Parametric Methods in Reconstruction of the Medieval Proto-Town in Pultusk, Poland

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This paper describes methods, processes and the outcome of the reconstruction in the medieval wooden settlement complex in Pultusk, Poland. It is the result of the interdisciplinary cooperation between architects from Warsaw University of Technology and archaeologists from Regional Museum of Pultusk. They have undertaken the research issues of information exchange and knowledge-building processes in the digital environment. Main issues were related to the methods of computer reconstruction in architectural and urban scale, which enable alternative narrative threads. To achieve this, parametric techniques were adopted and the 'Pultusk Reconstructor' application was developed in Grasshopper. The interaction between architects and archaeologists over hypotheses and alternatives was supported in urban scale by 'Rapid Reconstruction Modular Model'. This 3D printed urban model, consist of segments which can be simultaneously exchanged. It became not only a substrate for scientific debate, but also may serve an education role for the permanent Museum exhibition.

**Keywords:** Cultural heritage, Parametric design, Urban archaeology, Virtual reconstruction, 3D printing

**Introduction**

Knowledge of the cultural heritage covers an area represented by multiple scientific disciplines. This knowledge, as a matter of interest to archaeologists, historians, architects and urban planners, is consistent on the substantive issue (knowledge acquisition), but differs in methods. The issue is widely considered by Andrzej Tomaszewski, indicating that regardless of differences, common is the need to fully and objectively present the results, which complement the knowledge (Tomaszewski, 1999). The merits of interdisciplinary research also follows Maria Brykowska noting that the reliability and logical reasoning remain independent from technology, but can be effectively supported by them (Brykowska 2003). So it is with parametric techniques which can be used whenever dynamic processes are crucial, especially in the design. They also attract the interest of scientists in other disciplines of scientific exploration. Digital 3D modeling which uses procedures and mathematical functions is exceptional because the objects are treated as a hierarchical component
system based on parameters and variables. It can be understood as strategic actions plan enabling the implementation of partial tasks. This strategy was used in the research work on the reconstruction of medieval settlement complex in Pultusk. It helps not only for mapping its form, but also recorded changes in its lifetime at the turn of the XIII - XIV century. The shape grammar rules formulated for wooden huts and algorithms of transformation enabled the efficient reconstruction of buildings and in consequence the entire complex. The cyclical nature of the process (fig. 1) allows the input data entry of all relicts located in archaeological stratigraphy layers. As a result this algorithm can be used to simulate the time factor in order to restore the 140 years of Pultusk settlement existence.

**Artifacts as the basis for the reconstruction**

In the 70s of the XX century, for more than 10 years, archaeologists conducted excavations in the castle courtyard in Pultusk. The outcome were superbly preserved remains of hundreds of wooden structural elements (huts and streets) and several thousands of everyday objects. The features of Pultusk excavation were found in stratified form, one layer upon the other. This allowed to determine the chronology in which 17 layers of the east street became the basis for relative dating. During the next 30-years the artifacts were laboriously analyzed and documented, usually in analog form. Over a 150 wooden corner-joint huts were precisely described (Mierosławski, 1985). Although the excavation area covered about 40% of the medieval settlement, archaeologists presented the thesis that the whole complex may be defined as the proto-town. Information gathered by archaeologists formed the basis of reconstruction activities. This required analysis, new alignment of data and digitalization. The collection of archival materials included among others: excavation boundaries, grid system over the site (10x10 m), more than 470 plans of wooden constructions elements in scale 1:20, plans of huts relics in scale 1:50 and tens of thousands of Z coordinates for points which represent excavation layering. The reference system was based on the geodesic map in scale 1:500, the grid and the castle walls. All this information helped to

![Figure 1](https://example.com/f1.png)

**Figure 1**

Diagram for reconstruction. Relicts are the basis for elementary hut models. Huts, terrain and streets form the urban layer. This expands knowledge and helps interpretation for upper layer. Procedure is cyclical and allows reconstruction of urban structure in space and time.
build up 17 models of relics in stratigraphic layers of the east street and based on principles formed by Edward C. Harris (Harris, 1979). This represents the chronology of urban layout (fig. 2).

**Digital terrain model**

Terrain model for level 04 of the east street was the basis for the later steps of proto-town reconstruction. It was selected as the most representative of the original urban plan because of the amount of preserved huts. Plans of relics were turned into flat vector graphics. Then Z coordinate information's were applied. They cover only the excavation area. Points outside this area were obtained in three steps. First step was to develop terrain cross sections by analyzing archaeological information and geological data. They were used to generate a surface. Second step was to cut the surface by horizontal planes every 50 cm. In effect contour closed curves were obtained. Third step was to generate points on curves. Moat in relation to the Narew river was a research hypothesis due to lack of information. Points defined by archaeologists and generated from contour lines as well as moat edges made possible to reconstruct model of terrain for level 04. On the model have been applied polygons of inventoried huts and hypothesis of other structures outside excavations: bishop’s residence, entry gate building, palisades and putative streets layout (fig. 3).

**Archaeological facts: parametric huts**

In traditional techniques of 3D modeling, which is surface or solid creation, implementation of dozens of objects would have been ineffective. Each object has to be built independently. Reconstruction of all wooden corner-joint houses in Pultusk could take months or even over a year. However, it was noted, that wooden structures are governed by certain rules. Analysis of the individual huts made it possible to identify the characteristics of their geometry. Specific cases of its shape and their mutual relations were observed and defined. This allowed the algorithmic approach to the problem and uses a shape grammar strategy. Linking huts with vestibules is nothing else than the relationship of two quadrangles where one side is situated on a common straight line. 64 variants of mutual positions where found (fig. 4).

In practice various forms of quadrangles and dimensions allow creating any alternatives for a hut with frontal vestibules. The algorithm was implemented in Grasshopper. Each program block is responsible for structural elements of the hut. Components are controlled by over 50 parameters - which controls position of the corners of the hut and vestibule, dimensions and position, including the location of the door and wholes in the walls.
Complex houses, which consist of more than one hut and vestibule, use Rhino philosophy which able user to turn elements on or off and "bake" them in Rhino virtual space. The implementation named *Pultusk Reconstructor* had been developed with its unique user interface controlled by dialog box programmed in VB Net language (fig. 5). The parametric application allowed reconstructing and almost fully reflecting architectural objects inventoried during excavations. In fact, some houses, which where built with another carpentry technique, had to be reconstructed with use of solid modeling.

**Research hypotheses: palisade, entry gate**

Complementing the reconstruction of the huts were hypotheses about fences and the gate. The shape of fencing is still discussed by archaeologists due to lack of information. It was considered that the excavations carried out in the "border zone" were so random that they were unable define its final form. In conclusion, it was thought that corner-joint palisade fencing was build in Pultusk (Stabrowska, 2002). The study started with two-dimensional drawings. The research was carried out on the dependence between 'true' information which comes from excavations and probable information from the synthesis of data and logical thinking. The modeling process helped to define the basic parameters of the palisade, among other things its average height. This value was verified during the work on the possible shape of the gate. Radial street layout marked its location. Using *Pultusk Reconstructor*, the story house was built with the huge whole of gate generated with solid Boolean operation. The gate building were compared with the palisade and a coherent picture was received and the elements fitted together (fig. 6). Palisade structural stability has been verified by a model in scale 1:20 with use of 3D printing technology. Palisades' beams, which represent two spans, were printed as separate elements. Only three vertical beams are foundations based in a model (nodes of corner-joint construction). The whole construction proved to be stable. In this way it was demonstrated
that the palisade foundation did not have to be linear. The possible reason might be that archaeologists had not found its remains. The digital models of the palisade and gate building were also used in urban model in scale 1:100. Located in the area with bishop residence, they where a background for huts' relics, which were scientifically developed by archaeologists and digitally reconstructed with use of Pulkusk Reconstructor application.

**Proto-town modular model**

In the reconstruction of the settlement complex two 3D-printed models were completed: architectural in the scale of 1:20 and urban in the 1:100 scale. The first one represents two adjacent huts near palisade (fig. 7). The terrain and relics have been developed realistically and reconstructed elements where left in the natural color of printer filament. The model consists of separate components and is fully demountable. It is an illustration of the join-corner structure, represents palisade hypothesis and can be used as a tool for education. The urban model has modular structure and allows alternates for architectural and urban solutions (fig. 8).

Acronym R2M2 comes from Rapid Reconstruction Modular Model. The name reflects its most important features. The basis of the model is a frame consisting of a laser-cut modules 10x10 cm, corresponding to an archeological grid and frame structure for segments of the terrain. The recess for huts and streets where traced on the surfaces. The model consist of 120 terrain segments, 11 palisade sections, over 40 huts, gate building and bishop's residence. Huts, which were explored by archaeologist, are marked with color (fig. 9). This model allows an exchange any item and can be a tool to verify even different hypotheses. For example, the bishop's residence were discussed on three different 3D-prints.
Reconstruction renderings

An important issue was the graphical representation of the results. It is usually expected that the renderings will be close to the real pictures, but it is nearly a passive use of technology. Renderings used in the reconstruction visualize selected features of an object but are also to give imaginative atmosphere of a place, support situational background, and highlight the formal values. It is important that renderings should be used according to the purpose for which they are intended. During the work on the Pultusk settlement, an agreement was reached for representation of the relicts and its reconstructions in confrontation with other objects based on hypothesis and imagination. Reconstructed artefacts have realistic shape while every other object is stripped of color and even rendered transparent, to emphasize their scientific uncertainty (fig. 10).

Conclusions

The potential of parametric modeling is limited only by the user’s knowledge and imagination. It should be presumed that in any field of science new areas of use will be discovered. The key issue seems to be the possibility of dynamic evolution of the object under the influence of parameters. The object’s information determines the logical structure of phenomena (objectively) or user (subjectively). Parametric techniques are usefull wherever reconstruction process refers to more than a few similar objects. This includes the reconstruction of an urban structure with plots, buildings and streets. With this method, the form of the model is never final and immutable. It may be subject to constant review, in accordance with the current state of knowledge. An analogous analysis can be a problem to simulate the phenomenon of the time. Relative dating refer directly to the stratification of the archaeological site, and in practice means that the lifetime of a historical object is not represented in a continuous manner, but with the characteristic points on the timeline, defined by the explored layers. Research supported with parametric techniques is as a research tool extremely effective and in verification of hypotheses almost irreplaceable. It enables multi-threading activity and alternative trains of thought. It also supports research on the analysis of the source material and is a basis for action aimed at synthesis and conclusions. It is an indispensable platform for dissemination of knowledge and a tool to promote the conservation of cultural heritage.

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Figure 10
Huts reconstructions based on relics are in color. Hypothetical objects are transparent.