# Work in Progress: Educational Uses of an Intelligent System to Teach Construction Processes – A Case Study of the Giant Wild Goose Pagoda

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Abstract-

With the rapid development of building industries around the world, understanding the processes needed to complete a series of construction operations in a timely and cost-efficient manner has become paramount to most fields in the business. Unlike traditional processes in building construction, a new method reliant on an interactive system can allow learners to envision construction operations involving more accurate use of equipment, materials, and laborers allocated to any particular activity. Advanced three-dimensional simulation tools have thus been created and step-by-step processes are introduced to facilitate this process. The authors used these tools to simulate the processes of ancient construction technologies, with the examples discussed being those employed in the erection of the most famous pagoda in China, the Dayanta or the Giant Wild Goose Pagoda. This pagoda, in Xi'an, the ancient capital of China, was originally built by Xuanzang in AD 652, the legendary monk who travelled to India to acquire Buddhist scriptures and translated and stored them in the Dayanta, and several renovations/versions have appeared, making it ideal for exploring multiple versions of the structure over the eons. For the sake of feasibility, this paper focuses on the final version of the pagoda that currently stands in the city of Xi'an. The software used to represent the 3D components includes 3DS Max and Visual Studio. The authors believe that the learning processes pertaining to these engineering processes can be enhanced by the introduction of this software to the classroom environment.

Most ancient buildings were constructed manually with primitive resources, and in many cases, the information about these building processes has been lost to time. Yet some monuments remain magnificent even as they stand now, and the Dayanta is arguably one of these. By using the present as a guide to the past, this paper will describe how the ancient Chinese likely implemented the construction processes employed to erect such an extraordinary structure. The objective of this research is to introduce an interactive system that allows users to learn how this ancient pagoda was built almost 1,400 years ago, aided by three-dimensional images of building components of the substructure (foundation) and superstructure (pagoda) of the Dayanta. Students will be guided through the correct construction sequence and operations with the assistance of animation and ample descriptions of the use of materials, equipment, and technology. To verify the effectiveness of this interactive system, the authors plan to conduct a survey assessing the usefulness and ease of use of the system and the realism of the construction sequence and operations of the Dayanta as well as both immediate and delayed assessments of content retention. It is felt that the best use of interactive systems would be to complement traditional instruction rather than replace it. The interactive system can be embedded in a course as either pre-work or homework. This paper introduces an interactive system to model the construction of the Dayanta and provides an example of a possible assignment related to it.

Key Words: 3D pagoda construction, ancient pagoda, Chinese pagoda, Dayanta, Giant Wild Goose Pagoda, pagoda construction simulation

1. Introduction

The Chinese pagoda or *ta* is a multi-story religious structure built commonly for Buddhist worshippers, and is generally accompanied by a temple or *si*. Arguably, the term *pagoda* originated from Indian's *dagoba* or Sinhalese *stupa* [1]. In this paper, the authors focus their investigations on one of the most famous pagodas in China (if not the most famous), the Dayan pagoda or Dayanta located in Xi'an, one of China's ancient capitals in the Shaanxi province. The Dayanta's prominence is related to the religious and cultural legacy brought from India to China and beyond: Xuanzang, a Chinese Buddhist monk traveled to India to translate the "sutra" (Indian scriptures) of the Buddhist religion, and in the 7$^{th}$ century AD, he brought these scriptures back to China and stored them in Dayanta, where they remain today, as shown in Figure 1.

Figure 1. The Dayanta in Xi'an

How this monument was built is a question that has attracted numerous researchers. The activities of erecting a building are collectively called the construction processes or construction activities, and the materials, equipment, and labor are the three main participants in these activities. As in ancient China, the construction techniques can be revealed in diverse kinds of buildings, including temples, palaces, and pagodas. Among these buildings, the *ta* is unique for the high-rise building techniques of the time that had to be applied. Thus, as the most famous *ta* in China, the construction method of the Dayanta reveals nearly all of the construction techniques of this type of structure along with the nuances in the renovations after the reconstructions in different periods [2].

In spite of the passage of time, along with the loss or degradation of various documents or records about how the pagoda was built, people have remained curious and interested in the construction techniques behind this monument. Additionally, by studying the construction techniques of high-rise buildings such as the Dayanta, the authors of this study intend to contribute to the physical restoration and reconstruction of other ancient monuments in China with potential sources of engineering information. In a classroom environment, teaching and learning are two main activities. Given the rapid development of computer engineering since the 1970s, it is natural that more and more computer-aided teaching and learning methods have been imported into the classroom. In this particular research project, the authors have worked on applying one teaching-learning system for educational purposes. The system was created with Autodesk 3DS MAX and Visual Studio, the former being applied to form the element in the construction activity of the Dayanta and the latter employed as the platform application, with the 3D elements embedded in it. The interactive system would ideally allow the users to study the Dayanta more thoroughly than through typical learning methods, via a digital representation of the construction processes of the Dayanta built using the knowledge base embedded in the interactive system.

In the field of construction specifically, the authors will apply the interactive system technology to the construction field, which allows users to input their opinions as embedded data and output the evaluation results after analysis of the translated values. The authors believe this interactive system will greatly assist the students in accessing the construction knowledge of the Dayanta and other, similar historical monuments.

## 2. Background

As the designer of the Dayanta, Xuanzang, who flourished in AD 596-664, studied for seventeen years in India. As noted by the authors' previous studies of the Dayanta [3], it was probably built in the Indian Ta style, though after several renovations over the years, the appearance of the pagoda changed greatly. The four recognized 'versions' of the Dayanta chosen for the study are shown in Figure 2.

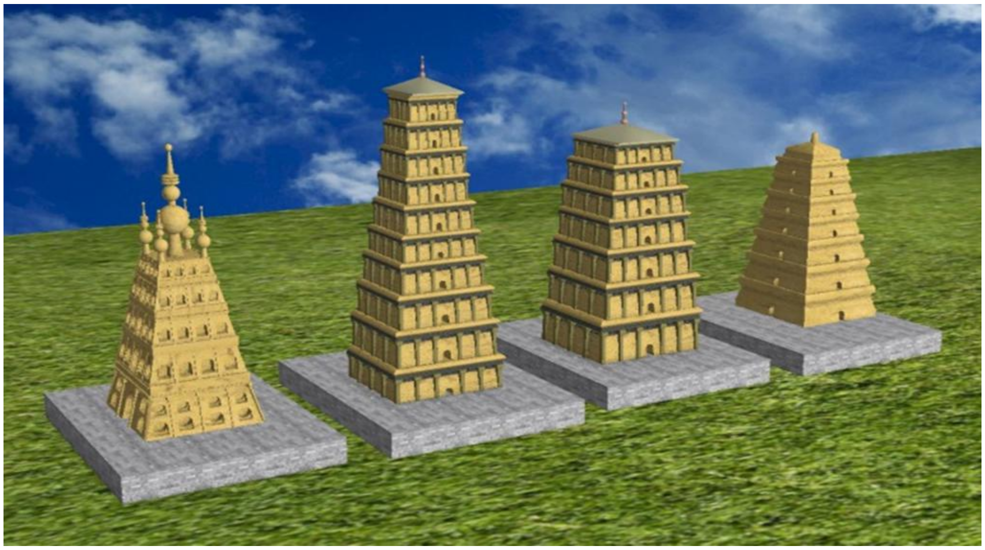


Figure 2. Simulation of four versions of the Dayanta [4]

From a functional perspective, the foundation is the substructure underneath the ground. As the first part of the construction process, the foundation is very important for the overall stability of the whole building (discussed more extensively in [3], [4], and [5]). In the evaluation of the construction of the foundation, there are several assumptions about the foundation building type, since the foundation is both invisible and lacking in corresponding records or documents. The base serves as an important function to cover the foundation and provide additional support for the columns and walls. Additionally, the base was constructed with a built in slope providing for drainage.  The base is composed of bricks bound with sticky rice mortar placed above the lower foundation.

The superstructure features the columns, beams, slabs, and walls as supportive components that help to hold up the whole structure of the Dayanta. Besides the supportive components, there are also auxiliary structure components such as the roof covering, horizontal decorations on the eaves, connections, and wind bells, all of which were structurally elaborated in the authors' previous research [3] and [6]. Among all the auxiliary structure components, the *dougong* (cap-and-block bracket connections of timber components) as one of the most important support members of the structure, has been comprehensively simulated in an earlier study [7].

## 3. Building the interactive system

In this system, the goal of the learner is to recreate the construction of the Dayanta from the foundation to the spire/roof, using a step-by-step operation that represents all known components. Given the information embedded in the program, the users can interact with the system by providing the correct guesses pertaining to each step of the process within a set time and space frame in the program, as well as corresponding with the practical construction matters relevant to each step.

After the graphics software is used to finish the graphical simulation, Visual Studio is employed to produce a platform for the interactive system, realize the interactivity between machines and users, and keep the records stored for users to inspect when they use the program. By embedding the graphics from models created in Autodesk and Inventor, the system can reveal each of the construction processes concerned by allowing users to input their options towards questions. When using the interactive system, users can be guided by the programming to study a wide selection of different construction process routes for putting the building together. This is especially important for a knowledge background which may vary widely, with users ranging from high school students to academic professionals, from laborers to managers in construction sites, and from architects to engineers. The flowchart for the program of the interactive system is shown in Figure 3.

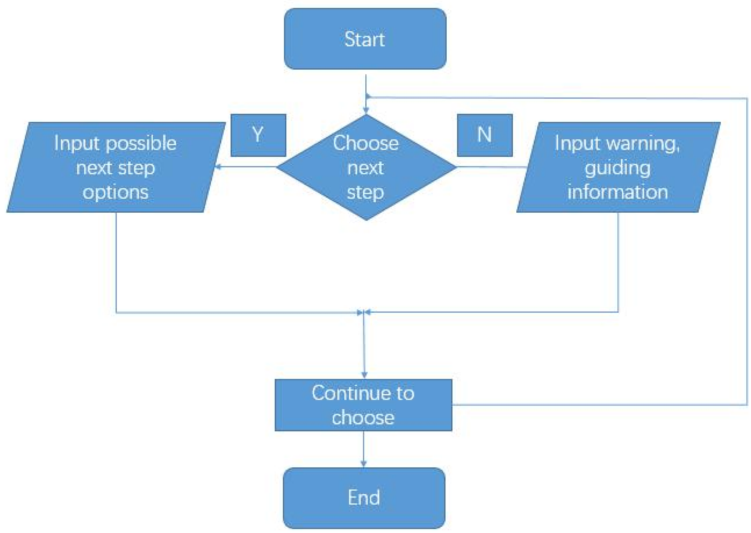



Figure 3. Flow chart of the program design

In this flow chart, the users can input their choices by providing options for the next step of the construction process of the Dayanta throughout the whole construction process for this building. Once the users complete each step of the construction path, the next available step will show up. As per the design of the program, if they choose the correct path, the possible following step will appear so the user to continue with the process, but if they choose the incorrect step, a warning box will appear so the users can reconsider their path, with the relevant information being presented in a nearby text box. With this assistant function, users can learn the reasons for their incorrect answers, reconsider their choices, and revise their options given the extra information. Additionally, to encourage the students to study the knowledge base, a scoring system is assigned: the score is counted automatically based on the correct or incorrect choices made for each step. If an answer points to the correct step, there will be ten points added to the score holder, while if the choice is incorrect, five points will be deducted. Given the consideration of user-friendly design, there are also one-hundred reference points in total listed as a basic score to encourage students to study to a satisfactory degree. A typical design of the framework of the interactive system is shown in Figure 4.

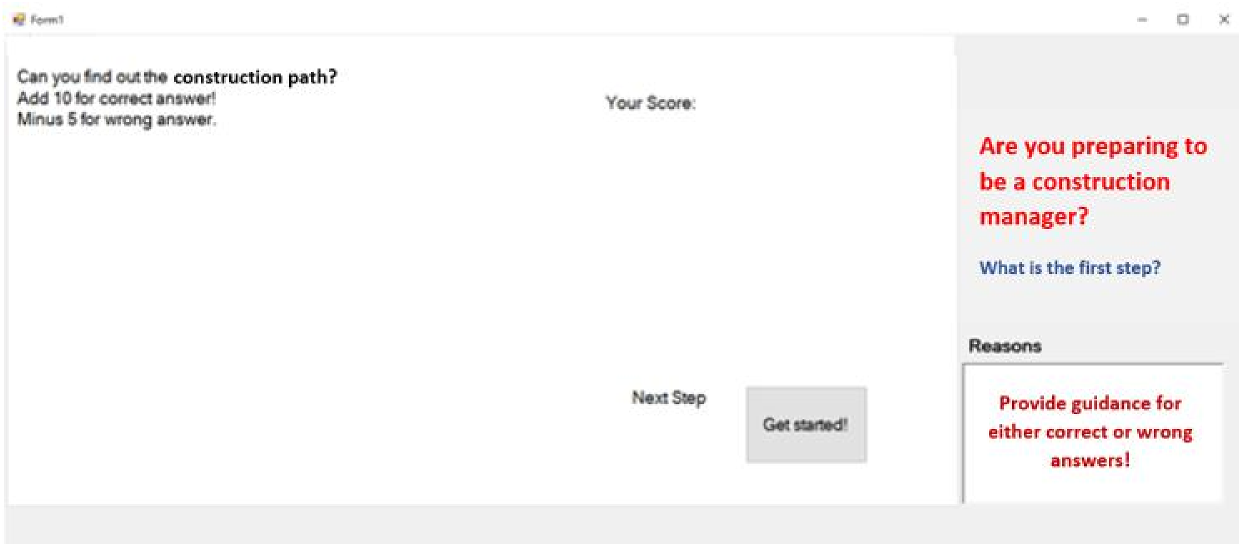



Figure 4. A typical design of the framework of the interactive system

After the students have selected each choice, whether correct or not, feedback will be given on their answers. If the students make the correct decisions, the next possible options will also show up for the users to continue to choose from, and ten points will be added to the overall score. Conversely, if the students choose incorrectly, a message box will pop up telling them to pick again, and five points will be deducted from the final score. There are 11 choices in this game, so a perfect score is 110. The game begins with students needing to correctly pick the foundation and base as the first two components, for example. Figure 5 shows the feedback given for a wrong choice for the third step; Figure 6 shows the feedback for the correct choice.

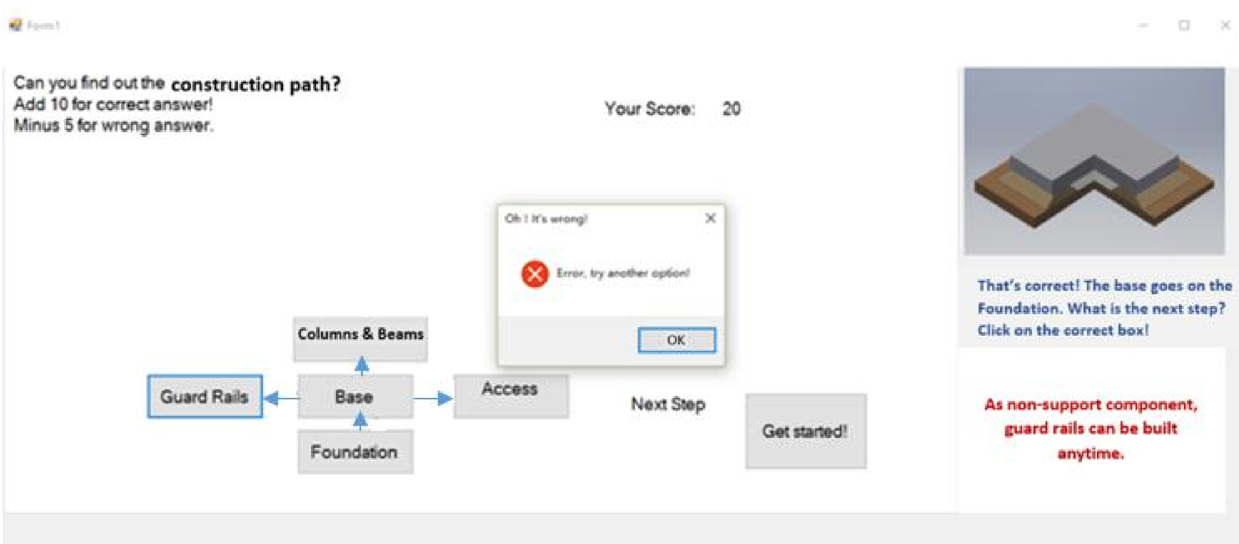



Figure 5. The screenshot of what happens if the students selected “Guard Rails” after the base.

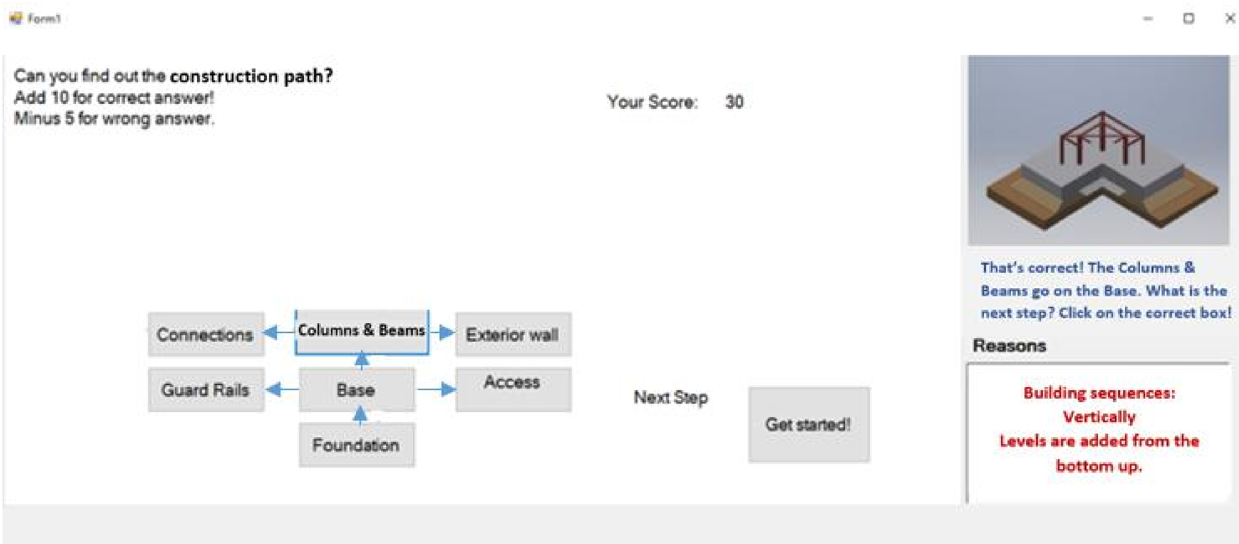


Figure 6. The screenshot of when the student chooses the correct step after the base.

In this example, after the foundation and the base have been "built", the next step can be the guardrails, access stairs, and floor slab. For users who have no background knowledge about the construction, those three elements are very likely to be chosen for each of the three options that are connected to the foundation physically. However, the most probable answer for this step is the floor slab. This is because the base provides a supportive function, while the guardrails and access stairs are auxiliary structure components, which makes them non-structural components that do not bear the structural load of the monument. In the field of construction, supportive components are much more important than the auxiliary components, because damage to the structural components is far more likely to induce a failure or collapse of the whole structure. Thus, during the decision-making process for the construction sequence, the supportive components must always go first before the auxiliary components. To illustrate the structure components and auxiliary components, Figure 7 shows the overall components as the indicator of the structural features, whether they are structural components or not; a value of N = 6 means there are six loops after building the base, corresponding with the first to sixth floors for the Dayanta.

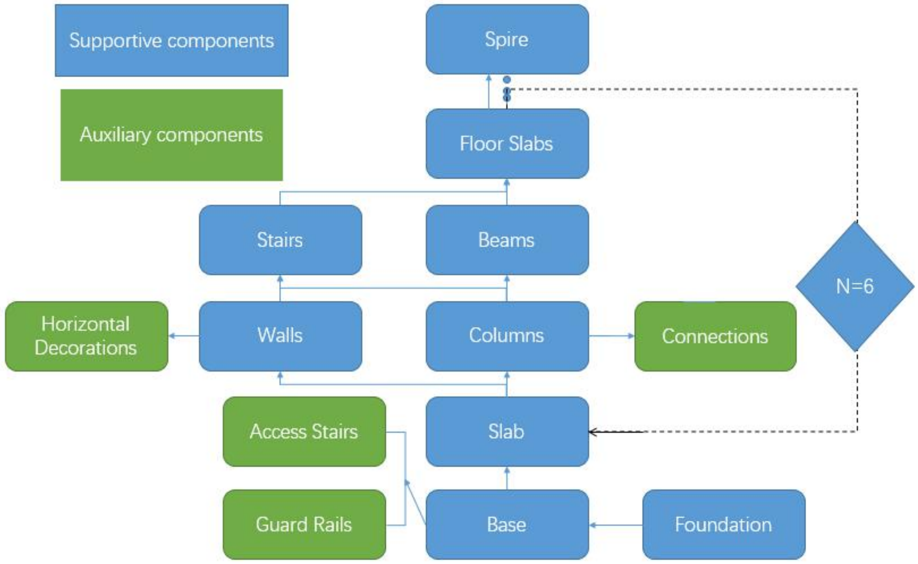



Figure 7. The type of components and the construction processes of the Dayanta [3]

After the users complete the choice of the first floor, through repetition of the same construction processes, they are asked to finish the building of each level up to the sixth floor. Similarly, the students are asked to choose the correct construction path among all supportive and non-supportive components. Only after the students complete the whole path correctly will they achieve the goal of completing the virtual erection of the Dayanta using the interactive system. A typical choice at the 6$^{th}$ floor and the completeness of this path choice is shown in Figure 8 and Figure 9, respectively.

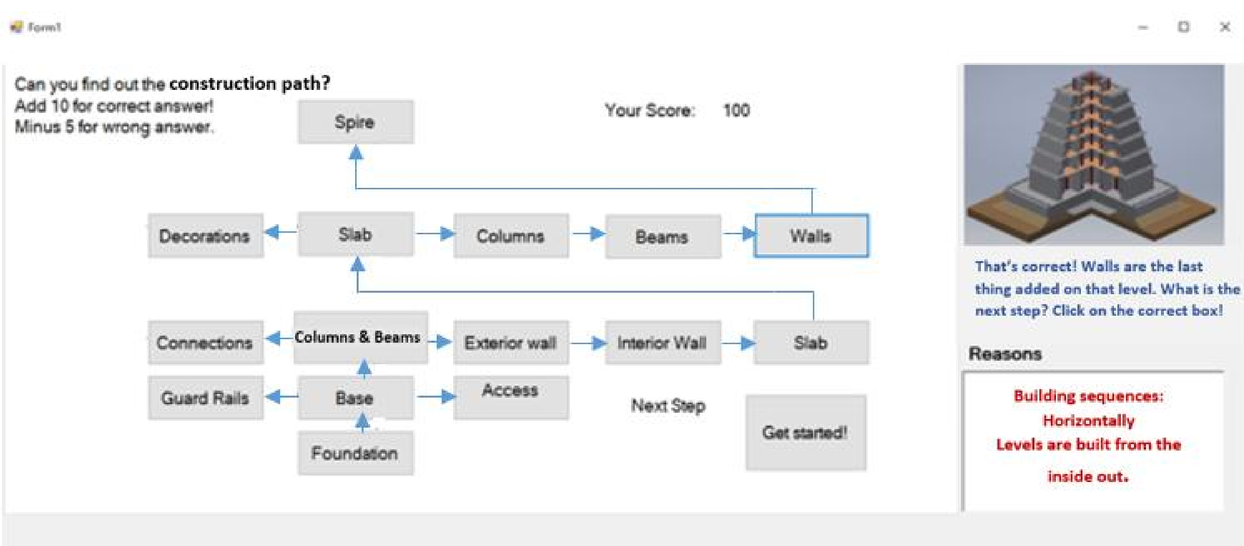



Figure 8. Typical choice on the 6$^{th}$ floor

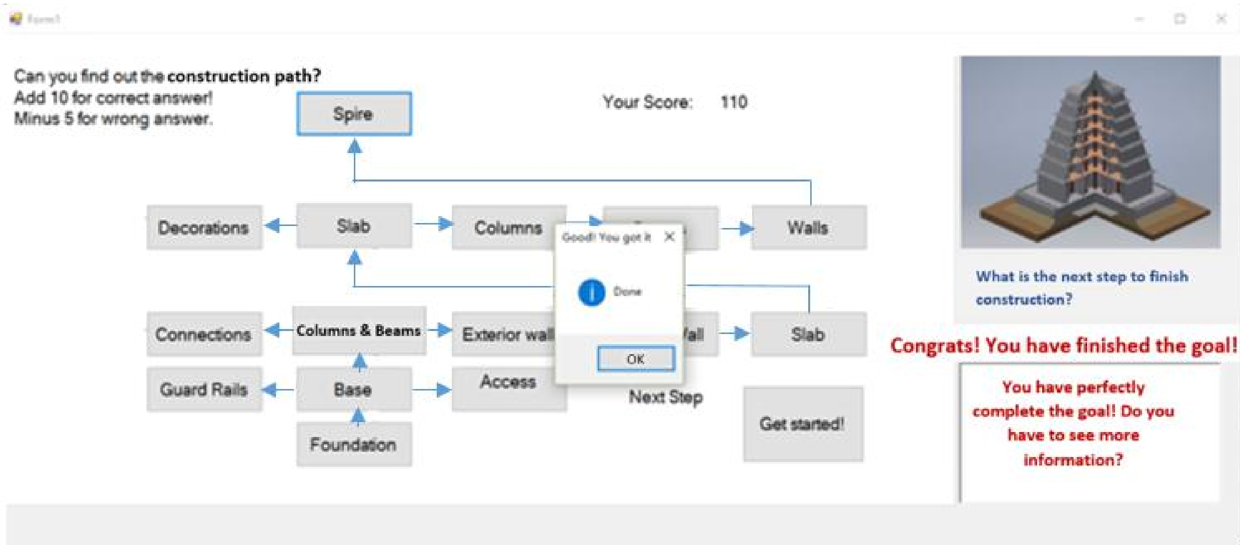



Figure 9. Finished construction path

Aside from the construction path test, the tools applied during construction can also be viewed in this interactive system. On any particular construction stage, such as the building of the foundation and building of the superstructure, this can be viewed as embedded information, as shown in Figures 10 and 11.

As shown in Figure 10, the construction materials for the foundation consisted of cement, stones and pebbles, indicated by yellow arrows. Foundation construction techniques included the installation of timber piles and timber-lagging as indicated by orange arrows. Laborers, carrying logs on their shoulders, transported boulders using wheelbarrows, and measured the timbers for cutting, are indicated by green arrows.

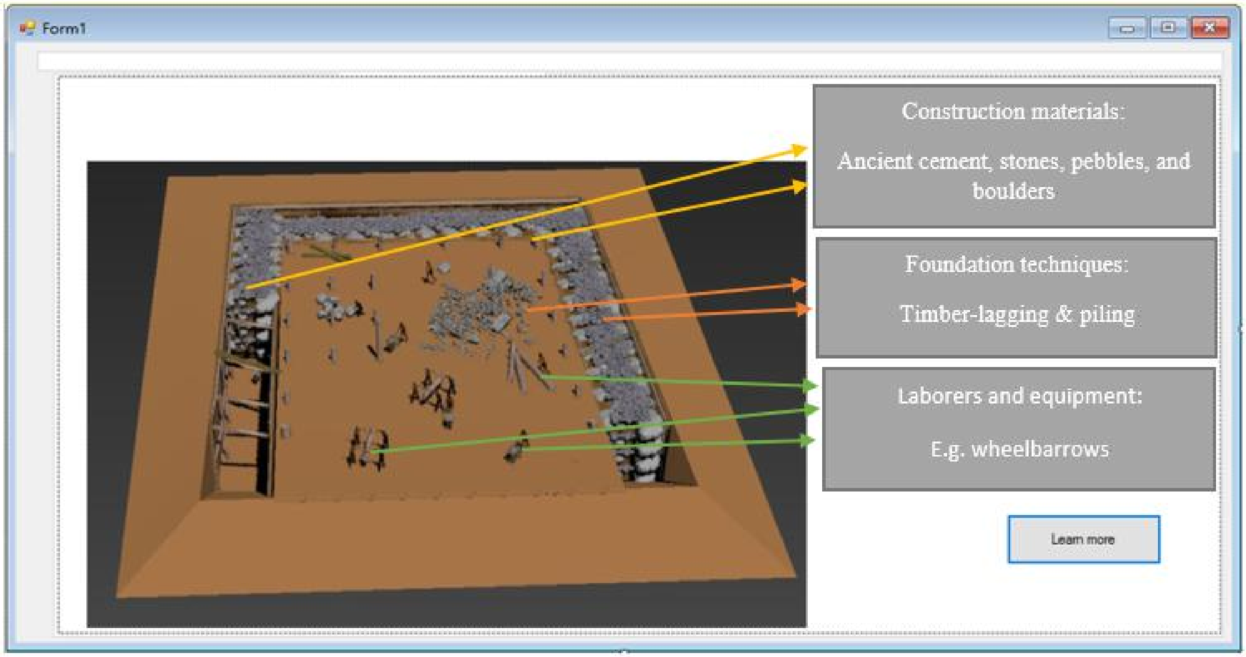



Figure 10. Illustrative simulation of the construction of the foundation

When considering the superstructure, one must note that the simulated construction site includes the equipment and laborers working at the top level to lift the construction materials. As shown in Figure 11, the scaffolding shown by the orange arrow allowed access to various levels of the existing structure. A worker, who stands on the top floor, is transporting materials from the next lower level by using a pulley system, shown by the green arrow.

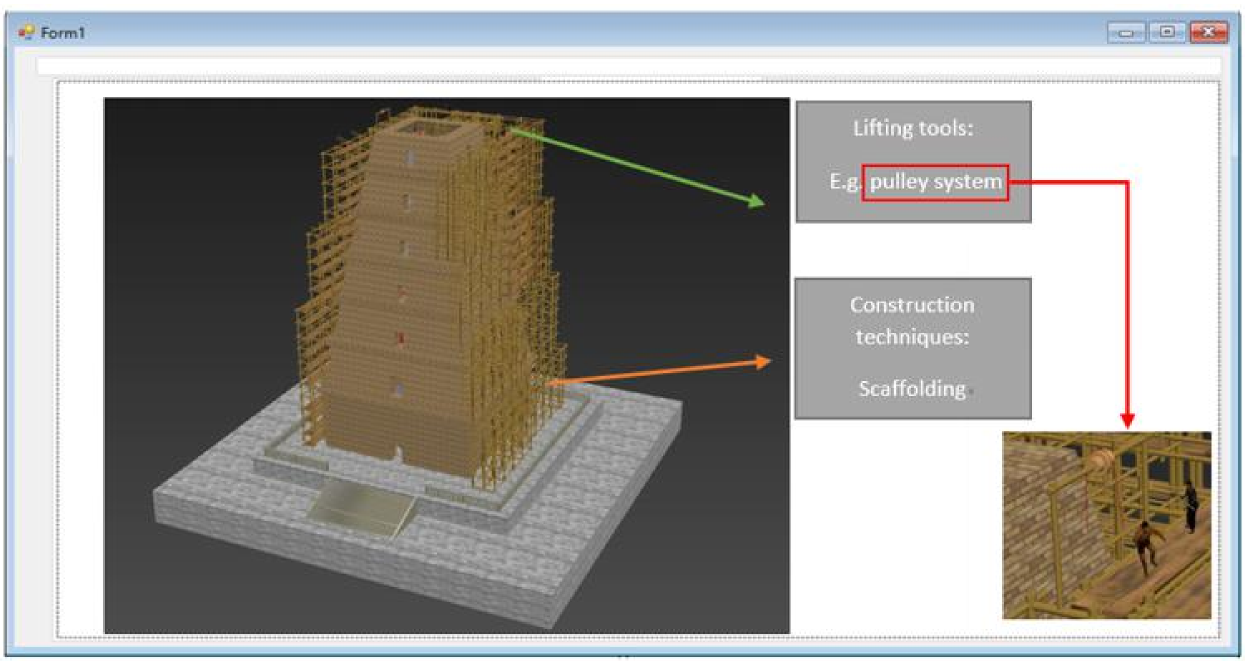



Figure 11. Illustrative simulation of the construction of the superstructure

If the students wish to know more about the application of the tools themselves, an introduction to them can be viewed based on the students' preference. Figure 12 shows several illustrations of the ancient Chinese construction tools [8], many which were likely used during the construction process. Different tools were used for different stages of this process, including surveying of the construction site, excavation, measuring and marking materials, making holes, and cutting and assembling construction materials.

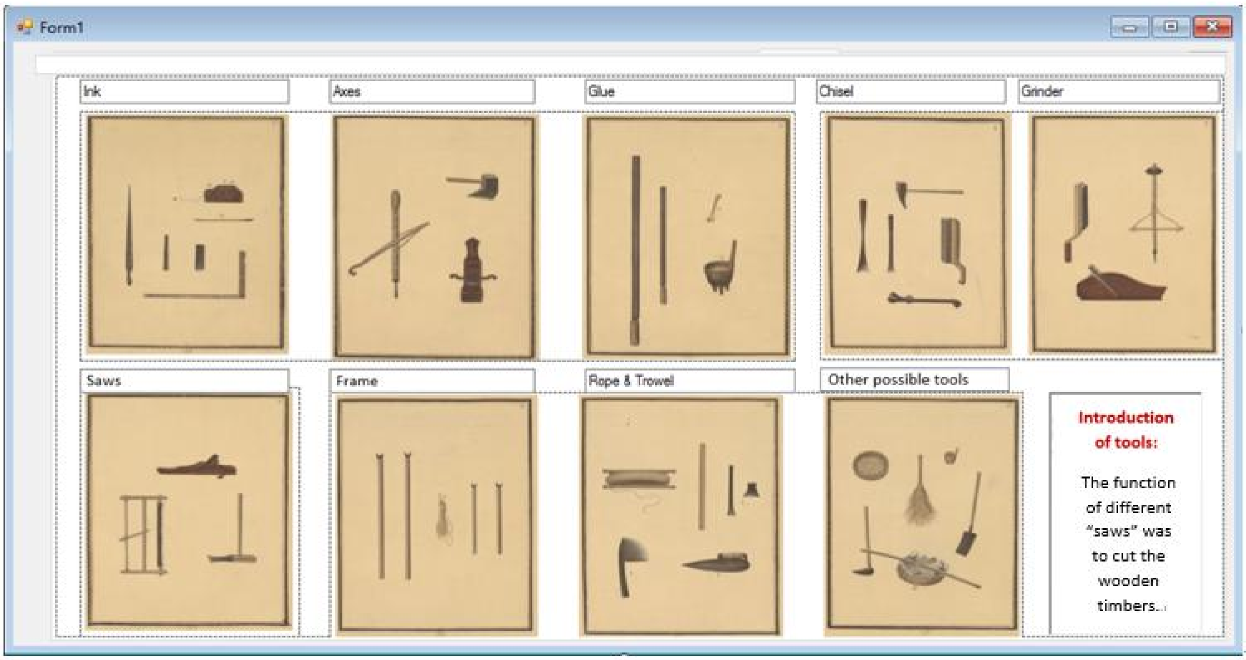



Figure 12. Ancient Chinese Construction Tools [8]

Additionally, if the students would like to see other views of the Dayanta, the system can present different choices for viewing the monument, as illustrated in Figure 13. The top view help students to see the structure from top down, the side view allows students to see its side, and the isometric view reveals the structure inside the pagoda.

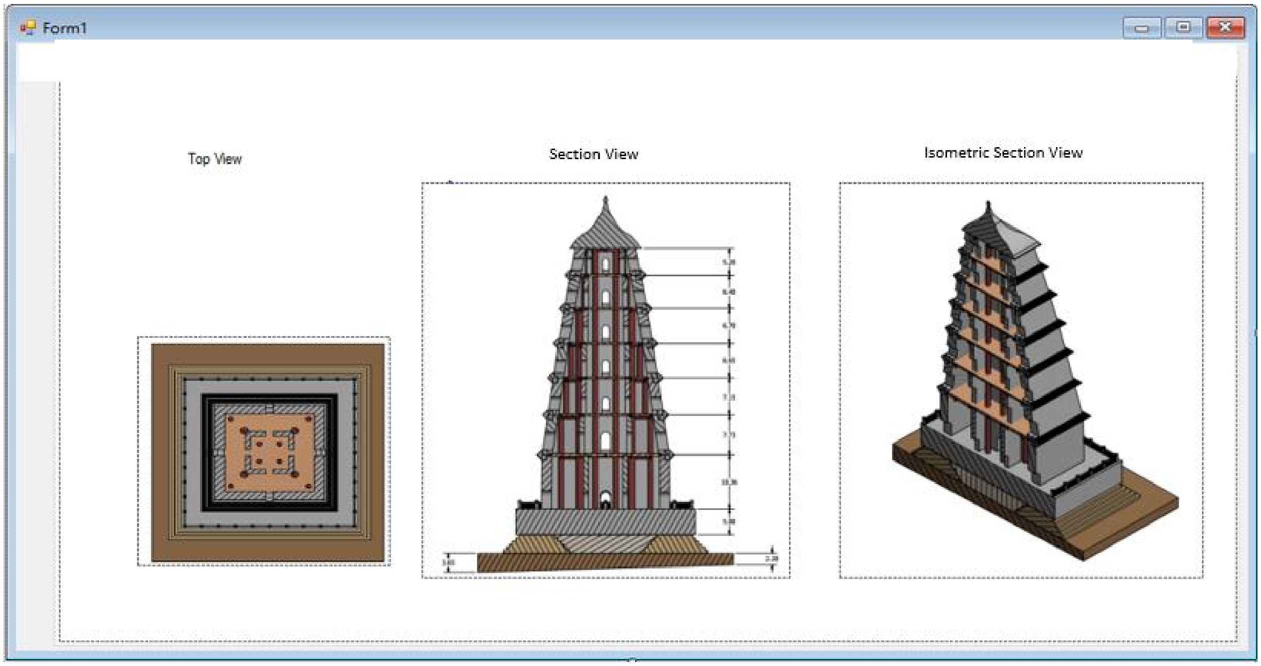
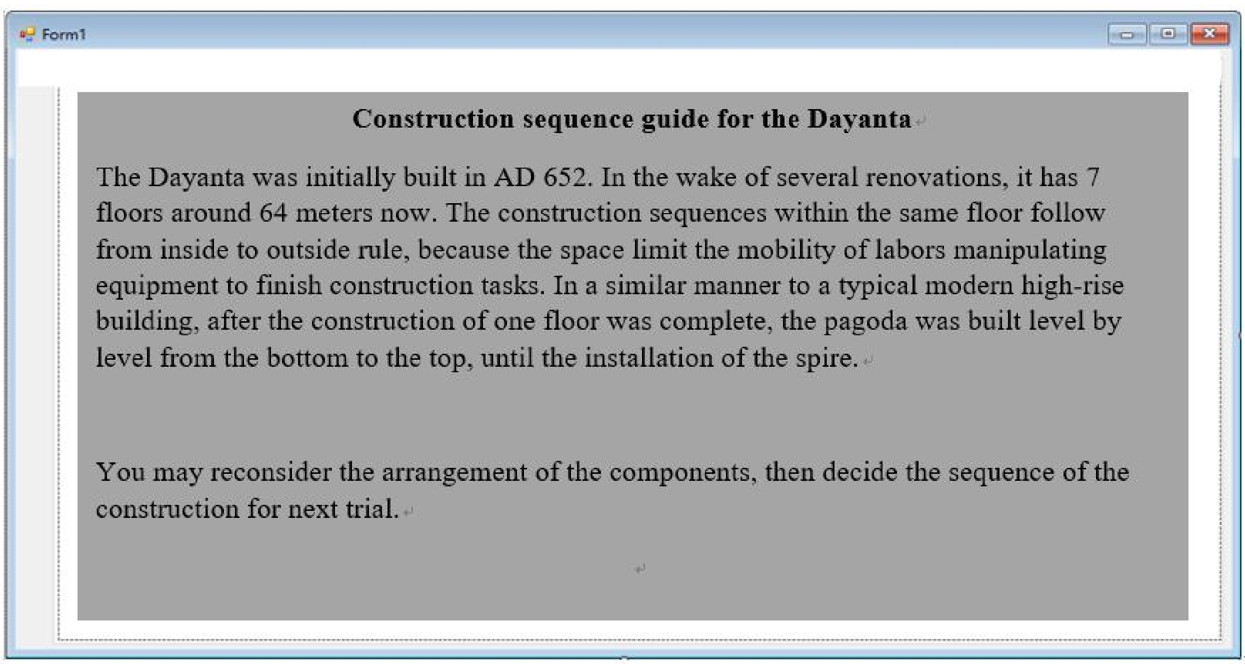



Figure 13. Three views of the Dayanta

Serving as the guide of the construction process of the Dayanta, a brief introduction shown in Figure 14 allows students to predict the correct construction sequence.



Form1

**Construction sequence guide for the Dayanta**

The Dayanta was initially built in AD 652. In the wake of several renovations, it has 7 floors around 64 meters now. The construction sequences within the same floor follow from inside to outside rule, because the space limit the mobility of labors manipulating equipment to finish construction tasks. In a similar manner to a typical modern high-rise building, after the construction of one floor was complete, the pagoda was built level by level from the bottom to the top, until the installation of the spire.

You may reconsider the arrangement of the components, then decide the sequence of the construction for next trial.

Figure 14. Information for the construction sequence

Using this interactive system, the students are guided in a step-by-step manner to complete the construction path. Thanks to a combination of the scoring system, the warning message function tools, and the assistant information for choices, this interactive system can facilitate the communication between students and computers.

## 4. Classroom application

This section explains the applications of the above-described interactive system in the classroom through feedback from the students' choices. Specifically, the scoring system allows students to navigate through the construction process of the Dayanta using the embedded knowledge base. The navigation of this scoring system is shown in Figure 15 based on three ranges of scores described below.

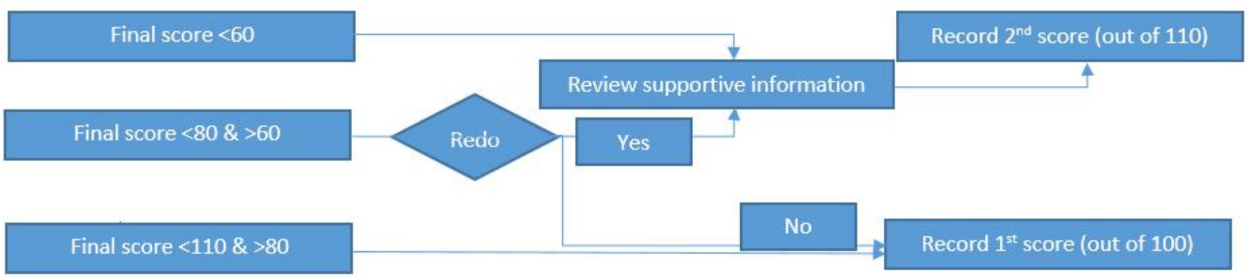



Figure 15. Scoring navigation flowchart

A. Score range: from -100 to 60

   If in the first trial a student earns a low score (between -100 and +60), then he/she is required to review the information displayed by the knowledge base of the system. This is usually the case when the student has made repeated errors. In this case, the knowledge base prompts the showcasing of the construction sequence and processes of building the Dayanta in 3D models. All of the requisite materials – materials, equipment, tools, substructure and superstructure – must be reviewed thoroughly before the student can proceed. Once this evaluation is completed, the student may repeat the process after a two-week time period has passed. This two-week time interval can be tailored to any period. The purpose of this hiatus is to avoid the retention of the results the students have just received [9].

B. Score range: from 60 to 80

   If a student earns +60 to +80 at first trial, indicating that he/she missed only a few steps, the system will still encourage him/her (though not mandatorily so) to review only related information provided by the system feedback. If the student would like to receive a higher score, he/she can schedule a period around one week later to redo the exercise after reviewing the embedded materials. This one-week period is shorter than for the previous result because fewer materials are needed for the student to learn [10]. Only for the first trial will the student earn a bonus score of 10%.

C. Score range: from 80 to 110

If for the first trial a student earns a good score (in the range from +80 to +110), then the system will keep the final score with a 10-point bonus added to it.

## 5. Potential benefits of the interactive system in education

The interactive system produced by this research can help users gain a better understanding of the construction knowledge of the Dayanta in several different ways.

Firstly, 3D modeling can assist students to understand the construction processes intuitively. Compared with the traditional teaching methods in the classroom (e.g. lecture, reading materials, video, etc.), 3D models provide a more basic, direct, and tangible presentation of the building. As the Dayanta is as complex as many other Chinese buildings if not more so, imagining the structure would be difficult for most readers without a 3D model of the building to help them better understand it. Additionally, since the dimensions can be viewed in the 3D model, the students can have a good understanding of the scale of the pagoda from a professional perspective. Should they plan to check the dimensions and scales of the Dayanta, the students can export the compatible and readable file from Autodesk Inventor with different resolutions for better views of the detailed structure of the Dayanta. Lastly, the 3D model helps to simulate the construction tools that were applied to the construction site, especially in Autodesk 3DS MAX 2018. The model generated from Autodesk 3DS MAX can thus help the students to better understand the various possibilities for ancient Chinese construction processes, sequence, tools, and materials.

Second, the interactive system based on the model can help students to better understand the construction processes of the Dayanta in a graphically and theoretical context, with the aid of the embedded information. Additionally, the system would allow students to look through the information outside of the classroom, review the construction processes after the lessons, or conduct a self-test of what they have learned.

Thirdly, the scoring system, as elaborated in the previous section, can be employed to assist teachers as a complimentary tool in order to keep the students' study performance on track. This can aid in improving student performance as well, providing a positive incentive to analyze the structure and the construction processes and allowing them to retain the relevant knowledge and feedback to a greater capacity.

## 6. Summary and conclusion

In this research, the authors have applied an interactive system to guide the users through the construction knowledge base of an ancient Chinese building. Additionally, with the guidance in the system, the users are allowed to interact with this system by inputting their choices and outputting the results to aid in guiding them toward correct answers. There are multiple choices pertaining to how to use this model, and it may not be possible to test all options in one class session. The authors therefore plan to focus on using the model as a post class assignment for field testing: students will be divided into two groups that are as balanced as possible and will all have the same in-class presentation. One half will be given a regular homework assignment and the other half will be given the interactive system to complete, and both groups will have a quiz and a survey immediately following the assignment. Following this, after a waiting period of two weeks, all students will be given an unannounced pop quiz about the Dayanta, with the results being compared between the groups to look at the impact of the interactive system on both short-term and longer-term memory. Given this heuristic study, the authors believe this research will contribute to a better understanding of the use of 3D models and interactive media containing them in undergraduate instruction.

## 7. Acknowledgments

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