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# GIS tools for analysis of city morphology and metrology using the square grid method

## Narzędzia GIS do analizy morfologii i metrologii miast metodą siatki kwadratów

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***Abstract***

*The main aim of the study was to present the possibility of using GIS (Geographic Information System) tools for measurement analysis of urban spatial layouts, using the square grid method, on the example of three medieval towns from the area of the former Teutonic Order (currently the territory of Poland) (Musiaka, Nalej, 2021). Determination of measurement modules of town layout, especially for a larger group of towns, was a very time-consuming task. New methods of spatial analysis using GIS tools have helped in the implementation of this type of research. Using the Python programming language, authors developed the HGIS Tools toolkit consisting of two tools: HGIS Fishnet and HGIS Fishnet Rhombus. First tool is based on the CreateFishnet_management (...) function of the ArcPy package and allows to precisely adjust the grid to the research area determined on the basis of the city plan. The second tool uses the UpdateCursor (...) function and allows to create a rhomboid grid. The obtained results confirmed that HGIS Tools allowed to determine the hypothetical measurement module of the studied towns layouts. The results were consistent with analysis conducted with the traditional square grid method and showed significant potential of HGIS Tools in conducting morphometric analysis of urban spatial systems on a larger scale.*

**Keywords: HGIS, historical GIS, urban morphology, fishnet, GIS tools**

*Słowa kluczowe: HGIS, historyczny GIS, morfologia miast, siatka, narzędzia GIS*

## Introduction

The main aim of the study was to verify the possibility of using GIS (Geographic Information System) tools in the analysis of the morphology and metrology of cities using the square grid method, based on the example of selected medieval cities (Musiaka, Nalej, 2021).

The study of cities morphology and metrology is a multistage process, including the metrological analysis of city plans, historical studies of non-cartographic sources, as well as archaeological and architectural studies. One of the stages of the research is the determination of the size of the measurement modules of urban spatial systems, i.e., the discovery of the measurement units of distance and area used for staking the grid of streets and urban blocks of cities in the field.

The method used for this type of analysis is a square grid (Golachowski, Pudełko, 196; Pudełko, 1960; Pant, Funo, 2005; Krasnowolski, 2008, 2015; Malik, 2015; Warner-Smith, 2020). The knowledge of the dimensions adopted when staking out city modules makes it possible to explain the origins and stages of development of a given settlement (Kulesza, 2011). It is not an easy task because it is very rare to meet geometrically perfect cities. Usually, their original plans were distorted by terrain constraints, such as river meanders, steep hills, old buildings, and roads, or ownership divisions (Smith 2007). New cities founded on a " raw root" or in previously uninhabited places had a greater chance of having a regular network of streets and urban blocks (Boerefijn, 2000). Discovering the size of the modules of urban settlement systems, especially for a larger group of cities, was a very time-consuming task due to the necessity to manually drawing a set of grids of squares with different cell size and scale. These meshes were drawn on copies of city plans, often by trial and error, until a matching module dimension was found. Advances in computerization came to the rescue of this research. In the last twenty years, new methods of spatial analysis have appeared, using GIS tools, as well as Historical Geographic Information Systems (Historical GIS or HGIS) dedicated to historical research, which allow for the improvement of traditional research methods and data processing (Kvamme, 1999; Gregory, Ell, 2005; Gregory, 2021; China Historical GIS, 2021; Dempsey, 2021; Mapping Medieval Chester, 2020; Atlas Fontium, 2020; Jeremicz, Kowalski, Kuna, Przystojecki, 2020).

## Materials and methods

In the presented research, the possibility of using GIS tools to carry out a morphometric analysis of the plans of three medieval cities of the Teutonic Order in Prussia (now in Poland) was tested. Selected urban centers are characterized by a regular spatial arrangement, typical of late medieval cities. The "Create Fishnet" tool available in ArcMap

10.7. and the “Create grid” tools from QGIS software were used in the initial phase of the research. Tests showed that the functionality of these tools is insufficient to conduct morphometric analysis, as they do not allow for full adjustment of the applied square grid to the shape and orientation of the studied areas. This significantly limits their usefulness, especially when analyzing a larger number of city maps. For this reason, work on the creation of GIS tools that allow for a better adjustment of the square grid to the studied area was undertaken. For this purpose, the Python programming language and ArcPy package, which provides access to geoprocessing tools as well as additional functions, classes, and modules of ArcGIS software were used. HGIS Tools were created for ArcGIS 10.7. release and placed in a toolbox that can be added to ArcToolbox.

The HGIS Tools kit consists of two tools: HGIS Fishnet and HGIS Fishnet Rhombus. The first tool is based on the CreateFishnet_management (...) function of the ArcPy package. The main innovative function of the HGIS Fishnet tool is the ability to precisely adjust the mesh to the research area determined on the basis of the city plan. The functionality of the tool allows to create any number of meshes with different mesh sizes. The mesh location must be defined by the user as a rectangle – polygon saved in a shape file. This allows for acceleration and significant automation of work with minimal requirements for the user, who has to define only four parameters: the workspace – the location where the output layer (grid) will be saved, the name of the output layer, the location of the shape file containing the range of the study area and the grid cell size. In addition, the authors made it possible for users to choose the cell size from the list of medieval distance measures. In addition, the HGIS Fishnet tool allows to set a different cell width and height by filling in the "Multiple" field.

The second tool allows to create a grid for a nonrectangular study area. HGIS Fishnet Rhombus allows to create a grid with diamond-shaped cells. The principle operation of this tool is different than that of HGIS Fishnet. Grid geometry (α and β angles) is based on the drawn polygon (tetragon) that includes the study area. The tool mainly uses the UpdateCursor (...) function from the ArcPy package and creates construction lines, parallel to the boundaries of the examined area, at user-defined intervals equal to the cell size in the list or defines it directly as the value in meters. Then the construction lines are converted into a grid with the selected cell size.

## Results

The possibility of using GIS (Geographic Information System) tools in the analysis of the morphology and metrology of cities using the square grid method has been checked by applying a series of grids to archival and contemporary maps of selected cities: Elbląg, Grudziądz, and Nowy Staw. In the studies, mainly digitized maps of the above-mentioned

cities and orthophotomaps at various scales were used. The time range of the selected cartographic materials is 1710–2020. Historical cartographic materials were spatially fitted using the georeferencing tool available in the ArcMap software. The mean square error (RMS) was used as a measure of the quality of the spatial fit. Based on the literature (Giętkowski, Zachwatowicz, 2010; Wolski, 2012; Zachwatowicz, 2012), the obtained RMS values and the number of ground control points (GCP) were considered sufficient to conduct the study.

The possibility of creating multiple meshes was tested, as well as applying them to calibrated maps and plans of selected areas in various configurations. In addition, the correctness of the operation of HGIS Tools was confirmed by comparing the designated measurement modules of urban spatial systems with the results of studies carried out for these cities using traditional methods, the results of which are described in the literature. The tests confirmed the usefulness of HGIS Tools for morphological and morphometric studies of cities.

## Summary and conclusions

A certain limitation in the use of HGIS Fishnet Tools may be caused by errors in the calibration of historical maps. However, the proper preparation of source materials and taking into account the occurring calibration errors allows for efficient and time-saving analysis. Another limitation in using the tools is their incompatibility with software other than ArcMap. HGIS Fishnet Tools do not cooperate with ArcGIS Pro and opensource software, such as QGIS. However, it is possible to develop the tool and adapt it for use in other types of software.

The analysis showed that in the study of city morphology and metrology with the use of square grid method, HGIS Fishnet Tools demonstrated good functionality and speed. Tools can be especially useful when the survey covers more than one city. The greatest advantage of the proposed tools is the ability to easily and quickly adjust the cell size to the calibrated maps or city plans, while traditional methods require drawing separate grids for plans in different scales. HGIS Fishnet Tools also provide a custom fit of the grid to the study area and the ability to automatically convert historical units of measure to modern and vice versa. Additionally, the tools make it possible to easily compare and analyze the results for many cities and to apply grids to contemporary cartographic materials (including Numerical Terrain Models - DTM and orthophotos). HGIS Fishnet Tools set has been made available and may be used in other research under the terms of the CC BY Creative Common license (Musiaka, Nalej, 2021).

***Streszczenie***

*Głównym celem badania było sprawdzenie możliwości wykorzystania narzędzi GIS (Geographic Information System) do analizy miejskich układów przestrzennych metodą siatki kwadratów, na przykładzie trzech średniowiecznych miast zakonu krzyżackiego w Prusach (obecnie w Polsce) (Musiaka, Nalej, 2021). Określenie wielkość modułów miejskich układów osadniczych, szczególnie dla większej grupy miast było zadaniem bardzo czasochłonnym. Z pomocą w realizacji tych badań przyszły nowe metody analizy przestrzennej, wykorzystujące narzędzia GIS. Korzystając z języka programowania Python, autorzy opracowali zestaw narzędzi HGIS Tools składający się z dwóch narzędzi: HGIS Fishnet i HGIS Fishnet Rhombus. Pierwsze z narzędzi bazuje na funkcji CreateFishnet_management (...) pakietu ArcPy i umożliwia precyzyjne dopasowani siatki do wyznaczonego na podstawie planu miasta obszaru badań. Drugie z narzędzi, wykorzystuje głównie funkcję UpdateCursor (...) i umożliwia tworzenie siatki o oczkach w kształcie rombów. Otrzymane wyniki potwierdził, że narzędzia HGIS Tools pozwoliły określić hipotetyczny moduł pomiarowy układu badanych miast. Wyniki były zgodne z analizami innych autorów przeprowadzonych tradycyjną metodą siatki kwadratów i wykazały znaczny potencjał narzędzi HGIS w prowadzeniu analiz morfometrycznych miejskich układów przestrzennych na większą skalę.*

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