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Metrological approach to the study of Central European regular cities

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In this paper we want to explore the workshop of medieval surveyors to better understand the circumstances of emerging and evolution of the medieval towns'. On the basis of two examples from Silesia, Poland - Namysłów and Dzierżoniów, we illustrated problems connected with application of two methods: modular analysis and cosine quantogram. We discuss their usefulness for reconstruction of the original measuring system and town's layout. Despite the limitations as: level of precision in construction of medieval town's layout at the moment of its foundation, later changes of plots division and known inaccuracy of modern maps, it seems that combining both methods improves the methodology of urban analysis of historic towns.

I. INTRODUCTION

Imagine you are a surveyor, hired to plan a new town in the middle of nowhere using only a rope and a stick. Is it possible that the effect of your work will be visible after hundreds of years?

The issue of surveying and dividing the *intramuralis* area of the medieval town has been a subject to an academic debate [eg. 1-4]. Research on reconstruction of the primary layout of medieval towns in Central Europe had a long tradition [eg. 5-7]. The debate was mainly stimulated by historians, architects and urban planners, however few archaeologists influenced the discussion as well. Central Europe from the 12th to the 16th century was a place of urban and rural revolution. As a result of colonization action, hundreds of towns and thousands of villages were newly established. Regular town was a result of implementation of so called German law in spatial dimension. Towns with market square and orthogonal grid of streets appeared very early, at the beginning of the 13th Century in Silesia, region of today's Poland. During this period some improvements of a layout of towns were made: evolution from a market street to rectangular or square market took place, also the length of building blocks and dimension of plots were optimized. Silesian model of regular town was used in neighboring lands.

Where the medieval towns really planned with mathematical precision? And even so, is it possible after all these years to reconstruct the idea of medieval urban planner bassing on modern cadastral plans?

II. METHODS

In this paper we try to combine method of modular analysis of town layout with cosine quantogram, which are the methods of two different approaches. In the first one the unit of measure has to be established. In the second one the unit is unknown.

A. Modular analysis

Modular analysis or meteorological-geometric analysis method allows reconstructing the parcellation based on a module. The method assumes the existence of a module that can be found in the city structure (ex. area of the market square, dimensions of the building blocks, width of streets). Among the lengths of basic objects on town's plan, a pattern of "round" multiplications (50, 100, 150) of the base unit (foot) length is searched to establish which measure system was used for the planning by medieval surveyors. Having established a base measure system, the whole plan is fitted into a rope-length grid, recalculating the lengths to the multiplication of the rope

lengths. The modular analysis method is widely criticized for its susceptibility to errors resulting from inaccurate measurements made on historical plans and dependence to the arbitrarily selected basic length unit.

B. Cosine quantogram

Cosine quantogram is a method of reconstruction of the smallest basic unit used in the design and construction process. Funcionwas developed by D. G. Kendall for detecting a quantum of an unknown size from a set of data [8]. A statistical model of cosine quantogram, has successfully been implemented during the analysis of architectural sites of Mediterranean culture, successfully applied to studies on the layout of the early medieval Anglo-Saxon settlements [9] and even in meteorological analysis of architectural units in Incas's archictecture on Machu Picchu [10].

In a case medieval town planning each parcel dimension X_i can be described as an integer M multiplied by the basic unit q plus an error ε (episilon) i.e.. The error might be a result of inaccuracy in the layout of the medieval city as well as todays methods of measure (1).

$$X_i = M_i q + \varepsilon_i \tag{1}$$

Where M is the sample size and is the set of building dimensions. osine quantogram function is defined as:

$$f(q) = \sqrt{\frac{2}{N}} \sum_{i=1}^{n} cos\left(\frac{2\pi X_i}{q}\right) \tag{2}$$

Applying (1) to (2) reduces the integer M and makes the formula depend directly on ε - the remainder of dividing a measurement by q. In the equation ε which is significantly smaller than q is analysed and then formula calculates an amount which clusters around q. The value of q which maximizes the formula within given range is the one with the highest probability of being a quantum. (3):

$$f(q) = \sqrt{\frac{2}{N}} \sum_{i=1}^{n} cos\left(\frac{2\pi \varepsilon_i}{q}\right) \tag{3}$$

The main problem of application of cosine quantogram to urban studies is the small size of the sample. We usually can get only a dozen, rarely few dozens of measurements. To make sure that estimated quantum is neither evaluated by chance nor dominated by some outlier measurements we applied Monte Carlo bootstrap method, used to construct confidence intervals – the estimation of most possible quantum values range. Assuming 5% significance level, if quantum estimation for original data falls within the confidence interval, it can be interpreted that the risk of quantum happened by chance is very low.

III. CASE STUDIES

For evaluation of described methods we choose two regular towns from Silesia, founded in developed phase of colonisation. Both towns were founded on *cruda redis*, so no previous settlements affected their shape. In both towns some architectural and archaeological excavation confirmed the existence of medieval masonry buildings, witch presence can bring information on localisation of medieval plots boundaries.

1. *Namysłów*

Namysłów was located according to written sources around 1250 [11]. Layout of the town is quite well preserved. Small changes of building blocks lines are connected with the existence of wooden buildings and arcades around the market square and some introduction of new buildings after World War II damages. Nethertheless, northern frontage of market square was fully built from bricks in the 14th-15th century, which freeze the medieval boundaries of plots. It gives opportunity to verify the measurements made on cadastral plans of town in the field and cheque the accuracy by measuring fasades of the tenement houses.

First of all we calculate the quantum from the archive data, used to establish the original dimension of urban plot with neighbouring plot method. Cosine quantogram function get clear result - 0,25 m. But comparison of this result with the quantum from field measurements of tenant houses was confusing (Fig. 1).

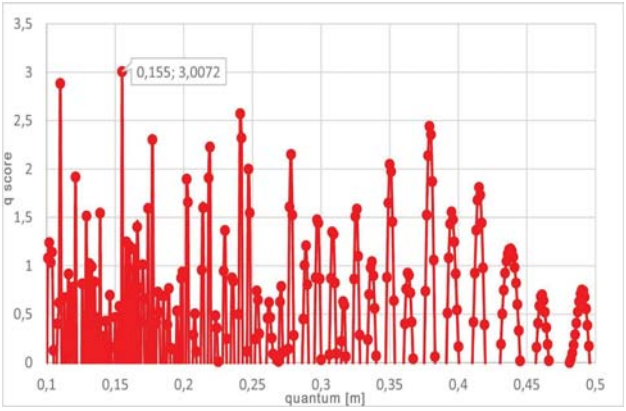

Fig. 1. Namysłów, cosine quantogram from field survey data set.

The value of quantum from field measurements was

0,155 m, which was nearly half of the foot value known from the written sources - 0, 313 m so called renish foot, however the value of 0,25 m was not the value of unit used to measure the town.Wrong result was influenced by the accuracy to which the actual measurement values were rounded.

Nevertheless the application of cosine quantogram proofed, that in case of Namysłów northern building block witch medieval plots division is still preserved.

With already confirmed unit of measure - renish foot - 0,31 m, we tried to apply modular analysis of town plan. We built the modular grids based on 3 different units used in medieval Poland: modular grid: 44,5 - based on 0,296 m foot standard; 43,2 - 0,288 m (chełmińska); 46,5 - 0,31 m, to compare the results. Our reference for fitting a grid includes location and orientation of the most important elements of the town: like the main frontage of the blocks (the west one) and very well preserved north frontage of the main square. Borders of the grid should finish within the line of fortification. and tried to adjust it to the main elements of town (Fig.3)

Fig. 3 Namysłów, matching different sizes of grids to the town plan

The differences between the matching of individual grids were not large, however, it was possible to say that the most elements from the preserved layout of the city fit into a rope grid with a side of 46 m (foot 0,31 m). The market has dimensions of 3x1,5 ropes and area of the whole regularly planned town was fitting probably into a grid 6x9 ropes.

1. *Dzierżoniów*

Location of Dzierżoniów (ger. Reichenbach), took place around 1260 [12]. The organization of the city center is based on the model of cross, with a centrally located market square and streets intersecting in the center. The course of the city walls surrounding the city is almost round.

We started the analysis of the plan of Dzierżoniów from fitting the rope-length grids into the town plan the same way as before (Fig. 5.). The most regular part was the market, with dimensions around 2x3 ropes. Although the western and eastern fronts fit well into the grid, the southern and northern frontages are withdrawn. Seemingly regular streets after the imposition of the grid seem to diverge, which is to a certain extent the result of uneven terrain and the town's location on the hill. It seems that area of the medieval town was fitting into square of 10x10 ropes The most probable rope used was rope 43,2, which corresponds to the foot of 0,288 m (polish foot).

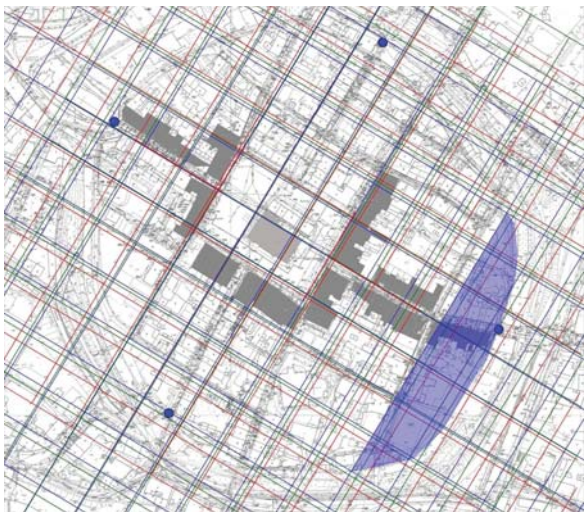

Fig. 5. Dzierżoniów, matching different rope-length grid into the town plan.

We tried to verify the exact value of basic unit used in town measurement using cosine quantogram. In case of Dzierżoniów, there are only few tenant houses, which can be built with preserving boundaries of medieval plots. Archaeological surveys conducted in eastern block document the significant transformation of the former buildings. Estimation of quantum for the widths of present plots did not give a similar value to any historical foot. Although after reconstruction of potential medieval plot division, basing on the results of modular analysis and neighbouring plots method, archeological survey and analysis of preserved boundaries, we tried to cheque the existence of potential quantum in reconstructed model of town (without later divisions of plots). The value of quantum was 0,272 m and was differed from the expected value by 0,016 m (Fig 6, 7). This error does not seem gross, if we take into account that measurements were made of the plan with accuracy about 0,10 m.

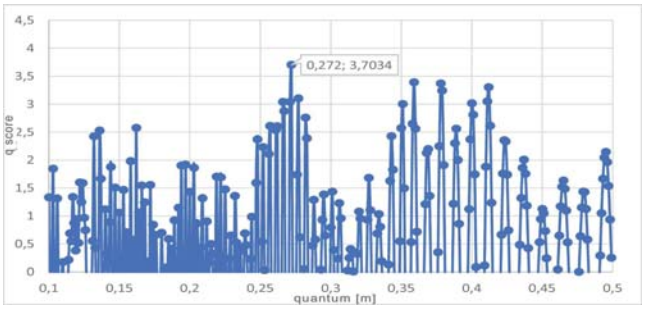

Fig. 6. Dzierżoniów, value of quantum for reconstructed plot division of eastern frontage.

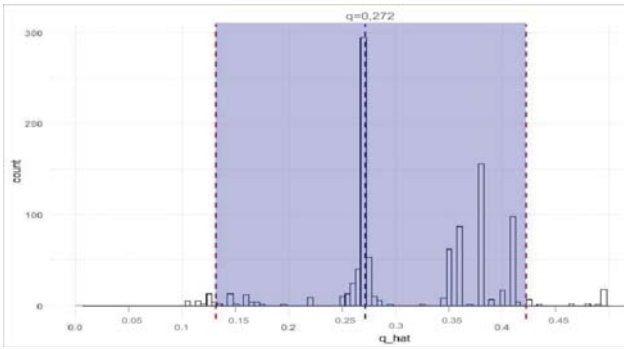

Fig. 7. Dzierżoniów, bootstrap confidence interval for quantum 0,272 m.

Even if the quantum value obtained as a result of disturbed measurements is not identical to the expected one, the quantum can be an indication in the selection of the unit used in specific period of time. In this example value of quantum 0,272 m is closer to polish foot (0,288 m) than renish (0,313 m). We presume that more precise measurements made in the field can make the quantum value closer to the original unit of measure.

IV. DISCUSSION

Studies on reconstruction of layout of medieval towns face many limitations. First group of limitations is connected with the essense of the measured object. Inaccuracy was made already at the time of foundation of the town. could be caused for example by human errors, terrain conditions and imperfection of tools used during measurement as rope and rod. Second group of limitations is the result of numerous transformations of the original layout. In many cases of Central European small towns, they were primarily built with wooden buildings, which did not perpetuate the original boundaries, including the arcades occupied the space of street or market square. Even the early introduction of masonry buildings did not preserve the original boundaries, as the law allowed the construction of frontier walls with the use of a neighbor's plot. Numerous distortions in the original arrangement of building blocks have also been lost as a result of divisions and linking of neighboring plots. Third group of limitation is connected with inaccuracy of modern plans used for analysis. The accuracy of big scale maps is about 0,10 m. This value is rather big, when we think of determinate units of length between 0,27-0,35 m. Only in the few examples we have boundaries of plots confirmed by archaeological excavation (ex. Wrocław, Kraków, Głogów).

Even in the most regular towns only the central part, near the square market is regular and the further from the market, the more irregularities. It is caused by process of towns building which took decades. Fortifications, built even a hundred years after the towns location, usually cut off the rope-length grid.

Only in Silesian and Lesser Poland towns there are few known systems of measurements in which basic value varied. Depend on the time period, location, role and foundation of the town we can expect differences in the value of module. In some cases we have written sources where the standard measurements where mention but in the vast majority of cases only driven analysis can bring information about the measure used to plan the towns layout.

Results presented above indicate that application of metrological methods in urban history studies has many limitations and requires holistic and interdisciplinary approach. For this reason we will focus our studies on silesian regular towns with large excavated areas in the city centres (for. ex. Glogów, destroyed during World War II, Wrocław). In those cases archaeological excavations made evidence of original plot's boundaries. In our further studies we will try to apply the methodology we adopted for regular cities founded on *cruda redis* in Western Europe, e.g. France, Italy. The appearance of stone houses there, build shortly after the process of location should affect the stabilization of measured boundaries in the city structure, therefore the results obtained in the measurement analysis should be more accurate.

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