Rapid and Reproducible Reconstruction of Ancient Architecture by Procedural Generation

Reconstruting the “Pavilion of the Rise of the Yuan Dynasty” in Karakorum, Mongolia

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Motivation and Introduction

The Mongol Empire spanned an area from Korea to Russia and Asia Minor in the 13th century. It’s capital city during the phase of rapid expansion in the first half of the century was Karakorum (Hüttel 2016). The site of the city lies in the UNESCO world heritage Orkhon Valley in today’s Mongolia. In the last 21 years, archaeologists of the joint Mongolian-German Karakorum Expedition (Mongolian Academy of Sciences, University of Bonn, German Archaeological Institute) are exploring the remains of this fascinating urban centre in the steppe. From the years 2000 until 2006 the work of the team of the German Archaeological Institute was focused on a major building of the city, which was thought to be the remains of the palace of Ögedei Khan (r. 1229–1241) (Киселев and Евтюхова 1965, p.138). During the excavations it became clear, that this site could not have been a palace, but was a buddhist sanctuary (Hüttel 2009). Right in front of the surviving platform of the temple a large stone tortoise once served as foundation for an inscription stele. It most likely carried the famous, bilingual Sino Mongolian inscription of 1346, which gives an account of the foundation of the city and the erection of a large buddhist state sanctuary under the reign of Möngke Khan (r. 1251–1259) and subsequent renovations of this building by his successors. The inscription identifies the building as the 興元閣*(xīng yuán gé)* which can be translated as the “Temple of the rise of the Yuan Dynasty”. (Cleaves 1952, pp.29–34). The study of the excavated remains of the architecture has shown, that the temple was erected using Chinese style carpentry but was based on the concept of a mandala in Tibetian-buddhist tradition (Franken 2015). This combination was interestingly also followed in later centuries, when the rulers of the Qing empires had monasteries erected in the Mongol territories of their empire (Charleux 2010).

With this information, a comprehensive reconstruction can be ventured. Any reconstruction of ancient architecture, which is only recovered by the foundations and artefacts found in the rubbly suffers from uncertainties and must take other sources into account. Furthermore, an approach is needed to try out different reconstructions to discuss their plausibility. The parameters that led to every single Version must be made transparent and documented, to ensure reproducibility and confirmability of the reconstruction hypothesis. In this case, the method of procedural generation was chosen.

The traditional Chinese timber architecture lends itself especially well to such an approach. It is governed by strict rules about the measurement, placement, and proportion of construction elements. All parts of the construction are proportionally related to each other, which enables to reconstruct the dimensions of the building from some measurements which are known from the excavated foundations of the buildings. The principles of medieval Chinese timber architecture have been laid down in the Yingzao Fashi (the State Building Standards) during the Song Dynasty. The book has been printed in 1104 (Guo 1995, pp.14–32). The aim of this study, which was conducted in the course of a bachelor's thesis by the main author, was, to formalize the architectural rules of the Yingzao Fashi and to enable automated creation of such constructions. This process was to be controlled by user-defined parameters that represent the input of archaeological and historical data and assumptions.

Findings and methods

There are already similar comparable approaches for the reconstruction of different buildings and buildings from Chinese architecture. One approach is presented by Hua Liu et al., here they use so-called patterns, which have prefabricated layouts for the columns, the walls, and the roof (Hua Liu et al. 2005). Another approach is the method of Kolenda and Markiewicz. For their method they used both standard objects and objects that had already been processed, the shape of these objects could be changed using parameters (Kolenda and Markiewicz 2017). The approach of Kolenda and Markiewicz proved to be the most effective for the reconstruction of the "Great Hall".

Instead of patterns that ensure the arrangement of the individual objects, various functions were defined which, depending on the individual parameters, compose the reconstruction from the individual objects. The knowledge about the "Great Hall" by Franken and the Chinese timber frame construction by Guo are integrated into the generation with the help of predefined rules within the functions (Franken 2015, Guo 1995). By complying with the rules and findings, a flexible and traceable generation can be made possible in combination with changeable parameters.

The open-source graphics suite Blender, which provides an interface to the Python programming language, is used to implement the method. With the help of the Python interface, objects can be created and edited in Blender. It is also possible to create your own blender panel with which the parameters can be set individually. The parameters can be used, for example, to set the number of columns, the distance between the columns, the width and height of the column-bases as well as the bars and the number of floors. This information is derived directly and indirectly from archaeological and written sources and are therefore debatable to a different degree. The choices made during the reconstruction process are made explicit by the predefined rules and functions and by the entered parameters, which ultimately lead to the reconstructions.

In addition, it is possible to display the model in two different levels of detail, one variant with a lot of details and one variant with few details. The number of corner points of the pillars can also be specified. With the option of setting the level of detail, the generated model can be used for several different purposes, e.g., as a model for an augmented reality app or as a detailed model for an image.

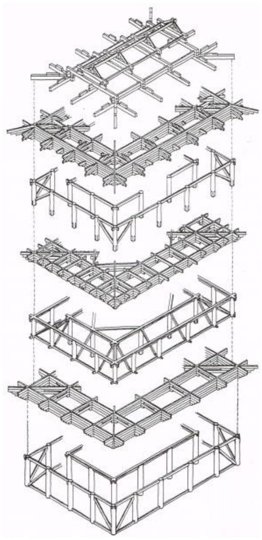

Fig. 1. Different units such as the Puzuo system, the network of colums or the roof construction (Guo 1995).

Several different constructive units shown in Fig. 1, such as the “Puzuo”-system – the interlocking beams and brackets between columns and upper floors or the roof which is characteristic for Chinese timber architecture – or the network of columns are required for the construction of the building. The individual units or floors of the "Great Hall" are each generated by an individual function. For example, there is a function for creating the Puzuo system, one for the network of columns and another for creating the roof. As an example, the Puzuo system consists of a total of five different components that must be placed and extruded individually depending on the size of the building. One of them is shown in Fig. 2.

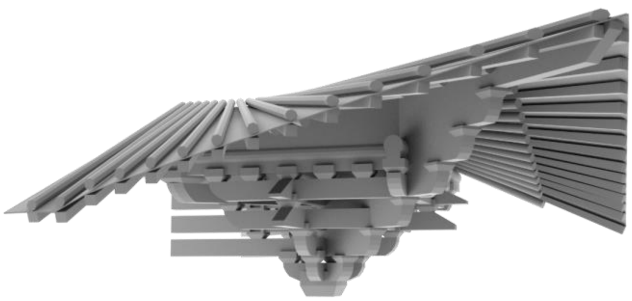

Fig. 2. One of the components of the Puzuo system, that is placed on the corners of the building.

With the help of the function that is responsible for the creation of the Puzuo system, these individual components, depending on the transferred parameters, are put together to form a complete Puzuo system. The individual functions are then executed many times according to the number of floors and can now generate possible reconstructions of the "Great Hall" depending on the knowledge gained by Guo and Franken and the individual parameters (Franken 2015, Guo 1995).

Results and challenges

A first possible reconstruction of the “Great Hall”, in which all values were set in such a way that they correspond to the known values of the "Great Hall", can be seen in Fig. 3.

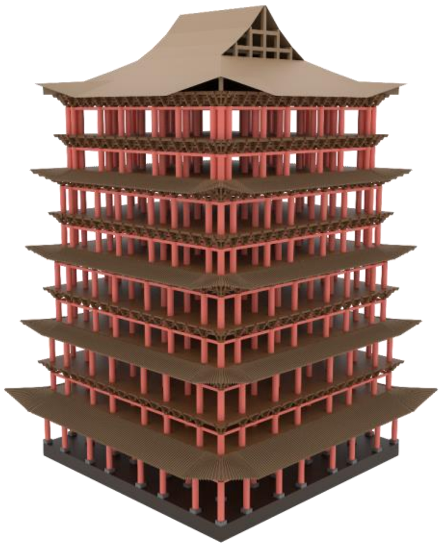

Fig. 3. A possible reconstruction of the Great Hall.

The generated model consists of a total of 315,348 verts and 250,955 faces when using the components with a low level of detail and a corner number of the pillars of five. The same model with a higher level-of-detail and a number of corner points of the pillars of 16, consists of 770,412 verts and 670,851 faces.

As can be seen, the number of verts and faces of the model can be reduced by a little more than half. The file exported for an augmented reality app is almost 9 megabytes with a low level-of-detail and almost 25 megabytes with a high level-of-detail. A reduction of a little more than half can be seen here.

In conclusion, it can be said that the programming language offered a lot of freedom and flexibility as an approach to implementation, but on the other hand it is also more error-prone compared to the method with patterns. Due to the frequent repetitions when generating the "Great Hall", this susceptibility to errors could largely be avoided.

Nevertheless, the method of the programming language gets closer and closer to its limit the more complex an object becomes. As a result, the processing of the objects within the script is restricted the more complex they are. Furthermore, the functionality of the script depends on the individual objects that have already been created manually, since the functions within the script are precisely adjusted to the corresponding objects. Despite the individual challenges, the method of the programming language for the reconstruction of the "Great Hall" offers a particularly good method for introducing gained knowledge and hypothetical assumptions into the generation of the models. In addition, thanks to the changeable parameters, vague information and alternatives can be incorporated into the reconstruction in a comprehensible manner, which means that hypotheses can be checked for plausibility.

Thanks to the procedural generation, considerable time savings can be guaranteed for the user since models would have taken several hours or days to create and can now be created in a few seconds to minutes.

Due to the integration of the findings of Guo and Franken and the possibility of checking hypotheses using individual parameters, the resulting reconstruction can be used for archaeological analyses and further studies (Franken 2015, Guo 1995).

Conclusion & Future Work

The work proved the feasibility of the application of methods of procedural generation for the object in question. By the usage of programming code and parameters choices made in reconstruction process are made explicit and different versions of the reconstructions can be generated quickly and be compared and analysed for their plausibility. However, the information is not embedded in the generated model itself. The resulting model also lacks the information as to why the parameters have been chosen for the reconstruction. At the current state, this information has to be stored along with the program code and the basic elements from which the model is generated. In future work, a deeper integration of this three elements within an appropriate data structure.

Author Contributions

Please list the contributions of the project participants here, according to the CRediT system. See specific descriptions of the role here: (http://credit.niso.org/). You can omit non-applicable roles.

Conceptualization: Dominik Klenk, Hendrik Rohland, Marco Block-Berlitz
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Supervision: Marco Block-Berlitz, Hendrik Rohland
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Writing – original draft: Dominik Klenk, Hendrik Rohland
Writing – review & editing: Christina Franken, Hendrik Rohland, Marco Block-Berlitz

References

Charleux, I. (2010). Qing Imperial Mandalic Architecture for Gelugpa Pontiffs Between Beijing, Inner Mongolia and Amdo. In E. Lehner, A. Harrer, & H. Sint, eds. *Along the Great Wall: Architecture and Identity in China and Mongolia*. Wien: IVEA-ICRA, pp. 107–118.

Cleaves, F. (1952). The Sino-Mongolian inscription of 1346: In memoriam Wladyslai Kotwicz. *Harvard Journal of Asiatic Studies*, 15, pp.1–123.

Franken, C. (2015). *Die 'Große Halle' von Karakorum: Zur Archäologischen Untersuchung des ersten buddhistischen Tempels der alten mongolischen Hauptstadt*. Bonn.

Guo, Q. (1995). *The Structure of Chinese Timber Architecture*. Göteborg.

Hüttel, H.-G. (2016). Die Stadt als Herrschaftssymol: Beispiel Karakorum. In Walravens, Hartmut, Müller, Claudius, ed. *Status und Symbol*. Neuerwerbungen der Ostasienabteilung. Berlin, pp. 63–82.

Hüttel, H.-G. (2009). Royal Palace or Buddhist Temple? On Search for the Karakorum Palace. In J. Bemmann et al., eds. *Current Archaeological Research in Mongolia*. Bonn Contributions to Asian Archaeology. Bonn, pp. 535–548.

Киселев, С.В. and Евтюхова, Л.А. (1965). Дворец Кара-Корума. In С. В. Киселев et al., eds. *Древнемонгольские города*. Москва, pp. 138–166.

Justyna Kolenda and Malgorzata Markiewicz. A medieval bishop's palace in milicz: 3d reconstruction as a method of a research hypotheses presentation. Studies in Digital Heritage, 1(2):428{443, 2017

Hua Liu, Qing Wang, Wei Hua, Dong Zhou, and Hujun Bao. Building chinese ancient architectures in seconds. In Vaidy S. Sunderam, Geert Dick van Albada, Peter M. A. Sloot, and Jack J. Dongarra, editors, Computational science - ICCS 2005, volume 3515 of Lecture Notes in Computer Science, pages 248{255. Springer, Berlin, 2005.