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The Importance of Contextual Topology in the Process of Harmonization of the Spatial Databases on Example BDOT500

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Abstract

In this work, we present two detailed problems of topological errors in spatial database. Both issues are inconsistencies in the database, i.e. interior topological relationships layers of buildings and the relationship between the buildings layer and the layer of plots. That inconsistency is related to the residual polygons that arise as a result of overlapping objects, or gaps between objects. The occurrence of this type of error causes inconsistency in spatial databases. The authors present two algorithms indicating the elements of inconsistencies base.

***Keywords*— spatial databases; geographic information systems; relational databases; spatial inconsistency; inconsistency tolerance.**

I. Previous Works

Description of the logical relationships between objects is directly inspired by the graph theory which has been described for the first time by Euler in Konigsberg bridges problem. Due to the importance of topological relationships in many fields of science and technology they have been the subject of numerous studies[8]. In terms of the functioning of the topological relations in the domain of spatial data their description was of interest to many researchers[7] and research, among others Egenhofer, which were the basis for determining the standard description of spatial analysis[4][5].

The topological relations have quickly gained recognition among those who study the consistency spatial databases allowing the study of this phenomenon[1][2][6][18][16]. Also they allow assessment of the consistency state of spatial databases. Rodriguez (data) defines consistency in database systems as the fulfilment by a database instance of a set of integrity constraints that restricts the admissible database states[17].

In addition, because of the variety of use of spatial data objects representing the same element of reality are stored in multi-resolution/scale spatial databases[3][9][15][19]. The same object in different visualizations will be represented by a different geometry and the value of inconsistency tolerant will be different. Although many studies that are carried out, process automation tools to improve database, entering generalization operators, the problem is still not resolved. And it is a necessary element for optimal harmonization of databases.

The problem of isolation and identification of topological inconsistencies in the database objects between the buildings and parcels was described among others by Rodriguez[17]. The proposed solution is based on building spatial queries to the database. Consistent query answering is an inconsistency tolerant approach obtaining its semantically correct answers from a database that may be inconsistent with respect to its integrity constraints[17]. In this work we propose an indication of topological inconsistencies through polygons residual constituting the "inconsistency tolerant".

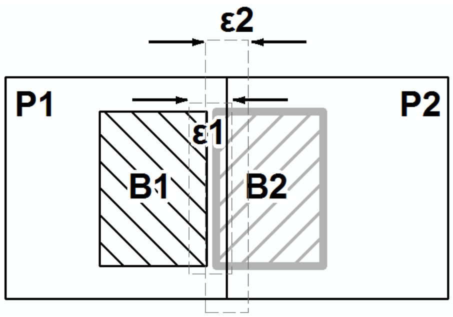

Fig. 1: *An example of inconsistent spatial database between buildings and parcels* (source: self)

Consider a simple example (Fig. 1), we have two objects representing the building situated on two parcels to which they are assigned. Buildings have an object identifier attribute id_n and geometric gb_1. The first problem addressed by the authors is unjustified gap between buildings resulting from the error database. The geometry of the two objects must be separate buildings or in contact with each other, it follows that the two geometries can internally intersect. Severability is to be preserved when objects protrude from each of the size of epsilon. On the other hand, data inconsistency in relation to the position of the building relative to the parcel to which it is assigned is the second problem. Both the parcels and the buildings have descriptive attributes binding objects together, i.e., the building has a number of parcel on which it is located and the parcel has the building's number. The geometry of the building in relation to the geometry of parcel is to contain or be contained and in contact with a foreign parcel. With data on membership, we can demonstrate the position error of the building B_2 because of the plot P_1, because the interiors of objects mutually intersect and descriptive data do not indicate affiliation building B_2 to the parcel P_1.

Spatial relations play an important role in spatial databases, since they are usually we the basis for specifying integrity and query constraints[16]. For this reason, in this example, you can apply a mathematical description of topological relations proposed in the work Rodrigeuez[17] [18] [16], Brisaboa[1][2]. Based on the above, the authors use topological relationships to identify errors in databases and determine the residual polygons.

The authors conducted their studies on the basis of data obtained from Geodetic and Cartographic Documentation Centre, testing data encompass one cadastral in the centre of Gdaśk. Buildings database counts 953 objects. Spatial

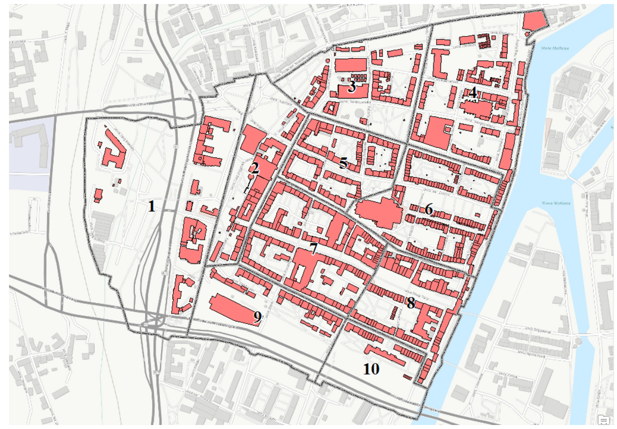

Fig. 2: *The selected part of the Gdańsk divided into 10 fragments that help to analyse the problem of inconsistency (source: self and Basemap)*

data of buildings and parcels was divided into ten smaller parts for simplification of analyses of the inconsistency problem. To divide data have been used structural objects which are the streets.

II. The Legal Aspect of the Harmonisation and Interoperability of Spatial Data Bases

The term spatial data infrastructure was coined in 1993 by the U.S. National Research Council to denote a framework of technologies, policies, and institutional arrangements that together facilitate the creation, exchange, and use of geospatial data and related information resources across an information-sharing community. Many countries influenced by the provisions of EU law introduces or adjusts the laws, regulations and national standards; such act is the law of the infrastructure for spatial information (Dz.U. nr 76, poz. 489). In the provisions of the general law of IIP has been established the definition called "interoperability of spatial data sets and services, understood as the ability to combine spatial data sets, without repetitive manual intervention, in such a way that the result was consistent, and the added value of the collections and services of spatial data has been increased" (Dz.U. nr 76, poz. 489). In the further text the legislature indicates that Administrative Agencies that keep public data bases, in the scope of its activities implemented technical solutions, ensuring interoperability and harmonization of their databases with others[10][14]. What follows from this is that the concept of harmonization and interoperability is important for multi-

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resolution and multi-representational database[11][12][13]. Regulation BDOT500 indicates that the computer system used to carry out BDOT500 had to provide the ability to update and topological control between objects (Dz.U. 2015 nr 0 poz. 2028 §8). This control applies in particular to: duplicating vertices of the line, looping lines, line faults, shortcomings connection line or surface strokes connection line or surface, proximity neighbourhood vertices, missing segments of linear and surface - not resulting from source materials (Dz.U. 2015 nr 0 poz. 2028 §1p2). All interchangeable databases are connected by a common base objects layer - buildings and parcels. Given recalled earlier legislation which provided for the harmonization of data, the database should be able to update and there should be consistency between them in identical layers. Objects representing the buildings have been obtained in accordance with Regulation "On the technical standards performing geodetic measurements situational and height as well as the compilation and transmission of these measurements to the national geodetic and cartographic," which means the measurement accuracy of 0.1 meters. In the case of a point defining the boundaries of cadastral parcels regulation specifies accuracy of 0.3 meter.

The authors consider value of 0.1 meters as tolerance inconsistencies between building's objects layer, while 0.3m is tolerance for parcels. In the case of relationship building parcel should take additional attribute's values.

III. Spatial Relationship Between Object Surface

For the purposes of the work, which concerns the objects of relational database layer buildings and parcels, we shall consider only the relationship between spatial objects surface. Description of the structure and characteristics assigned to the objects surface, hereinafter referred to as polygons adopted in accordance with the international standards of the Open Geospatial Consortium, Inc.[20]. For the purposes of Article let us quote only those definitions that will be used. The object O (Fig. 3) is a surface object if and only if the dimension $dim(O)$ is equal to 2. These facilities must be topologically closed, ie. the object has a boundary $B(O)$ which defines the interior $I(O)$ and external $E(O)$ of the object in accordance with Fig. 3. The limit of $B(O)$ is made of points that serve as nodes $W(O)$.

Tested The topological relationships (Fig. 4) between objects will be presented in accordance with Brisaboa[1][2]. Let T be one of the topological relationship (Tab. I) or the conjunction of topological relationship for spatial objects defined as $O_i(g_i,id_i)$.

$$\begin{aligned}\forall g_1, g_2, id_1, id_2 (O_1(g_1, id_1) \wedge O_2(g_2, id_2) \wedge \\ (id_1 \neq id_2) \rightarrow T(g_1, g_2))\end{aligned} \tag{1}$$

where:
$O_1(g_1,id_1)$, $O_2(g_2,id_2)$ — spatial objects,
g_1, g_2 — spatial attributes (geometry and values of topological attributes),
id_1, id_2 — IDs objects representing the relationship with other domains of attributes or objects.

And in accordance with Brisaboa[2][3] a we will defined building object as - Bi(gbi, idbi) and parcel objects as Pi(gpi, idpi), and their relationship as:

$$\begin{aligned}\forall gb_1, gb_2, idb_1, idb_2 (B_1(gb_1, idb_1) \wedge \\ B_2(gb_2, idb_2) \wedge (idb_1 \neq idb_2) \rightarrow \\ \rightarrow Touches(gb_1, gb_2) \vee Disjoin(gb_1, gb_2))\end{aligned} \tag{2}$$

where:
$B_1(gb_1,idb_1)$, $B_2(gb_2,idb_2)$ — buildings,
gb_1, gb_2 — spatial attributes (geometry and values of topological attributes) for building,
idb_1, idb_2 — buildings IDs representing the relationship with other domains of attributes or objects,

$$\begin{aligned}\forall gp_1, gp_2, idp_1, idp_2 (P_1(gp_1, idp_1) \wedge \\ P_2(gp_2, idp_2) \wedge (idp_1 \neq idp_2) \rightarrow \\ \rightarrow Touches(gp_1, gp_2) \vee Disjoin(gp_1, gp_2))\end{aligned} \tag{3}$$

where:
$P_1(gp_1,idp_1)$, $P_2(gp_2,idp_2)$ — parcels,
gp_1, gp_2 — spatial attributes (geometry and values of topological attributes) for parcels,
idp_1, idp_2 — parcels IDs representing the relationship with other domains of attributes or objects,
Building - $B(gb, idb, bb, bp)$ in LandParcel - $P(gb, idp, pp, pb)$

$$\begin{aligned}\forall gb_1, gp_1, idb_1, idp_1, bb_1, bp_1, pp_1, pb_1 \\ (B_1(gb_1, idb_1, bb_1, bp_1) \wedge P_1(gp_1, idp_1, pp_1, pb_1) \wedge \\ (bp_1 \subset pp_1) \wedge (pb_1 \subset bb_1) \rightarrow Within(gb_1, gp_1)\end{aligned} \tag{4}$$

where:
bb_1 — attributes one of the building or many buildings B_1,
bp_1 — attributes one of the parcel or many parcels which include the building B_1,

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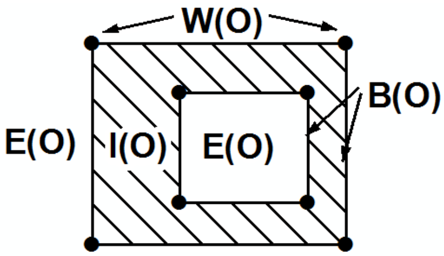

Fig. 3: *OGC — compliant surface object (source: self)*

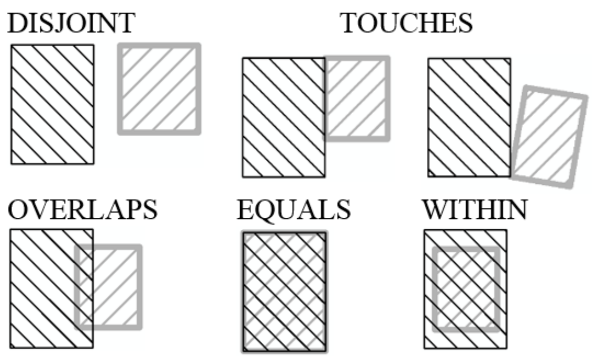

Fig. 4: *Relations between the two spatial objects (source: self)*

Table 1: *Definition of Topological Relation[20]*

Relation		Definition
Disjoint(O_1, O_2)	True if	$O_1 \cap O_2 = \emptyset$
Touches(O_1, O_2)		$(I(O_1) \cap I(O_2) = \emptyset) \wedge$ $\wedge (O_1 \cap O_2 \neq \emptyset)$
Overlaps(O_1, O_2)		$(dim(I(O_1)) = dim(I(O_2)))$ $= dim(I(O_1) \cap I(O_2) \wedge$ $(O_1 \cap O_2 \neq O_1) \wedge$ $(O_1 \cap O_2 \neq O_2)$
Equals(O_1, O_2)		$O_1 \subseteq O_2 \wedge O_2 \subseteq O_1$
Within(O_1, O_2)		$(O_1 \cap O_2 = O_1) \wedge$ $(I(O_1) \cap E(O_2) \neq \emptyset)$
Contains(O_1, O_2)		Within(O_2, O_1)
Intersects(O_1, O_2)		$O_1 \cap O_2 \neq \emptyset$

pp_1 — attributes of the parcel P_1,
pb_1 — attributes one of the building or many buildings which belong to parcel P_1.

Cited patterns describe the topological relationships between objects in the buildings layer, parcels layer and mutual relationship of these layers. Modified record takes into account identifiers representing indexes of internal and external to obtain other relations; this provision results from the specific national registers. Both layers have to meet the same assumptions, the geometry of the object relative to the geometry of other objects may enter into relations *Touches* or *Disjoin*. A piece of important information is the record $ido_1 \neq ido_2$, claiming study of the relationship of the building with itself. Equation 4, relating to the determination of relationship building - parcel, parcel - building, based on the contextual topology. Objects belonging to the layer of parcels (P_n) in addition to the object identifier must contain descriptive attributes, such attribute is the number of cadastral parcels (pp_m), similar buildings contain numbering - attribute descriptive (bb_n). Other attributes (bp_n, pb_n) are associated with the mutual relationship between these layers, each building is located on the plot, but not every plot has a building within its borders. In addition, relationships are complicated because "One To Many" relationship must be taken into account, cadastral parcel can contain more than one building and the building can be placed on more than one plot. The database of descriptive data must retain logical correctness of these relations.

IV. One Layer Objects Topological Relationships on Example of Buildings

Objects in the layer of the buildings are within the topological control using standard tools such as database tools and GIS application like ArcGIS, Geomedia or other tools having built-in topology tools. According to the formula (2) objects in building layer cannot overlap each other. Relationships: Overlaps, Equals or Within the relationship can be demonstrated through Intersects the interior of objects: $Intersects(I(gb_1), I(gb_2))$. While outside these errors databases exists unjustified gaps between buildings, whose width at the narrowest point is less than the specified tolerance, the value of the error is defined as the degree of topological inconsistencies and defined as epsilon ϵ. Consider first the situation (Fig. 5a), between two objects the relation topological $Disjoin(gb_1, gb_2, \epsilon)$.

If the minimum distance between these objects is greater than ϵ it means that objects maintain topological consistency. In contrast, the distance being less than the value ϵ indicates topological error. The problem of identi-

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fying invalid Touches relationship is more complicated. This relationship in its definition (Fig. 5b) excludes the intersection of two interior objects but involves intersects the boundary objects. This means that the relationship is achieved when the section boundaries of both objects formed segment: $Intersects(B(gb_1), B(gb_2))$, the boundary of one object contains a node of the second: the $Intersects(I(gb_1), W(gb_2))$ or both objects have a common $Equal(W(gb_1), W(gb_2))$. Given these assumptions, the objects shown in Fig. 5b, 5c touch each other but there is a gap between them, the value of which is less than ϵ. Authors, to solve this problem, propose an algorithm that creates the polygonal residual gap in place.

1 **Algorithm**: *Dilatation*
2 Let D be non-empty inconsistency collection of spatial data represent building
3 **foreach** $b \in D$ **do**
4 **begin**
5 $a = Buffer(d, \epsilon)$
6 $s = b_1 \cap b_2 \wedge idb_1 \neq idb_2$
7 $c = B(a)$
8 begin
9 $c = c \setminus s$
10 Let ps and pe be respectively the first and last node of boundary c
11 $cp \leftarrow$ create new line based on node $(ps_1, ps_2) \wedge (ps_1, ps_2)$
12 $cn = c \cup cp$
13 end
14 $u \leftarrow$create new object $dim(u) = 2$, where $cn = B(u)$
15 $e = u \setminus b$
16 end

Action of the above algorithm comes down to determination of the relationship of proximity (on the basis of the value of ϵ) between objects (lines 5-6). Parts of the boundaries of objects included in this relationship are removed (line 9), then the ending vertices are analysed, (both) of the objects boundaries which entering each other in the relationship of proximity, on the basis of pairs of nodes are created missing sections so that the contour covering buildings with gaps (line 10, 11, 12) is achieved. The last step is to create a new polygons layer based on the subject line (line 14) from which will be deleted geometry of input objects (line 15). The results of the algorithm (Fig. 6) derived residual polygons (sign in red) are generated in the gaps where the value of the distance of the neighbouring buildings was below ϵ.

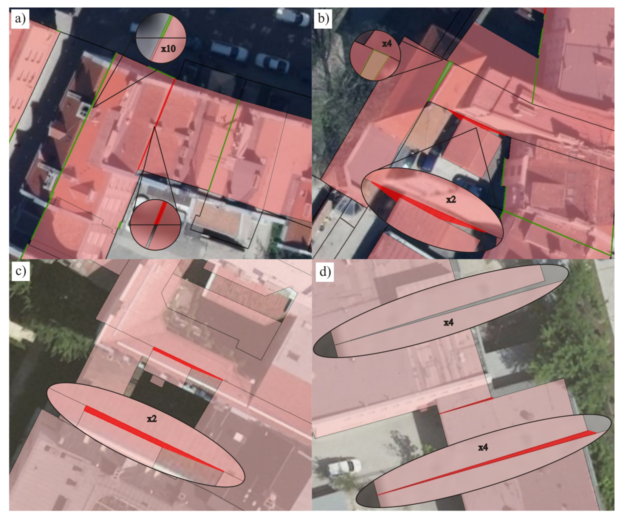

Fig. 6: *Four cases considered as the conditional topological errors: a) gap, b) partial c) and d) touching (source: self)*

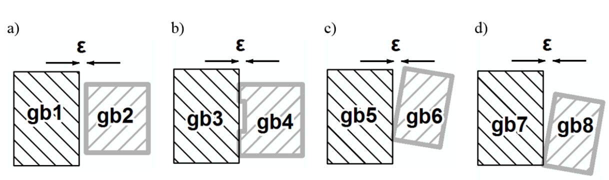

Fig. 5: *Four cases considered as the conditional topological errors: a) gap, b) partial c) and d) touching (source: self)*

V. Topological Relations for Two Layers of Objects for Example, Parcels and Buildings

The second presented algorithm is used to detect the components of inconsistencies in the error position of the substation of the building - $W(B) < \epsilon$. The correct location of the building relative to the plot is when the building is within the parcel or parcels to which building is assigned. Conclusion of the object may be complete, such a situation occurs at Fig. 7a, the boundaries of a building belonging to the plot does not intersect $Within(gb_1, gp_1) \wedge (B(O_1) \cap B(O_2) = \emptyset)$ or limit building form part of the joint (Fig. 7b) $Within(gb_1, gp_1) \wedge (B(O_1) \cap B(O_2) \neq \emptyset)$, both forms

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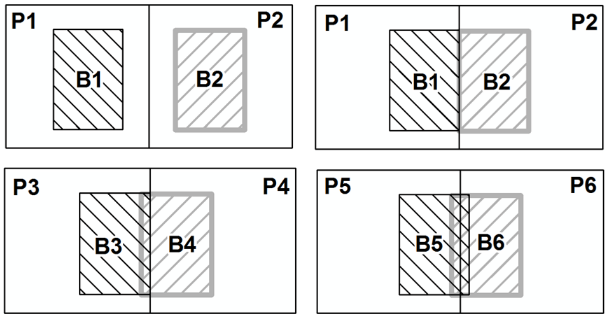

Fig. 7: *Topological events between parcels and buildings: a) disjoint, b) point touching, c) and d) overlapping (source: self)*

are correct.

$$Within(gb_1, gp_1) \wedge Within(gb_2, gp_2) isTrue \quad (5)$$

$$\begin{aligned} &Within(gb_3, gp_3) isTrue \\ &Within(gb_4, gp_4) isFalse \end{aligned} \quad (6)$$

$$Within(gb_5, gp_5) isFalse \wedge Within(gb_6, gp_6) isFalse \quad (7)$$

Incorrect location of buildings B_4, B_5, B_6 (Fig. 7) can be considered only on the basis of the descriptive attributes, according to the formula 4, house number B_4, $(B_5, B_6)$is not assigned the data to parcel P_3, (P_6, P_5)even though it creates a spatial relationship with her: $Intersects(gb_4, gp_3)$. Ability to use the contextual topology was used in the algorithm for determining the positional errors of the building in relation to the parcels.

1 **Algorithm**: *LandParcelAndBuilding*based on patterns 5,6,7
2 Let P be non-empty inconsistency collection of spatial data represent Land Parcel
3 Let D be non-empty inconsistency collection of spatial data represent building
4 **foreach** $p \in P, b \in D$ **do**
5 **begin**
6 $c = b \cap p \wedge pb \not\subset bb \wedge bp \not\subset pp$
7 $f = Buffer(p, \epsilon)$
8 $n = c \cap f \wedge pb \not\subset bb \wedge bp \not\subset pp$
9 end

Table 2: *Results of the Dilatation Algoritm*

Regions	Count of buildings objects	Mean area buildings objects $[m^2]$	Count of errors Dilatation	Sum area errors Dilatation $[m^2]$	Mean area errors Dilatation $[m^2]$
1	41	315	4	0.337	0.084
2	47	257	5	0.445	0.089
3	91	135	11	2.100	0.191
4	147	167	10	0.460	0.046
5	105	125	11	0.301	0.027
6	223	88	14	0.873	0.062
7	126	189	10	0.337	0.034
8	110	144	6	0.412	0.069
9	36	276	3	0.155	0.052
10	27	123	5	0.123	0.025
Sum	953	—	79	5.543	—
Mean	—	155	—	0.554	0.068

This algorithm creates objects that we obtain as a result of the intersection of the object representing the building with the parcel object to which it does not belong (line 6), as a result of this operation we get the residual polygons with different error position node of the building in relation to the plot. Then we take into account of the Îţ value to the border and create the buffer in which they are to be our objects (line 7, 8).

VI. Results of the Both Algorithm

In the test of Buildings database counts 953 objects, Dilatation algorithm exhibited 79 errors (for 157 objects buildings into relationship between them), average object surface was about 0.07 m^2. The cadastral was chosen due to its dense development. The second algorithm created 1080 residual polygons, after aggregating, there are 507 buildings which are beyond the parcel's borders. The mean values of surface residual polygons treated as errors (Tab. II col.6), detected by expansion algorithm, point to the phenomenon of the lack of proper model for edge node. A small number of these errors (Tab. II col.4) and the low value of the mean (Tab. II col.5) indicate indirectly the source of this error, which may be different origins of data (direct measure-

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Table 3: *Results of the Algorithm LandParcelAndBuilding(LPaB)*

Regions	Count of buildings objects	Mean area buildings objects $[m^2]$	Count of errors LPaB	Sum area errors LPaB $[m^2]$	Mean area errors LPaB $[m^2]$
1	41	315	4	0.337	0.084
2	47	257	89	31.092	0.351
3	91	135	101	8.106	0.082
4	147	167	158	26.920	0.145
5	105	125	134	15.932	0.12
6	223	88	184	13.092	0.098
7	126	189	176	46.006	0.263
8	110	144	110	21.193	0.194
9	36	276	55	30.452	0.555
10	27	123	31	0.355	0.013
Sum	953	—	1080	228.466	—
Mean	—	155	—	22.847	0.268

ment, vectorization, photogrammetric data). The exception here is the region 3 (Tab. II col 1) in which for 91 (Tab. II col 2) buildings were detected 11 (Tab. II col. 5) dilatations of the total area of more than 2 m^2.

Reading from a table of the number of errors (Tab. III col.4) algorithm LPaB detected in relation to the number of buildings in the region, you will notice an increase in the number of errors with increasing number of buildings, this growth is non-linear regression, however, testifies to the prevalence of this phenomenon on the test sample. A large number of errors of this type can be associated with different accuracy of the source material or using other methods of measuring land and buildings. Please note that the permitted measurement error for the vertex of the building is 10 cm in the case of parcels value is three times higher and is 30 cm. The value of the average area of polygons residual (Tab. III col. 6) also did not show a linear regression but increases with the average area of the buildings and in all regions except for 3, 6 and 10 exceeds 0.1m2, providing error greater than the tolerance values.

Fig. 8: *Visualization of errors generated by the algorithm LPaB (source: self)*

VII. Summary

The algorithms are applicable to detection of failure. Thanks to these residual polygons the Dilatation algorithm can precisely identify where there are gaps between objects layer buildings. The algorithm LPaB allows the determination of items outside the building cadastral plot. On the basis of residual polygons can be performed manual improvement of objects for residual polygons obtained from the LPaB algorithm; process improvement can be automated using the basic tools of GIS analysis. The results obtained from polygons residual elements of joints should be subjected to a process of generalization so that the residual polygon fills the gap and is aligned with the boundaries of buildings. Generated residual polygons can be used to automate the process of repairing databases, but during this process one must take into account many factors, including legislation. In the presented examples (Fig. 6, 8) are shown different elements of conflict and the relationship between objects: a) building belongs to two plots of land. joint geometry of the two plots of land to be equal to the geometry of the building. the building does not enter into a relationship of contact with another building. b) the geometry of the building and the plot should be identical. In addition, building is in contact with other buildings c) and d) should buildings be included in the plot wherein d) coming into contacting relationship with another building. Designed algorithms indicate the possibility of obtaining topological relationships in terms of context which is essential to achieve the proper functioning of harmonized databases.

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