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Section: Technologies of Geodesy and Cadastre

Network models of 2D and 3D carastral data

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Abstract

Cadasters are an important element of the national infrastructure. Decision-making processes relating to economic activities and crisis management rely mostly on cadastral data. Those processes require geographic information system (GIS) tools. Cadastral models are developed for analytical purposes. Those geometric and topological models are closely related to 2D and 3D space, and they illustrate the connections between cadastral objects. Cadastral models are developed in space in the form of graphs. The basic models of cadastral structures are described in detail in LADM (ISO 19152). The aim of this study was to develop and present a method for building network models of 2D and 3D cadastral structures with the use of CAD and GIS tools. The models are based on data structures available in the relevant applications. The results were presented in view of the available data from a 2D cadastral map and 3D building data. The generated models are presented in geometric format. They are used in network analyses during crisis management operations, and they support evaluations of spatial structures.

Keywords: cadaster; struktural model of cadaster data; cadaster 2D end 3D.

1. Introduction

The Land Administration Domain Model (LADM, ISO 19152) was approved on 1 November 2012. The standard incorporates four packages related to:
1. parties (people and organizations);
2. basic administrative units managing ownership rights;
3. spatial units describing cadastral structures – parcels, buildings, utility networks;
4. spatial sources (surveying) and spatial representations (geometry and topology).

This study focuses on packages 3 and 4 related to spatial data. Geometric and topological representations of cadastral data have been researched extensively for many years [2–7]. Data is managed in classes with a topological organization [8, 1]. Topology plays an important role in data management, and it contributes to organized processing of data in a given model. Data can be processed to create new forms of spatial representation, which supports the development of new analytical tools. The first attempts to transform 2D data were made upon the onset of the GIS approach [9–11]. Efforts were also made to write and transform topological data in algebraic – matrix form [12].

Various methods for developing cadastral models in 3D space have been recently discussed [13–17]. The results of those efforts have been incorporated into the ISO 19152 standard [1, 18, 19]. Numerous practical applications for theoretical models can be found in the relevant literature [20– 22].

The elements of data structures (geometry and topology) corresponding to LADM can be incorporated into the existing standard GIS applications. The present study relies on the above option. The aim of this study was to develop and present a method for building network models of 2D and 3D cadastral structures with the use of CAD and GIS tools. The models are based on data structures available in the relevant applications. The results were presented in view of the available data from a 2D cadastral map and 3D building data. The generated models are presented in geometric format, and they can be used in network analyses.

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2. Materials and Methods

In literature, the classes of spatial objects are described by geometry and attributes [8]. Object geometry is visualized with the use of points, lines, areas and geometric solids. Attributes – the properties and characteristic features of objects – are written in attribute tables. GIS tools generate topological data based on the geometry of cadastral objects. Topological data is also written in attribute tables. Objects represented by lines, areas or even geometric solids have to be identified by points (centroids) in the process of developing cadastral models. Centroids should be described by the attributes of identifiable objects. Attributes can also be used to describe a class of centroids that identifies parcel boundaries or passageways between apartments in a building. This form of data storage supports the construction of network models. For a network to be built, centroids have to be connected based on data from topological models. Different types of models can be developed. Below is a list of transformations relating to models that account for:

- neighborhood,
- neighborhood in transport corridors,
- neighborhood, including barriers,
- neighborhood in transport corridors, including barriers.

2.1. Neighborhood models of cadastral objects (parcels, apartments)

The processing of data for neighborhood models of cadastral objects can be described mathematically. Output data written in a topological model [8] can be presented as sets of boundaries and centroids that identify regions. Boundaries (parcel boundaries) will be represented by set K, Eqn (1):

$$K = \{ k_1, k_2, \dots, k_n \} \tag{1}$$

In topology, every boundary is assigned a left region *(Lr)* and a right region *(Rr)*, therefore, boundary set K can be transformed to set K^{LR} (2) described by pairs of regions: Lr – left region, Rr – right region, Eqn (3).

$$K = \{ k_1, k_2, \dots, k_n \} \rightarrow K^{LR} . \tag{2}$$

$$K^{LR} = \{(Lr, Rr)_{k1}, (Lr, Rr)_{k2}, \dots, (Lr, Rr)_{kn}\}. \tag{3}$$

The set of centroids (parcels or apartments) is represented by symbol C, Eqn (4):

$$C = \{ c_1, c_2, \dots, c_m \} . \tag{4}$$

When regions are identified based on centroids, set K^{LR} can be transformed into a set of centroid pairs C^{LR}, assigned to every boundary, Eqn (5):

$$C^{LR} = \{(c_{i_{k1}}, c_{j_{k1}})_{k1}, (c_{i_{k2}}, c_{j_{k2}})_{k2}, \dots, (c_{i_{kk}}, c_{j_{kk}})_{kn}\}. \tag{5}$$

Set C^{LR} is a subset of the Cartesian product $C \times C$, Eqns (6–8).

$$C^{LR} \subset (C \times C), \tag{6}$$

where:

$$C^{LR} = \left\{ (c_{i_{kn}}, c_{j_{kn}}) : c_{i_{kn}} \in C, \quad c_{j_{kn}} \in C \right\}, \quad n \in \{1, 2, \dots, n\}, \tag{7}$$

$$\underset{kn}{\wedge} (c_{i_{kn}} \; c_{j_{kn}}) = \begin{cases} c_{i_{kn}} & = \textit{centroid of the left polygon}_{kn} \\ c_{j_{kn}} & = \textit{centroid of the right polygon}_{kn} \end{cases} . \tag{8}$$

C^{LR} contains selected centroid pairs of areas situated on the left and right side of boundary k_n. Geometric data can be used to transform set C^{LR} to set C^{LR}_{xyh} of centroid ordered pairs that neighbor every boundary k_n , Eqn (9).

$$C^{LR}_{xyh} = \{((x, y, h)_{LC}; (x, y, h)_{RC})_{k_n}\} \qquad n = 1, 2, 3, \dots . \tag{9}$$

The resulting set C^{LR}_{xyh} can be used to map a network of connections between neighboring cadastral objects.

2.2. Network models of cadastral objects relating to transport corridors (parcels, apartments)

A method for building a network of connections between cadastral objects should account for transport corridors. Cadastral data relating to parcels contains attribute data for identifying parcels that are occupied by roads. In cadastral data relating to apartments, passageways can be identified in the floor plans of buildings. Network models that account for transport corridors and passageways can be developed with the use of neighborhood models. In the first stage of the process, objects from set K^{LR}, Eqn (10) are selected by choosing boundaries of transport corridors and passageways (boundaries of parcels occupied by roads, walls and passages in buildings).

$$K^{LR} \xrightarrow{selekcja} K^{LR(com)} \tag{10}$$

Successive transformations, performed in line with the adopted method Eqns (5–9), produce a network of connections between cadastral objects that account for transport corridors and passageways. The network will be developed based on subset $C_{xyh}^{LR(com)} \subset C_{xyh}^{LR}$, Eqn (11).

$$C_{xyh}^{LR(com)} = \{((x,y,h)_{L_C}\ ;(x,y,h)_{R_C})_{k_n}^{com}\} \tag{11}$$

2.3. Network models of cadastral objects that account for barriers

The adopted method of developing neighborhood networks and networks of connections between cadastral objects does not account for barriers, such as outdoor fencing or doors and stairs inside buildings. Those barriers have to be taken into account in the network development process. The existing set of parcel or apartment centroids should be expanded to include the centroids of boundaries (parcel boundaries, passageways between apartments – doors, and other barriers). The elements describing barriers in the form of ordered pairs of boundary centroids have to be incorporated into formula Eqn (11), to Eqns (12–13).

$$C_{xyh}^{LR} \rightarrow C_{xzh}^{LKR} \tag{12}$$

In theory, the result will be a set of three centroid coordinates (LKR):
L – left region,
K – boundary describing transport barriers,
R – right region.

$$C_{xyh}^{LKR} \subset (C_{xyh}^{L} \times C_{xyh}^{K} \times C_{xyh}^{R}), \tag{13}$$

The resulting subset is used to develop a network model of cadastral objects that accounts for transport barriers. In practice, this subset is represented by set C_{xzh}^{LKR}, described by formula Eqn (14).

$$C_{xyh}^{LKR} = \{((x,y,h)_{L_C}\ ;(x,y,h)_{K_C}^{barriers}\ ;(x,y,h)_{R_C})_{kn}\}\ . \tag{14}$$

2.4. Network models of cadastral objects relating to transport corridors that account for transport barriers

A model of cadastral objects relating to transport corridors that accounts for transport barriers will be a subset of model C_{xzh}^{LKR} Eqn (15).

$$C_{xyh}^{LKR} \subset C_{xzh}^{LKR(com)} \tag{15}$$

This model can be developed by selecting boundaries of transport corridors or passageways. In practice, the model will be represented by set Eqn (16).

$$C_{xyh}^{LKR(com)} = \{((x,y,h)_{L_C}\ ;(x,y,h)_{K_C}^{barriers}\ ;(x,y,h)_{R_C})_{kn}^{com}\}\ . \tag{16}$$

3. Model development

Digital cadastral data in the LADM model represents parcels, buildings and utility networks in a 3D digital elevation model. The cadastral structures discussed in this study are parcels and buildings. In the first stage of the process, the results of our previous work [23], involving a 2D cadastral map were evaluated. Those findings were used to develop 3D building models.

3.1. 2D cadastral structures

A digital map of parcels (Fig. 1) was used in our previous work [23] to develop 2D cadastral models. The map, digitized in the spaghetti mode and saved in a CAD file, contained linear objects in several layers. Geometric data was supplemented with descriptive textual data in separate layers. In the first stage, output data was converted from CAD format (.dxf files) into a topological format. Descriptive data was written in attribute tables. This approach produced the following classes of cadastral objects: parcels and parcel boundaries. Object classes described by geometric, topological and attribute data were used in further transformations. The generated sets K^{LR} and i C, relating to attribute and geometric data (coordinates) were applied to develop models C_{xyh}^{LR}, $C_{xyh}^{LR(com)}$, C_{xzh}^{LKR}, $C_{xzh}^{LKR(com)}$ (Fig. 2).

The shape of the resulting models is dictated by elongated parcels occupied by roads. In regularly-shaped cadastral structures, neighborhood model $C_{xyh}^{LR(com)}$ assumes the shape of a star (Fig. 2b).

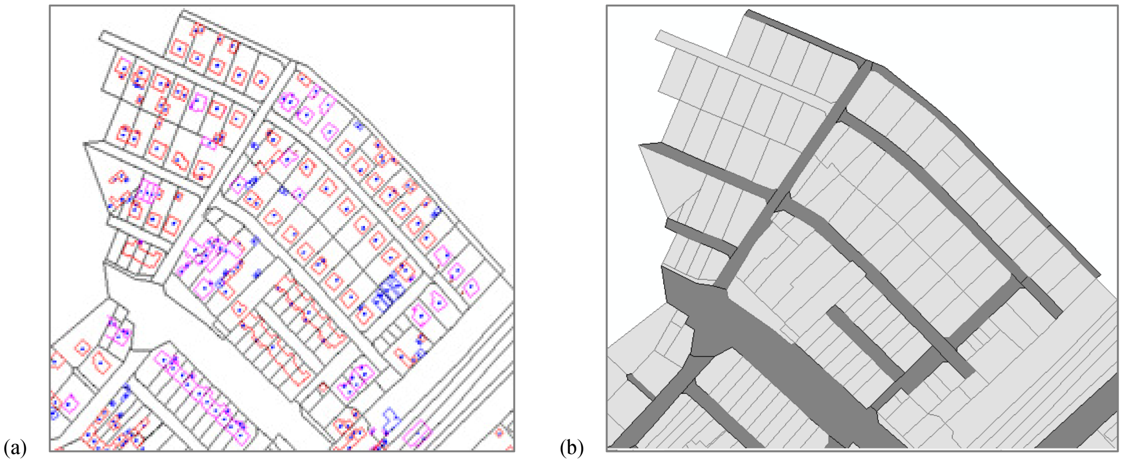


Fig. 1 Cadastral map: a) visualization of a map developed in the spaghetti mode in .dxf file, b) visualization of parcels based on the map

3.2. 3D building cadastral structures

3D building models were developed based on our previous experiences in building 2D models. Analog floor plans were converted into raster format and vectorized. Height information was added from the inventory database, and the images were georeferenced according to the base map. Floor plans in CAD format were converted into topological format and GIS object classes. The applied method was used to develop network models of each floor $C_{xyh}^{LKR(com)}$ based on the generated geometric, topological and attribute sets in report format (Fig. 3). Those transformations produced sets that were used to generate network models C_{xyh}^{LR}, C_{xyh}^{LKR} and $C_{xyh}^{LKR(com)}$ (Fig. 4, 5).

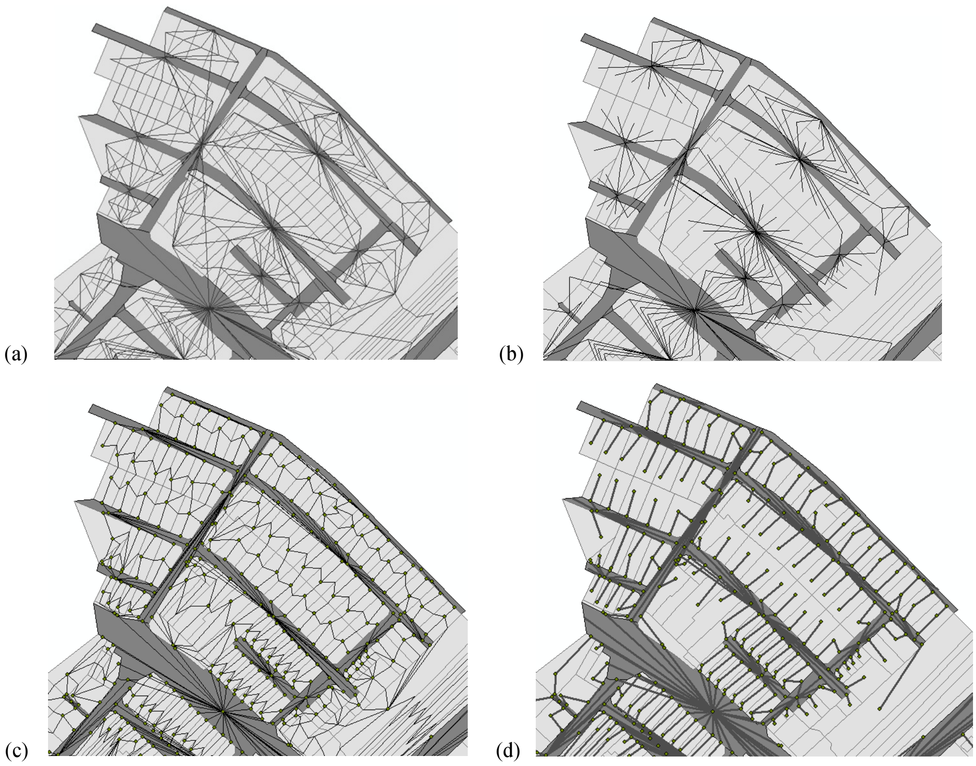
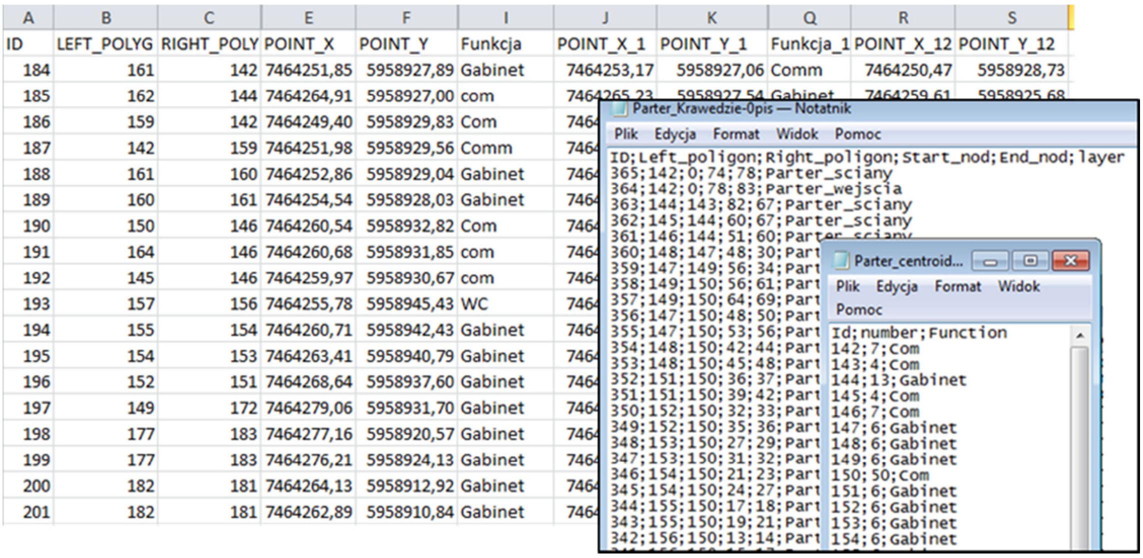


Fig.. 2 Models of cadastral structures: a) neighborhood model C_{xyh}^{LR}, b) neighborhood model with transport corridors $C_{xyh}^{LR(com)}$, c) neighborhood model that accounts for barriers C_{xyh}^{LKR}, d) neighborhood model with transport corridors that accounts for barriers $C_{xzh}^{LKR(com)}$



A	B	C	E	F	I	J	K	Q	R	S
ID	LEFT_POLYG	RIGHT_POLY	POINT_X	POINT_Y	Funkcja	POINT_X_1	POINT_Y_1	Funkcja_1	POINT_X_12	POINT_Y_12
184	161	142	7464251,85	5958927,89	Gabinet	7464253,17	5958927,06	Comm	7464250,47	5958928,73
185	162	144	7464264,91	5958927,00	com	7464265,23	5958927,54	Gabinet	7464259,61	5958925,68
186	159	142	7464249,40	5958929,83	Com	7464				
187	142	159	7464251,98	5958929,56	Comm	7464				
188	161	160	7464252,86	5958929,04	Gabinet	7464				
189	160	161	7464254,54	5958928,03	Gabinet	7464				
190	150	146	7464260,54	5958932,82	Com	7464				
191	164	146	7464260,68	5958931,85	com	7464				
192	145	146	7464259,97	5958930,67	com	7464				
193	157	156	7464255,78	5958945,43	WC	7464				
194	155	154	7464260,71	5958942,43	Gabinet	7464				
195	154	153	7464263,41	5958940,79	Gabinet	7464				
196	152	151	7464268,64	5958937,60	Gabinet	7464				
197	149	172	7464279,06	5958931,70	Gabinet	7464				
198	177	183	7464277,16	5958920,57	Gabinet	7464				
199	177	183	7464276,21	5958924,13	Gabinet	7464				
200	182	181	7464264,13	5958912,92	Gabinet	7464				
201	182	181	7464262,89	5958910,84	Gabinet	7464				

Fig. 3. Sets of geometric, topological and attribute data used in the construction of network models

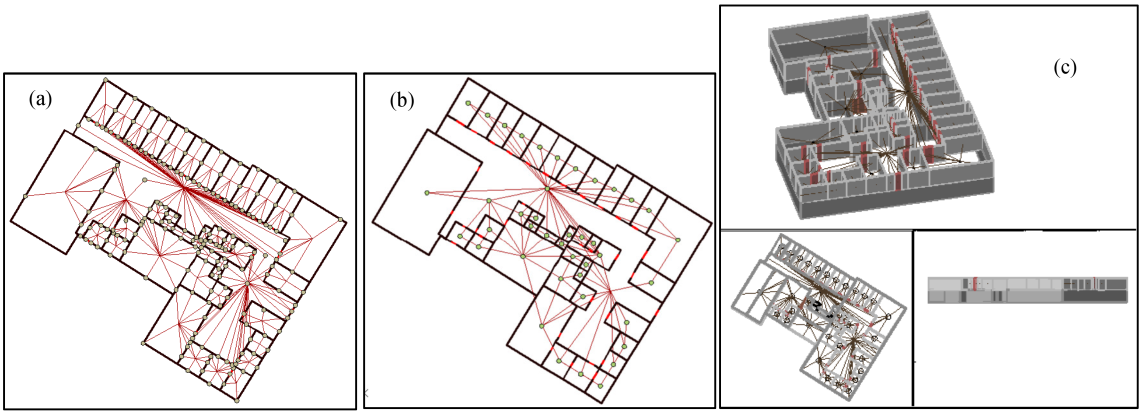


Fig. 4. Network models developed with the use of CAD tools based on transformed data sets; a) model C_{xyh}^{LR}, b) model C_{xyh}^{LKR}, c) visualization of two floors in a building

The resulting models illustrate the connections in cadastral structures. They can be combined with attribute data for practical applications. To visualize the attributes, the models generated in CAD applications were transferred to GIS software (Fig. 5). Model $C_{xyh}^{LKR(com)}$ illustrates connections that are useful in crisis management.

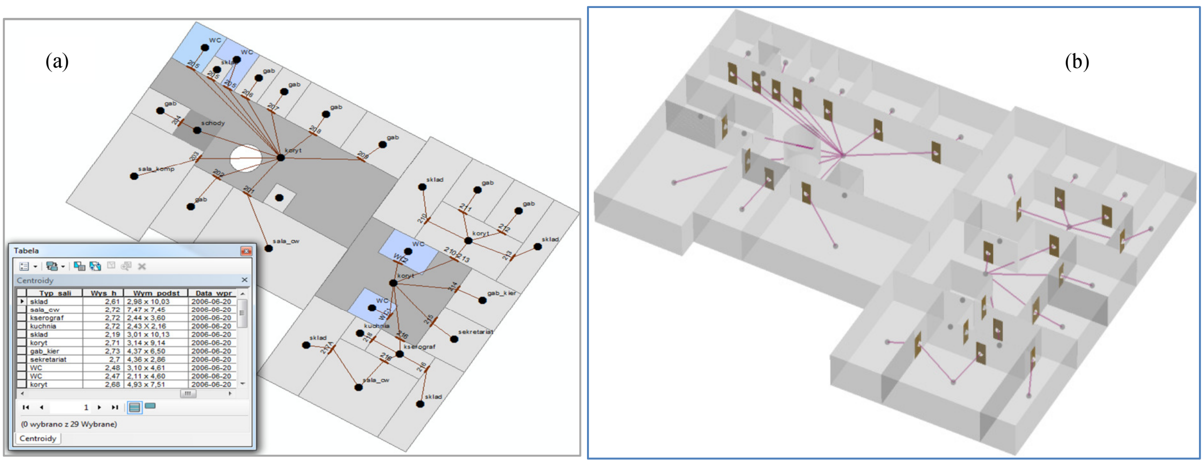


Fig. 5. Model $C_{xyh}^{LKR(com)}$ of the third floor presented in GIS software: a) with attribute visualization, b) in 3D space

3D modeling supported the integration of individual floor models into a single network model. The resulting model incorporates passageways in a building. The proposed solution can be used to generate models that account for other objects, such as windows, and can be deployed in crisis management. The discussed approach can also be used to link passageways in a building with the municipal transport system.

4. Conclusions

Topological structures of cadastral data support the conversion of 2D data for use in network models. The following models were developed:

- neighborhood model – C_{xyh}^{LR},
- neighborhood model with transport corridors – $C_{xyh}^{LR(com)}$,
- neighborhood model, including barriers – C_{xyh}^{LKR},
- neighborhood model with transport corridors , including barriers – $C_{xyh}^{LKR(com)}$.

The developed models can be supplemented with attribute data for analytical applications. They support evaluations of cadastral structures, descriptions of neighborhood and connections between objects, and they are vital for spatial management, in particular crisis management.

A 2D model was generated automatically in line with the adopted procedure. Minor adjustments were input manually when the models of each floor in a building were integrated in 3D space. The above approach required the transformation of output data into topological structures. In the future, the LADM model can be used to automatically to generate the required models without preliminary data processing.

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