Long Paper

Rapid and Reproducible Reconstruction of Ancient Architecture by Procedural Generation

Reconstructing the "Pavilion of the Rise of the Yuan Dynasty" in Karakorum, Mongolia

Dominik KLENK, HTW Dresden, Germany
Hendrik ROHLAND, German Archaeological Institute / HTW Dresden, Germany
Marco BLOCK-BERLITZ, HTW Dresden, Germany
Christina FRANKEN, German Archaeological Institute, Germany

Abstract: This paper on Rapid and Reproducible Reconstruction of Ancient Architecture by Procedural Generation uses the 3D-reconstruction of the "Great Hall" of Karakorum as a case-study. Since the "Great Hall" is an almost completely destroyed building, a possible reconstruction turns out to be quite difficult. The aim was therefore to develop a method with which existing research and theories as well as connections to other architectural styles can be incorporated into the reconstruction. Accordingly, many different variants come into question for a possible reconstruction. Therefore, it is important that hypotheses are not tested on the basis of a single reconstruction, but that it is possible to visualise and discuss several different hypotheses in a short time. Such a method can be created with the help of a procedural generation. In order to implement possible hypotheses as a 3D model with this method, it is important that the generation of the 3D model can be influenced with the help of changeable parameters. In the following the connections to the Chinese architecture are explained, as well as related works and theories are taken up, which pursued similar approaches and goals. Furthermore, the procedure of reconstruction is explained, and the method of procedural generation is illustrated by the creation of the so-called Puzuo system. Finally, a possible reconstruction of the "Great Hall" is presented, as well as the Blender panel created in the course of the work to determine the individual parameters.

Keywords: *3D-Reconstruction—Reproducibility—Procedural Generation—Karakorum—Mongolia*

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1. Motivation and Introduction

The Mongol Empire spanned an area from Korea to Russia and Asia Minor in the 13th century. Its 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 jointongolian-German Karakorum Expedition (Mongolian

Academy of Sciences, University of Bonn, German Archaeological Institute) are exploring the remains of this intriguing urban centre of 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 formerly 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 (Figure 1). It most likely carried the famous, bilingual Sino-Mongolian inscription of 1346, which gave an account of the foundation of the city by Genghis Khan and the erection of a large Buddhist state sanctuary under the reign of Möngke Khan (r. 1251–1259), as well as 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) (Figure 2). This pattern 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 the combined information from the archaeological excavations and the written sources, a comprehensive reconstruction of the building can be ventured. Any reconstruction of ancient architecture, which is only recovered by the foundations and artefacts found in the rubble, suffers from uncertainties and must take other sources into account. Furthermore, an approach is needed to test different reconstructions to discuss their plausibility. The parameters that led to every single version must be made transparent, to ensure reproducibility and confirmability of the reconstruction hypothesis. This paper demonstrates how the method of procedural generation can be used to meet these requirements.

Fig. 1. The podium of the Great Hall of Karakorum or the "Temple of the Rise of the Yuan [Dynasty]" has been reconstructed on site as an open-air museum. The stone tortoise in the foreground, presumably once bore an inscription stele, eulogizing the erection and refurbishment of the state sanctuary by the Mongol rulers and providing some details about its architecture. (© DAI / C. Franken).

Fig. 2. In the aerial view, the general layout of the Great Hall of Karakorum can be seen. During archaeological excavation, a square podium was unearthed. On top of it, the traces of 72 granite column bases allow the reconstruction of the floor plan of the building. (© DAI / M. Riemer).

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 extrapolate 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 during 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.

2. Findings and Methodology

The general idea of the reconstruction is based on the method of procedural generation. The meaning of the terms procedural and generation are described by Shaker et al. as the use of computer procedures and algorithms to create content (Shaker, 2016). Here they see "content" as the key element because it is content that is decisive for creating objects or textures. Furthermore, they point out, that with the use of procedural generation, it is possible to create a huge amount of content in a short time. A precise definition of procedural content generation is: "Procedural content generation is the automatic creation of digital assets for games, simulations or movies based on predefined algorithms and patterns that require a minimal user input." (Freiknecht, 2017, p. 5). A first approach for the generation of buildings with a complex architecture was shown by Martin (Martin, 2005). He tried to devise a method to create buildings with more details and even internal design. He mentions that it is necessary to deal with the construction of buildings and to consider the theory of the respective architecture. Another comparable approach was chosen by Hua Liu et al. (2005). They emphasized that the Chinese timber frame architecture follows strict design constraints, which is why they use their own method called Constructive-Grammar (Hua Liu et al., 2005). This method is based on so-called patterns, which have prefabricated layouts for the columns, the walls, and the roof.

Further possibilities of the procedural generation are described by Giorgio Verdani et al. (2020). They point out, that procedural generation helps to speed up the process of generating models. By this, it is possible to try out different hypotheses and check their plausibility in a short period of time. As a result, it is possible that variants are generated that were previously unthinkable. In archaeology in particular, the possibility of procedural generation serves as a very powerful tool for discussions and discoveries (Müller et al., 2006).

Another approach with similar intentions was taken by Kolenda and Markiewicz for the reconstruction of an almost destroyed palace in Milicz (Kolenda and Markiewicz, 2017). 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). They see opportunities in 3D reconstruction in the fact that they were able to gain a better understanding of the form and function of the palace and in addition that it offers the possibility to experiment with the reconstructed model without concerns and to analyse alternative possibilities in terms of form and function.

2.1 Procedural generation depending on the prevailing architecture

For the reconstruction of the “Great Hall” the individual objects of each floor need to differ in size and depend on many different factors like the width of the bays, according to the Yingzao Fashi. For this reason, the method to use patterns for the reconstruction would involve a lot of effort. So, the approach of Kolenda and Markiewicz proved to be the most effective for the reconstruction of the “Great Hall” (Kolenda and Markiewicz, 2017). 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 individual, pre-defined objects. The workflow presented here is based on the 3D-modeling software Blender[1], that allows to automatize parts of the modelling process with the Python scripting language. The knowledge about the “Great Hall” and Chinese timber architecture laid out in the works of Franken (2015) and Guo (1995) have been integrated into the generation with the help of predefined rules coded into functions. By complying with the rules and findings, a flexible and traceable generation can be made possible in combination with changeable parameters.

For the reconstruction of the “Great Hall” several floors are generated to form the whole building. Every complete floor consists of a Puzuo system, a network of columns, followed by a middle Pingzuo and a second network of columns. Several different constructive units are shown in Figure 3, 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. Each function can in turn be individually influenced by various, user-entered parameters. To give an example, it is possible to define the number or the diameter of the columns, the width of the bays and the number of

[1] https://www.blender.org/

storeys. The values for these parameters can be gained from archaeological excavations, written sources and theories about the reconstruction of the building. The changing of only one of these parameters will considerably alter the appearance of the resulting construction.

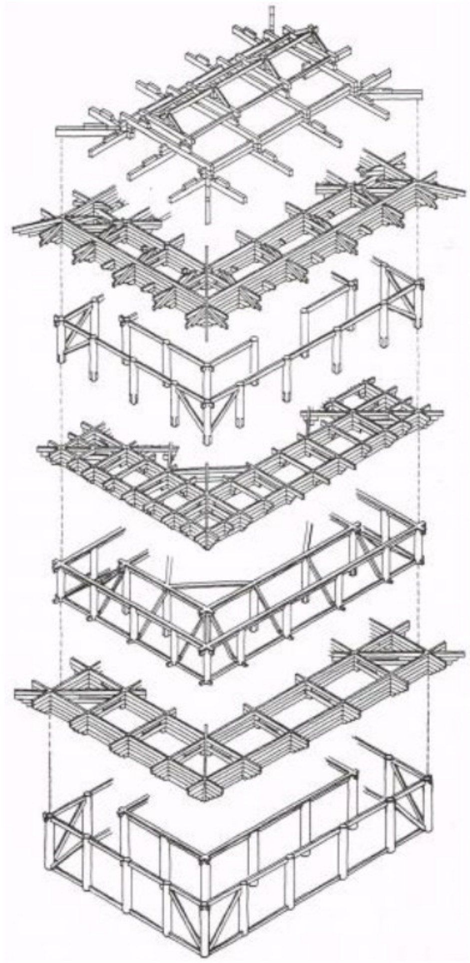

Fig. 3. Medival Chinese-style timber buildings of the dian ge type consisted of several storeys. The ground floor consisted of a network of columns and a puzuo unit, providing strength to the construction. Each of the upper storeys was made up of a substructure with a smaller puzuo for additional stiffness, a network of columns and another puzuo unit. On the last puzuo unit rests the roof construction. (© Guo, 1995, p. 67).

2.2 An example of the generation using the Puzuo system

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 Figure 4. For this reason, each component has to be generated by a separate function. The components are represented by pre-defined objects from an external Blender file. One component is placed on the columns at the corner of the building, one component on the beams between the columns at the corners, one component between the columns and two different components on the columns in the middle. In combination with a so-called mirror modifier, the parallelism of the buildings can be used to complete the reconstruction. Modifiers provided by Blender are used to influence the geometry and position of these objects.

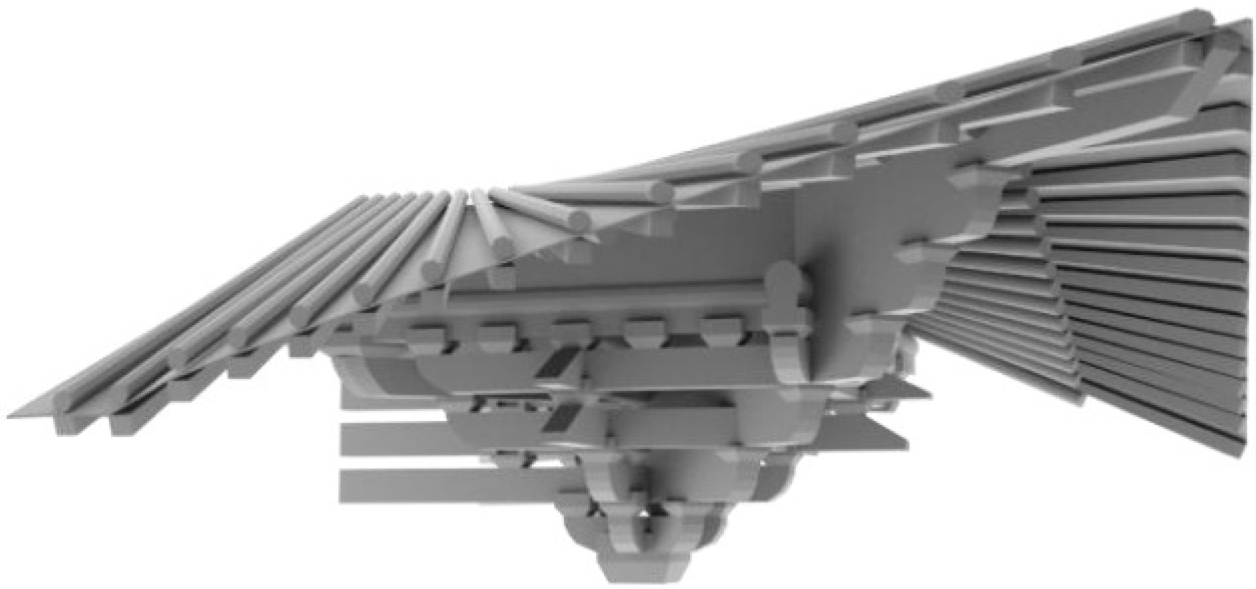

Fig. 4. The complex structures of the Puzuo system, such as these corner elements, where modelled manually and are being scaled, positioned and multiplied during the generation of the building as needed. (© Dominik Klenk).

With the help of the function that is responsible for the creation of the Puzuo system, these individual components, depending on the entered 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 building.

2.3 Programs used and the integration of the level-of-detail

The open-source graphics suite Blender in the version 2.92.0, 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 a specialised 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 is 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 reconstruction.

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 two different versions differ in the complexity of the mesh structures. 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. The ability to individually adjust the level of detail is important in respect of the problem, Brooks and Tobias (1996) describe: “For example, a model that is too simple will be unrealistic and so its results will be, at best, of little use, and at worst, misleading.”

3. Results and challenges

Two different reconstructions of the “Great Hall”, can be seen in Figure 5. They both take into account the archaeological evidence, establishing the floor plan and overall proportions of the building.

One of the main sources of uncertainty is the interpretation of the inscription of 1346, that describes the temple. It says: “The pavilion [was] five stories. It was three hundred ch’i 尺 high.” in the Chinese version (Cleaves, 1952, p. 29).

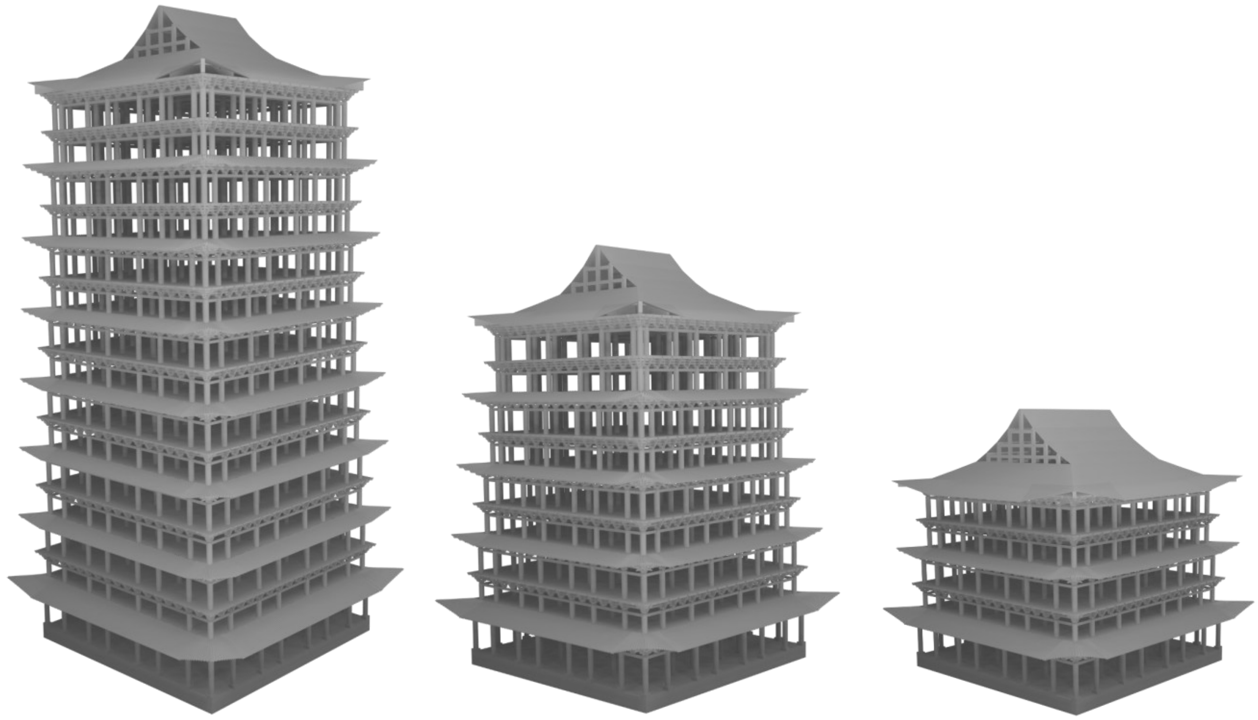

Fig. 5. The procedural generation allows for the quick visualization of hypotheses about the reconstruction. Here three competing hypotheses about the construction are visualized: The reconstruction on the left side visualizes the hypothesis, that, the inscription is to be interpreted literally concerning the absolute height of nearly 100 metres. The reconstruction in the centre is based on the inscription’s statement, that the building was five storeys high. The reconstruction on the right visualizes the hypothesis, that the eulogy written on the stele was a bit exaggerated, counting the substructures of the upper storeys as full storeys. This would lead to a building with effectively three full and two intermediate storeys. (© Dominik Klenk / DAI).

This statement leaves room for interpretation: The height of 300 chi – a Chinese measurement unit that is about a third of a metre – doesn’t seem very credible at all. According to the proportions laid out in the Yingzao Fashi for this building type, this would require. If the number of storeys is to be interpreted literally, the reconstructed pavilion would have been a huge tower, soaring about 60 meters high. However, a height of more than 35 meters has been doubted for structural reasons (Franken, 2015, p. 140). If the author of the inscription included the intermediate storeys into his count, a reconstruction with only three full floors would emerge, as is to be seen in Figure 5, too. The question cannot be finally decided at the moment, however, procedural generation allowed for visualization of both of the hypotheses for further analysis.

The five-storey generated model consists of a total of 315,348 verts and 250,955 faces when using the components with a low level of detail. The same model with a higher level-of-detail consists of 770,412 verts and 670,851 faces. As can be seen, the number of vertices and faces of the model can be reduced by a little more than half. The file exported for an augmented reality app is almost nine megabytes with a low level of detail and almost 25 megabytes with a high level of detail.

In conclusion, it can be said that the usage of a scripting language for procedural reconstruction offered a lot of freedom and flexibility as an approach to implementation. 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 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. For example, the generation of a complex object like a Puzuo unit within the script would turn out to be almost impossible. For this reason, it is highly recommended to create complex objects in an external Blender-file and add it into the reconstruction using a script. 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. So, there is almost no possibility of using other objects for the generation that do not correspond exactly to the dimensions and arrangements of the objects for which the script was implemented.

It is also possible that the script will not work like expected if the Blender version is newer or older. For example, during the project the Blender version was updated and the values for the rotation with Python have been changed and after this change, all objects faced in the opposite direction. Despite these 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 a transparent way. 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 quickly visualized and checked for plausibility.

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

4. Conclusion and Future Work

The work proved the feasibility of the application of methods of procedural generation for the object in question. By the usage of a scripting language 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. Since the uncertainties can be considered in this way, the models created during the reconstruction can be used for archaeological analysis and further studies. 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 these three elements within an appropriate data structure should be aimed.

4.1 Script and Blender-Panel

The script for the generation of the "Great Hall" will be provided[2]. To be completely sure that the script will work as expected it is recommended to use the Blender version 3.0.0, because it was developed to work with this version.

To use the Blender Panel, it is necessary to import the script via the "Scripting" tab. Inside the "Scripting" tab it is possible to add the script with the folder icon above the text editor. After the script was added, the source code should be visible inside the text editor area. Once the script has been added successfully it needs to be executed with the arrow icon above the text editor.

If the script was executed successfully, the panel should be visible in the 3D-Viewport of the "Layout" tab in the "Sidebar" labelled as "Tempel". It is necessary to use the "Object-Mode" and if the "Sidebar" is not visible, it is possible to open it with the "N"-Key or with the small arrow in the upper right corner. The panel should now be visible as shown in Figure 6.

Before it is possible to generate buildings with the panel it is important to add the path to the Blender-File, which includes the individual components used for the generation, as file path via the folder icon inside the panel. Now the individual parameters can be changed at will, and the possible reconstruction can be generated with a click on the "Generierung starten"-Button at the bottom of the panel.

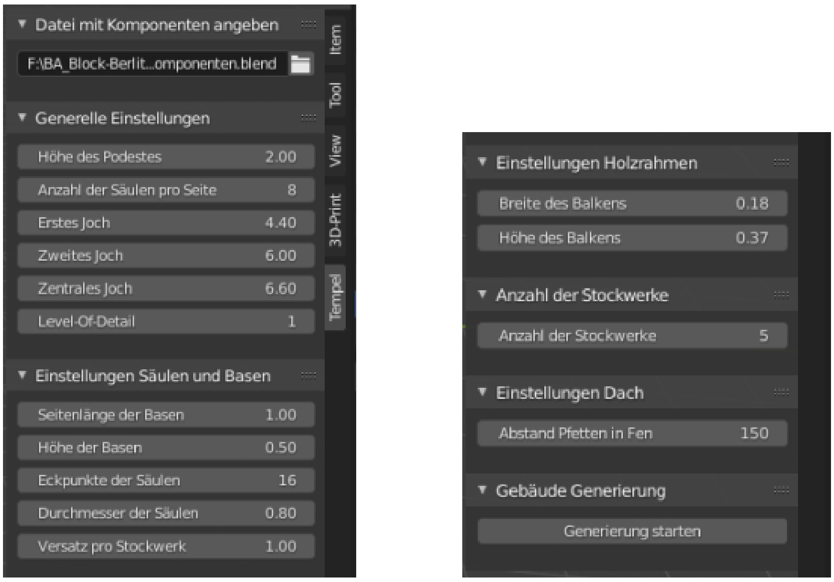

Fig. 6. The script also implements a Blender Panel with all important parameters for the reconstruction. This allows for experimenting with different assumptions about the structure of the building. (© Dominik Klenk).

Conflict of Interests Disclosure

The authors declare no conflict of interest to disclose.

Author Contributions

Conceptualization: Dominik Klenk, Hendrik Rohland, Marco Block-Berlitz

Methodology: Dominik Klenk

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Software: Dominik Klenk

Supervision: Marco Block-Berlitz, Hendrik Rohland

Visualization: Dominik Klenk

Writing – original draft: Dominik Klenk, Hendrik Rohland

Writing – review & editing: Marco Block-Berlitz, Christina Franken, Hendrik Rohland

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