AN ASSEMBLY GUIDANCE SYSTEM OF TOU KUNG BASED ON AUGMENTED REALITY

ZI-RU CHEN¹, CHIEN-JUNG LIAO² and CHIH-HSING CHU³
¹Southern Taiwan University of Science and Technology
²zrchen@stust.edu.tw
³National Tsing Hua University
²s105034562@m105.nthu.edu.tw ³chchu@ie.nthu.edu.tw

Abstract. Tou kung represent Chinese architecture. Due to the difficulty of learning from ancient books, some develop 3D assembly models. Still, there are limits while using 2D images for assembly instructions. The purpose of this study is to explore whether the application of AR technology can guide the process of tou kung assembly and address the recognition gap between paper illustrations and the physical assembly process. The method is to observes the user’s tou kung assembly behavior and performance. Then the study proposed an dynamic simulation AR guidance system to help people not only understand the structure, but also the culture behind to reach the goal of education promotion.

Keywords. Augmented Reality; Tou-Kung; assembly.

1. Introduction

1.1. IMPORTANCE OF TOU KUNG IN CHINESE ARCHITECTURE

Architecture is the largest, the most complex, and the most durable among human creations. Understanding an architectural structural system reveals its ethnic culture and art, and reflects the social life and scientific developments of that time. It records the living track of different regions and ethnic groups, thus, creating a live history reference book. “Tou kung” plays a decisive role in the Chinese architectural development process, and is one of the most notable features of Chinese architecture. The “tou kung” structure is the key characteristic in the structural determination method and development of Chinese architecture. It is an important feature of the “pillar” of Chinese architecture, and a unit of measure for the overall building volume (Liang 2011). As the foundation of Chinese architectural formal grammar, “tou kung” represents the oriental tectonic cultural characteristics, and tells of a system of tectonics different from the Western system. Therefore, tou kung can offer an insight into the life values and science history of Oriental nations.

Tou kung consists of a series of basic bracket sets placed on pillar tops, which support the wooden beams internally and the eaves externally. It is an object that buffers shear forces in the building structure (Liang 2012). Although the
standard of the tou kung structure was formalized after the completion of the book, Creation Grammar, by Li Jie in the Song Dynasty, the actual form and proportion of tou kung are quite varied. However, in practice, varied results can be produced in response to the overall building form. Therefore, through analysis of tou kung, we can understand the relationship among ancient Chinese building materials, structures, and external forms, and gain insight into the development of engineering and technology at that time.

However, as Chinese architecture is dominated by wood structures, and such architectural entities are easily damaged by nature and humans, there are fewer and fewer opportunities for actually observing, manually practicing, and deconstructing the tou kung structure. In addition, changes in the application of contemporary building materials renders the Western architectural style the mainstream of current architectural design teaching materials, thus, relevant research and historical data are very limited. As it is very difficult to understand the complex structural styles and other factors simply by 2D drawings, it sets a high threshold for the assembly learning of tou kung, and increases the difficulty of promoting oriental architectural culture, thus, it is necessary to propose a guiding method for the general public to understand tou kung.

1.2. RESEARCHES OF AUGMENTED REALITY ON MODEL ASSEMBLY

Augmented reality (AR) is a technology that combines the real world with virtual spaces, which enable them to interact through a camera’s location and image analysis algorithms, thus, providing users with different personal experiences. In the area of learning experience, AR can be applied to the tourism guides of monuments and temples, thus, improving learners’ sense of participation (Wang 2010). In addition, AR can be combined with three-dimensional puzzle teaching aids to enhance learning motivation (Le 2015), which shows that AR is helpful for learning. In the area of assembly guidance, an AR identification function can provide more detailed information regarding parts, enhance the sense of user space, and guide the assembly process. Compared with the traditional manual, the application of AR technology takes significantly less time to complete the assembly work, which demonstrates the AR system effectively helps users in assembly and enhances user satisfaction (Wu 2012). Therefore, if AR technology is used to guide the assembly learning of the tou kung model, there may be an opportunity for more people to recognize the complicated structure of tou kung to understand the beauty of Chinese architecture, and to realize the purpose of promoting culture and education.

In the interface design of AR assembly guidance, Renner and Pfeiffer (2017) explored the impact of different assembly instructions on assembly time, as shown in Figure 1a. The experimental results show that displaying both the leader and the part on a screen is better, presumably because they are more intuitive and the instructions still exist when the screen does not detect an object, thus, improving the assembly experience. The interface, as developed by Hahn et al. (2015), can provide assembly location information and display a progress bar at the top of the screen to let users know the current assembly progress. See Figure 1b. In addition, a study by Woodward et al. (2008) proposed increasing the users’ awareness of the
assembly instructions and the actual assembly object by combining the assembly instruction animation with the actual object. See Figure 1c.

Falck et al. (2017) allows users to wear AR glasses to view a recognition card, which shows the instruction buttons of the previous step and the next step to help the users complete the model assembly, as shown in Figure 1d. However, when compared with paper and video teaching, the teaching mode that requires the least time is the video teaching method, presumably because real human operation in the video makes it easier for the user to comprehend. Syberfeldt et al. (2015) proposed a process design for a 3D puzzle assembly. The system directly marked the parts required by the user in obvious colors. It also displayed the 3D assembly model at a specific location, as shown in Figure 1e. However, the experimental results also mentioned that the assembly time was not reduced, as users were unfamiliar with the system. The above studies are all examples of various assembly tasks combined with AR systems, demonstrating the feasibility of augmented reality technology for various assembly requirements; however, there is still room for improvement in the process and interface designs.

2. Problem and objective

As tou kung is a complex architectural object, although the Creation Grammar of the Song Dynasty interprets tou kung with a lot of writings and provides a large number of drawings, it is knowledge that is difficult for most people to read, thus, the tou kung structure must be explored through the actual assembly and implementation of the physical tou kung model. However, it is difficult to actually learn the structural system of a tou kung structure and its cultural meaning only through the assembly of the physical model. In addition, it is difficult for traditional paper-based illustrations to completely present complicated 3D shapes and structures, thus, it is necessary to provide a 3D interactive assembly interpretation system. Therefore, the purpose of this study is to explore whether the application of AR technology can guide the process of tou kung assembly and address the recognition gap between paper illustrations and the physical assembly process, as well as provide a better assembly learning experience, thus, achieving the purpose of knowledge inheritance.
3. Methodology and steps

The design of this research method first observes the user’s tou kung assembly behavior and their tou kung learning performance during the process, which can be used as reference for AR assembly guidance design. Next, a design for augmented reality assembly guidance is proposed in an attempt to address the assembly problems encountered during the assembly process of a physical tou kung model, facilitate assembly of the tou kung assembly process with the help of AR assembly guidance, and provide insight into the constitution principle.

3.1. SELECTION OF TOU KUNG ASSEMBLY PATTERNS

There are only two works about architecture in ancient Chinese books, one is the Creation Grammar, an architectural guidebook from the Song Dynasty, and the other is the Engineering Practice Cases of Qing Ministry of Works, an architectural regulation handbook from the Qing Dynasty. It can be observed that with the change of the times, the tou kung style developed from the early macro structure with a load-bearing function to a reduced volume with only decorative function in the Qing Dynasty (Liang 2016). Considering that the authors hope to use the AR system to explain the complex relationship of tou kung structure, the tou kung style exemplified in this study is mainly Song-styled tou kung, and a set of “five-story insertion” tou kung style of moderate difficulty is selected as an example, as shown in Figure 2.

![Figure 2. Left and middle: “Five-story insertion” tou kung in ancient books; Right: Model of “five-story insertion” tou kung.](image)

3.2. STAGE 1: PRE-TEST EXPERIMENT OF USER TOU KUNG ASSEMBLY

3.2.1. Step 1: selection of subjects

Five subjects were invited to assemble a set of “five-story insertion” tou kung model, and the subjects selected in the experiment were students, aged between 20 and 24 years, from polytechnic universities, who have basic assembly experience, such as furniture and Lego. However, none of them have ever come into contact with the tou kung model. The purpose of this experiment is to understand whether subjects with basic assembly experience can use their past experience to assemble a set of five-story tou kung model. If they can, which assembly experience and behaviors were used? If they cannot, what was the biggest assembly difficulty in the tou kung assembly process?
3.2.2. Step 2: manufacture of paper assembly manual for the “five-story insertion” tou kung model

According to Fan (2010), a few design principles for an assembly manual have been referred to, including that illustrations must fully express the steps and sequence. Icons should be used to depict the actions, arrows and dotted lines should be used to guide the assembly position, the model perspective should not be changed arbitrarily during the assembly display, etc. In this experiment, the assembly process of a “five-story insertion” tou kung model was divided into five stages, 4 to 7 components (object) must be assembled in each stage, and a common explosion diagram was used to display the assembly sequence. Refer to Figure 3 for the assembly drawing.

![Figure 3. Designed paper instructions.](image)

3.2.3. Step 3: planning of the assembly experiment process

The experiment process has three parts, as shown in Figure 4. The entire experiment took about 1 hour.

![Figure 4. Experiment process.](image)

3.3. STAGE 2: DESIGN OF AR ASSEMBLY GUIDANCE SYSTEM

Stage 2 is to develop and implement the AR assembly learning system. First, the pre-test observations of the user assembly behavior and the limitations of the paper manual served as the basis for the development and implementation of the AR assembly learning system. After that, with reference to the AR application in the assembly during previous studies, four kinds of AR assembly guidance methods were summarized, as shown in Table 1. Based on the above, the visual demonstration and interface design of tou kung information on the AR application were planned as the learning mechanism for guiding the users in tou kung assembly.
Table 1. Summarized of AR assembly guidance methods.

<table>
<thead>
<tr>
<th>No.</th>
<th>Reference</th>
<th>AR function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Renner and Pfeiffer, 2017</td>
<td>Interactive 3D model display</td>
</tr>
<tr>
<td>2</td>
<td>Renner and Pfeiffer, 2017; Schubert et al., 2015</td>
<td>Component identification and guidance feedback</td>
</tr>
<tr>
<td>3</td>
<td>Ludwig, and Wolf2013: Fulick et al., 2017</td>
<td>Interactive 3D model display</td>
</tr>
<tr>
<td>4</td>
<td>Woodward et al., 2008; Fulick et al., 2017</td>
<td>Dynamic video playing</td>
</tr>
</tbody>
</table>

4. Results and discussion

4.1. ANALYSIS OF ASSEMBLY TIME

<table>
<thead>
<tr>
<th>Subject</th>
<th>Classification</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
<th>Stage 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>20.34</td>
<td>20.37</td>
<td>20.29</td>
<td>20.27</td>
<td>20.32</td>
<td>20.30</td>
</tr>
</tbody>
</table>

There were a total of 5 subjects in Stage 1 of this study, respectively, which took an average of 20 minutes to assemble the same set of tou kung, as shown in Table 2. Regarding the analysis of the time spent on assembly in each stage, Figure 5 shows the box-whisker diagram of each assembly stage. Stage 2 had the maximum time spent on assembly, and the largest time difference among the different subjects, which may be because Stage 2 was the early stage of the assembly stage, and there were many new components that had to be identified and learned. Moreover, the subjects were still learning to interpret the surface descriptions of the assembly instructions, which increased the thinking and assembly time. However, as the assembly progressed to the late stage, it can be seen that the assembly time was significantly shortened. In particular, the time spent in the last stage was the shortest, and the number of components to be assembled in the last stage was six, which were more than with those in Stage 1 and Stage 2. However, observations indicated that the assembly time was significantly reduced, which was probably because there were fewer components that needed to be assembled, fewer judgment options were required, or because the subjects had gradually mastered the tou kung structure and the composition mode of tou kung in the previous assembly process, which reduce the assembly time. Thus, the subjects learned the structural relationship of tou kung through the assembly process of the physical model.

Figure 5. Box-whisker diagram of each assembly stage.
4.2. OBSERVATION OF ASSEMBLY TRIAL AND ERROR

The trial and error behavior in the assembly process can be divided into three forms: (1) selection of wrong components; (2) incorrect component assembly position; and (3) incorrect assembly direction. There are two possible causes for selection of wrong components: the first is that the subjects are not aware of the component size; second is that the shapes of different components are very similar, leading to judgment error. The incorrect component assembly position is mainly because the positions of the physical model and arrow guidance, as recognized by the subjects, are different. The incorrect assembly direction is because the perspectives drawn in the figure are different from the actual assembly model perspective, as recognized by the subjects, thus, the subjects had to shift among the different angles to find the correct angle. Figure 6 shows the statistics of the number of trial and error in each stage. The number of these trial and error behaviors significantly decreases as the stage progresses, which is speculated to be caused by the reduction in the selection of assembly components or the improved user recognition of the components.

![Figure 6. Errors of every stage.](image)

4.3. OBSERVATION OF OVERALL ASSEMBLY BEHAVIOR

From the overall observation of assembly behavior, with the exception of Subject D, all the subjects conducted component classification behavior at the beginning of assembly, mainly placing the bow-shaped tou separately from the arch-shaped kung, which is mainly due to their previous model assembly experience and strategies, or to the brief introduction about the basics before the experiment. However, although the complex forms of tou kung are composed of two basic units, tou and kung, there are a variety of results due to different locations and compositions. Therefore, it might not be suitable to adopt classification means of similar shaped components of the tou kung architectural structures. Moreover, in the early assembly stage, the subjects must spend a lot of time identifying whether the shape of each component conforms to the component required in this stage, which generates many mistakes in the selection process. It can be seen that, in the assembly process of tou kung, more information must be provided to help users to determine whether the current assembly steps are correct.
4.4. ASSEMBLY GUIDANCE SUGGESTIONS ON SUB-CONCLUSION AND POST-TEST INTERVIEW

1. In the late stage of the assembly process, the users were able to gradually master the structural relationship and composition principle of tou kung, thus, assembly and guidance should be the focus of the pre-assembly guidance design. In the post-assembly discussion, Subject A had expressed that he was not familiar with the mortise and tenon assembly mode of tou kung, and only began to understand the structural relationship between the tenon and mortise connection as the assembly proceeded to the later steps.

2. The size and the relationship of the components of the assembly model cannot be read through the paper assembly manual, which easily leads to a recognition gap from the physical model in terms of shape identification, body size, assembly position, and orientation, resulting in assembly errors. Subject A suggested that some details of the component cannot be seen in the whole picture, and therefore, would affect judgment regarding whether the selected component is correct or not, thus, more pictures from different angles should be provided. In addition, Subjects A, B, C, and E thought that a “steps completion figure” and a “sub-group component completion figure” were necessary, and should be added to the manual to help users make their judgment.

3. Provide guide design on component classification and assembly process. Component classification should be based on the content of the components needed in each stage, rather than the shape similarity method. The subjects need to understand this structure, and then decide the assembly order. The Subjects A, B, and D suggested that the instructions on the arrow should be distinguished by different colors, which could make the instructions more clear.

5. Design of the AR tou kung assembly guidance system

The experimental analysis of the previous stage can provide insight into the user’s problems and needs during the assembly of a tou kung model. Based on the above suggestions and conclusions, this stage explores how augmented reality can be applied to guide the assembly behavior according to different assembly situations and dilemmas. The observation process of tou kung assembly behaviors can be divided into two main situations: (1) component classification and selection, (2) component assembly. Thus, based on the observation results of the previous stage, different augmented reality assistance and guidance programs are proposed, respectively, for the above two situations, in order to explore how these auxiliary suggestions can solve the assembly problems.

5.1. COMPONENT CLASSIFICATION AND SELECTION

1. Component classification in each stage: display and switching of assembly steps As mentioned in the previous stage, users often classify scattered components prior to assembly, thus, the classification method should be based on the components required for each assembly stage. Therefore, augmented reality guidance can refer to a method to display and switch the assembly steps, and provide a progress bar and the component images required in each stage, as shown
in Figure 7. The user can use this in the augmented reality interface to classify the components in various stages to gradually understand the composition form of tou kung.

2. **Component searching: interactive 3D model display.** In the component searching process, an interactive 3D model display mode can be used to display the 3D virtual model of the next required component on the AR device screen, as shown in Figure 7. Users can zoom in, zoom out, and rotate the 3D model of the component to observe the different angles of the component, in order to help users identify each component. This approach also allows the details of the entire component to be observed, and thus, solves the problem of paper manuals, which provide only one perspective.

5.2. COMPONENT ASSEMBLY: DYNAMIC VIDEO PLAYING

In the design of the component assembly guidance system, the “dynamic video playing” mode can be used to display animated instructions combined with the actual scene in the augmented reality interface, as shown in Figure 7. The user can clearly understand the position and orientation of the component, which solves the complex arrow pointing problem of the paper manual. In addition, the design principle should be able to show the 3D completion figure of each step, and mark the newly added components in different colors, to help the user more easily confirm the position of the component (Fan 2010).

![Figure 7. Dynamic video playing.](image)

5.3. ARCHITECTURE OF ASSEMBLY GUIDANCE SYSTEM

To sum up above analysis, this study proposes a set of “dynamic simulation AR guidance system”. Firstly, a camera is used to recognize the image and identify the current progress of the physical model assembly. The system searches for the corresponding current digital model progress, including the 3D model files and assembly animation, and places them on the device screen through real-time calculation. The system then provides guidance on the progress implementation in the next stage. During the selection of components, the user can freely zoom in on the model to observe the details of the components, in order to guide the assembly behavior, and switch to the next step after completion. At this point, the system status will be updated. Repeat the above search for components and assembly process to help users until assembly is completed. Figure 8 shows the architecture of the augmented reality system for dynamic simulation assembly guidance.
6. Conclusion

Through the design of the AR tou kung assembly guidance system, the study proposes a set of innovative augmented reality applications for tou kung assembly guidance and learning. In addition to improving the problem of the inadequate information of only 2D images and the spatial recognition of complex structures, it provides more introductions regarding the structures and their construction during the interaction process, as well as more learning information, which a paper manual cannot provide. Future research requires further testing of this system for more users to understand the problems in the AR assembly guidance. At present, as only one set of tou kung is selected for testing in this study, the system should also be applied to tou kung with different modules in the future, in order to upgrade it to a more general AR assembly guidance system model.

References


