of the ancient heritage of construction techniques and arts. Many historically prominent but already destroyed ancient Chinese buildings are being reconstructed. At the same time, the design of modern buildings often learns from the structures and properties of ancient architecture. Architects in China have an urgent need of using computer-aided systems when designing ancient style buildings. Another motivation is to make the national historical relics at different locations accessible to a wide public when on-site visits are not available, or when the relics are not reconstructed yet and memories about them remain solely in ancient books and legends. Virtual museums are in demand for demonstrating ancient Chinese architecture.

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Using software to assist various phases in architecture-related tasks for both virtual and real-world buildings has always been one of the main application research topics in computer science and artificial intelligence (AI). Computer-aided design (CAD) technologies in architecture are the most important and fruitful, and there are many successful commercial CAD software in use. Early CAD systems focused on two-dimensional drawings of the building, while nowadays systems turn to support three-dimensional (3D) modeling and further include other aspects in engineering and construction such as time and cost. ICA^{3}D follows the CAD paradigm and in the meantime provides as much automation as possible. With this goal in mind, this paper presents an approach for supporting user interaction as well as automated generation in a uniform way for Chinese architecture design so that whenever possible or needed, automation is provided to complement or alleviate the manual efforts. Automation forms a pipeline that starts from a Chinese natural language description of the building required and eventually demonstrates a 3D animation of how the building is constructed piece by piece of wood. The steps in this text-to-scene conversion process include natural language processing, information retrieval, reasoning of components needed, computation of 3D size and position of every single component, reasoning of construction sequence, specification of animation scenes, and lastly video generation. This whole workflow is supported by knowledge bases implemented by the modern Semantic Web technologies including ontology and rules and their respective inference engines. The approaches that ICA^{3}D adopts can be applicable to other intelligent architectural design systems that pursue user friendliness and knowledge sharing and reuse.

The main contributions of this paper can be summarized as follows.

- A text-to-scene pipeline approach is proposed that supports both user interaction and automated generation for architectural design. Chinese natural language interface is provided for the user to describe the requirements for the building he/she wants, in addition to ordinary CAD user interaction functions.
- A knowledge-based approach is proposed that incorporates the Semantic Web technologies to explicitly represent the domain knowledge and reason about ancient Chinese architecture. Complex rules are devised for composing complete timber structures from individual pieces of wood and for inferring construction sequences.
- 3D animations are generated in addition to static 3D models to demonstrate the construction sequence and structure of the building the user wants. Explicit animation descriptions are generated in qualitative and then quantitative specification, and both video rendering and virtual reality preview are supported.

The paper is organized as follows. Section 2 describes the main phases in designing ancient Chinese buildings by ICA^{3}D. The infrastructure of ICA^{3}D and its every component are presented in detail in Section 3 including the model base, rule base and data base. Section 4 presents the workflow of ICA^{3}D, both interactive and automated, and the Semantic Web implementation considerations. Some resulting animations are shown to demonstrate the effectiveness of the system. Section 5 surveys related work in three directions, systems for Chinese traditional buildings, ontology-based approaches used in architectural domain, and the Building Information Modeling (BIM) [19] which is the standard technology for state-of-the-art architectural industry. More importantly, a comparison is conducted in order to provide a clear picture of what ICA^{3}D has in common with the related systems and how they can complement with each other. Lastly, Section 6 concludes the paper in summarizing the features and future work.

2. The design phases by ICA^{3}D

The very first official architectural law released by the ancient Chinese governments is called *Yingzao Fashi* [9] (treatise on building standards) published in the Song Dynasty in the year of 1103. ICA^{3}D is devised to support the design and development of ancient Chinese-style architecture based on *Yingzao Fashi*. The whole design process is divided into five main phases, the general requirement, structures, detailed 2D designs, component designs, and decorations.

The first phase is for the requirement specification. The following decisions have to be made at this phase: for what purpose is the architecture? Is it an independent building of full ancient flavor? Or is it just an ancient flavor architectural decoration for a modern building? Is it a real building to be built and used? Or is it just a virtual building to be displayed as part of a virtual museum? What social level it serves? Is it a palace, temple, or pagoda?

The second phase explores the structure of the architecture. The user needs to determine the extension and timber structure of the building, e.g., for the case of the temple and palace, whether the building is of *Yingshan*, *Xuanshan*, *Wudian*, *Xieshan* or tented type [6], as shown in Fig. 1. The most basic type of ancient Chinese building is *Yingshan*, which consists of two slopes and only one ridge on the top, middle of the roof, as shown in Fig. 1a. The structure of *Xuanshan* is basically the same as *Yingshan*, while the major difference is that *Xuanshan*'s eaves extend over the gable while *Yingshan* has its eaves match the gable vertically. *Wudian* structure is of the highest rank in ancient China and can only be used in imperial palaces and temples. The roof of *Wudian* buildings has four slopes rather than two, and five ridges rather than only one compared to simpler types of architecture such as *Yingshan* and *Xuanshan*. *Xieshan* is a beautiful composition with a *Yingshan* 'sitting' on a *Wudian* roof. For all of these types of timber structures, the user needs to specify the number of rooms from left to right and the number of purlins from front to rear. A further decision to be made is whether there is a veranda around the outer walls. Moreover, the user can describe whether he/she wants to have double eaves or just single ones. Double eaves are available only for *Wudian* and *Xieshan* buildings, as illustrated in Fig. 1e. There are also tented structured Chinese buildings, as shown in Fig. 1f, where the roof is cone shaped without any ridges.

The third phase focuses on the 2D blueprints of the building including planar, look-up view, sectional and elevation designs. A planar design provides the network of columns where the position of various kinds of columns and the distance among them are decided, as well as the walls and division of the building. Having a veranda would add more columns. The elevation designs specify the vertical values of the components. For columns, the proportion of their height to diameter varies with the time, and in ICA^{3}D a ration of 9:1 is adopted as in the Song Dynasty. Moreover, the proportion of width to height for a 3-section building is 1:1, and 3:1 for a 9-section building. Such regulations are incorporated by ICA^{3}D in helping the user going through the whole design process. Roof design is of the most complexity and its crucial points are the slope and curve form. Both depend on the proportion of height difference to width difference of two neighboring planar layers one above another. The larger this proportion, the steeper the curve of the roof is. In order to build a beautiful and reasonable roof curve, the rule is to take smaller proportion values near the eaves and to increase this value gradually from eaves to ridges. ICA^{3}D takes the proportion value of 0.35 as minimum and 0.9 as maximum.