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Modeling of Spatial Data on the Construction Site Based on Multidimensional Information Objects

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Abstract: ***The article presents information modeling different types of spatial data on the construction site. The description of spatial and attribute data based on multidimensional information objects (MIO) is determined. It is proposed to use a new type of MIO called modified multidimensional information objects (MMIO). MIO and MMIO schemes are developed for each type of master planning object in the form of one multidimensional information object. Complete descriptions of layers of point, linear and polygonal spatial objects are presented, which allows simplifying the model of the structure of existing databases of spatial information processing systems. The results of the study show that multidimensional information objects allow describing in unified mathematical form sets of various types of spatial data models. The result of modeling of general planning spatial based on multidimensional information objects corresponds the modern requirements of information modeling in construction – BIM-technology and design of master plans on the new technological level.***

Keywords: ***multidimensional information objects, construction site, building information modeling, spatial data models.***

I. INTRODUCTION

The spatial information is of great importance in the formation of the initial data for solving CAD-tasks related to the design of master plans and relief on the construction site. There is a need for a unified formalized description of spatial information in order to obtain an integrated building information modeling (BIM) of natural and manufactured territorial distributed objects. There are different types of spatial information according to the data, format, description method, distributed to the storage location, belonging to the existing information systems, etc. [1]. Design of master plan is implemented at different organizational levels, each of which requires its own level of detail (LOD). Therefore, information systems for processing spatial information should be built on a hierarchical principle with varying degrees of detailing, integration and generalization of information at each level. It is necessary to determine the types of structures for storing this information in the territories and describe methods for converting them into a one multidimensional model of spatial data on geographically distributed objects. To solve this problem, a method is proposed for describing large amounts of information using multidimensional information objects (MIO). MIO can describe one parameter, table, feature class, or the entire database. It depends on the MIO dimension.

The authors of the work [2] describe the basic advantages of multidimensional data models and their application. There is given a formalized description of data manipulation operations. In the work [3], the authors develop the operations of manipulating data stored in different two MIO cubes. Mathematical formalized procedures for creating multidimensional models are introduced in [4]. The operations of generation, projection, union and deletion are described for implement the basic data processing functions. The main idea is to generalize the relational approach, in which several different relations with the same structure are proposed to be placed in a certain multidimensional object called MIO. In thesis [5], a detailed review of the mathematical formalized procedures constructing multidimensional models for spatial objects. The proposed approach is adapted to describe in a uniform manner geographically distributed heterogeneous spatial data on geographically distributed objects and systems. All objects stored in a geographic database have a common set of attributes with spatial characteristics and other geometric parameters (such as length or area).

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The author of the work [6] formalized multidimensional data representation using the theory of relational databases. There are described mathematically main multidimensional data representation concepts, dimension, hypercube and operations with data hypercube. In works [7–10], there are studied the efficient organization and access of multidimensional datasets on storage information systems. There are analyzed approaches for spatial data and nonparametric modeling of multidimensional systems.

The articles [11] and [12] are devoted to the fast, efficient spatial method of data collection for multidimensional scaling. In work [13], the author shows procedure for selecting dimensionality in multidimensional scaling using the Bayesian network.

Authors of [14] examine dissimilarity structure from multiple item arrangements. The authors in the article [15] consider standardizing the creation of spatial databases to fill with spatial and attribute information.

At the conference [16] it was reported on the parallel coordinates as effective tools for visualizing multidimensional geometry. In works [17–19], the authors study multidimensional data visualization. They show details of multidimensional dynamic analysis for data acquisition.

Articles [20, 21] are devoted the problem of joint description of spatial data different types in the composition of the construction territory information model. It is proposing the application of multiplicative theoretical approach for the description of spatial data, which presents in a single formalized form a plurality of spatial objects different types.

It is necessary to study and descript the spatial and attribute data of the planning objects for design of master plan on based the multidimensional information objects (MIO). This approach meets the modern requirements of information modeling in construction BIM-technology. It will allow solving tasks related to the design of master plan on the new technological level.

II. MAIN RESEARCH

The spatial planning objects can be modeled by spatial data of various geometric types. There is point, linear or polygonal geometric model, taking into account their level of detail. This characteristic feature of spatial data is used in GIS and CAD systems. Coordinates X, Y, Z characterize a point spatial object. Examples of such objects are water intake, a well, a hatch, a pole, a tree, etc.

The linear spatial object is characterized by a set of attribute characteristics of a linear feature and a set of nodal points representing this feature. Examples of such objects are roads, channels, engineering communications, the boundaries of red lines, horizontal contours, etc.

The polygonal spatial object is characterizing by a set of attribute characteristics of a polygonal object and a set of closed lines bounding its contours. Individual buildings, special natural areas, planting trees and vegetation, lakes, etc. can represent such objects.

Different types of spatial data are described as multidimensional information objects (MIO) of various dimensions, where $T_i^{dimension}$ is elementary i-th characteristic of any geometric type (point, line, polygon) and its attribute type.

The complete description MIO of one point spatial object T^1_{point} is determined:

$$T^1_{point} = \{T^p_i\} * S_0, \ i = \overline{1, k_0}, \quad (1)$$

where S_0 is the list of various characteristics of point object, k_0 is the number of characteristics of the point object. The geometric description of a point spatial object can be represented by MIO T^1_{point} as follows:

$$T^1_{point} = \{T^p_1, T^p_2, T^p_3, T^p_4\}, \quad (2)$$

where T^p_1 is the point number (identification code – *IDp*), T^p_2 is the X coordinate value characterizing the object location on the selected coordinate system, T^p_3 is the Y coordinate value, T^p_4 is the Z coordinate value.

The complete description MIO of the one point spatial object T^1_{point} is determined:

$$Point = \{T^1_{point}, A^1_{point}\}, \quad (3)$$

where A^1_{point} is a set of point object attribute data (Fig. 1).

Points	ID_1	X_1	Y_1	Z_1	. . .
	. . .	. . .	. . .	. . .	. . .
	T^1_{point}				A^1_{point}

Fig.1.Graphical representation of MIO for the point spatial object

The description MIO of one linear spatial object T^2_{line} is given by the set of nodes in the line. MIO dimension 2 is determined:

$$T^2_{line} = \{T^1_{point}\}_i * S_p, \ i = \overline{1, k_p}, \quad (4)$$

where S_p is the list of nodes in the line, k_p is the number of nodes in the line, representing this spatial object, $\{T^1_{point}\}_i$ is the *i*-point spatial object MIO that defines a set of coordinates values characterizing the location of a nodal point in space in the coordinate system, where *X*, *Y*, *Z* are point's coordinates; *IDp* is point's number (identification code). In addition to the set of nodes, a linear spatial object is characterized by A^1_{line} is a set of attribute data MIO. So, one linear spatial object *Line* is described as a MIO pair. Its complete description is determined:

$$Line = \{T^2_{line}, A^1_{line}\}, \quad (5)$$

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The complete description of a one polygonal spatial object $Polygon$ represents as MIO pair: T^3_{polyg} is a set of lines bounding its contours and A^1_{polyg} – is a set of attributive characteristics. It is determined:

$$Polygon = \{T^3_{polyg}, A^1_{polyg}\}, \quad (6)$$

where T^3_{polyg} is MIO of dimension 3 for one polygonal spatial object. It is determined:

$$T^3_{polyg} = \{T^2_{line}\}_i * S_l,\ i = \overline{1, k_l}, \quad (7)$$

where S_l is the list of lines bounding the contours of the polygon object, k_l is the number of bounding the polygon lines, $\{T^2_{line}\}_i$ is *i*-linear spatial object MIO, defined by (4).

The complete description of one thematic layer on the master plan is represented as a group of similar objects are point, linear or polygon (for example, a river network or a set of hydrological control posts) and their attributive characteristics.

The description MIO of dimension 2 for one point layer is determined:

$$T^2_{layer\_point} = \{T^1_{point}\} * S_p,\ i = \overline{1, n_p}, \quad (8)$$

where S_p is the list of point identification codes (*IDp*), n_p is the number of point identification codes on master plan.

It is necessary to unite the totality of linear objects included in layer and their attributive characteristics for the complete description of one linear layer on the master plan. The description MIO of dimension 2 for set of linear objects attribute data is determined:

$$T^2_{AL} = \{A^1_{line}\}_i * S_l,\ i = \overline{1, n_l}, \quad (9)$$

where S_l is the list of linear objects identification codes (*IDl*), n_l is the number of linear objects identification codes on master plan.

The description MIO dimension 3 of one point layer is determined:

$$T^3_{layer\_line} = \{T^2_{line}\}_i * S_l,\ i = \overline{1, n_l}, \quad (10)$$

Since MIO (9) and (10) are different types, but have common dimension, there are identification codes of linear objects (*IDl*), then according to (5) they can be combined by this common element. The result is a fan MIO of dimension 4 of one linear layer (Fig. 2). It is determined:

$$T^4_{line} = T^3_{layer\_line} \cup T^2_{AL},\ i = \overline{1, n_l}, \quad (11)$$

It is necessary to unite the totality of polygonal objects included in this layer and their attributive characteristics for the complete description of one polygonal layer on the master plan, similarly (9)–(11). An attribute data set for polygonal objects is united MIO of dimension 2:

$$T^2_{AP} = \{A^1_{polyg}\}_i * S_{pl},\ i = \overline{1, n_{pl}}, \quad (12)$$

where S_{pl} is the list of polygonal objects identification codes (*IDpl*), n_{pl} is the number of polygonal objects identification codes on master plan.

The description MIO of dimension 4 for one polygonal layer is determined:

$$T^4_{layer\_polyg} = \{T^3_{polyg}\}_i * S_l, i = \overline{1, n_{pl}}, \quad (13)$$

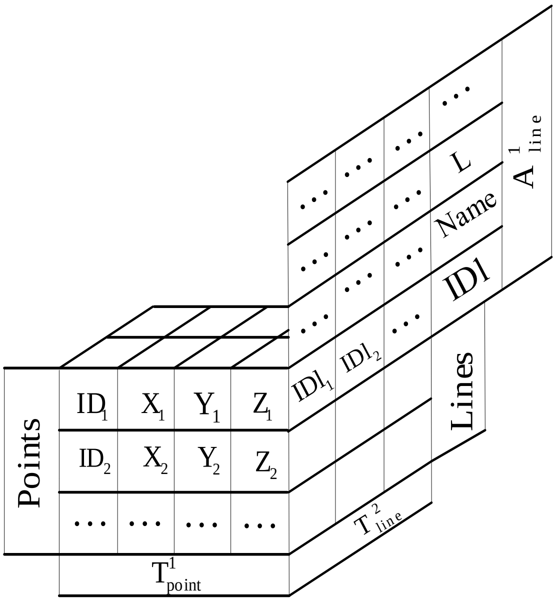

Fig.2.Graphical representation of MIO dimension 4 for the one linear layer

MIO (12) and (13) are combined by common elements – identification codes of polygonal objects *IDpl* according to [6]. The result is a fan MIO of dimension 5 of one polygonal layer (Fig. 3). It is determined:

$$T^5_{polyg} = T^4_{layer\_polyg} \cup T^2_{AP}, i = \overline{1, n_{pl}}, \quad (14)$$

It is necessary to combine the different MIO defined by (6), (11) and (14) representing the layers for each type of geometry (point, linear, polygonal), to describe the spatial objects grouped into layers, with a certain level of detail, and are elements of the master plan of the construction territory in the certain scale. However, it is very difficult to use the operation of combining different types of MIO, described in [5].

It is visibly presented that a complete description of one spatial object may consist of several MIOs of different dimensions and has a complex appearance. For a joint description of various types of spatial objects within a single information data model, it is necessary that the description of each type of spatial object is one MIO. In addition, there is no generality in the description of objects layers geometry different types, which makes it difficult to perform data transformation operations on them. For a uniform representation of spatial objects various types, it is necessary that they be of the same type.

Let be some MIO of dimension n is denoted as T_0^n and its scheme as $S(T_0^n) = S^n$. MIO of dimension n should be combined with MIO dimension (n+1), which is denoted as T_0^{n+1} and its scheme as $S(T_1^{n+1}) = \{S^n, S_{n+1}\} = S_1^{n+1}$. The data of these MIO differ in one element of the scheme S_{n+1}. In order for the scheme S^n to take the form S_1^{n+1}, it is proposed to use a new type of MIO – modified multidimensional information objects (MMIO), which are denoted as $\widetilde{T}^{n,m}$, where *n* is number of existing dimensions, *m* is number of extra dimensions.

These objects correspond to the MIO more dimension according to the scheme and MIO of the same dimension in information content. If m = 1, then MMIO is $\widetilde{T}^{n,1}$. The scheme of this object is as follows:

$$S(\widetilde{T}^{n,1}) = \{S^n, S_{n+1}\} = S^{n+1}, \qquad (15)$$

where S_{n+1} is the element of the scheme MIO of dimension n, it is different from the scheme MIO with which it needs to be combined. In this case, the MIO, which corresponds to the circuit element S_{n+1} in $\widetilde{T}^{n,1}$, is contained an empty data set. This dimension is called fictitious.

The operations of adding a dimension increases dimension I_1 to get a MMIO dimension n+1:

$$I_1(T^n, S_{n+1}) = T^n * S_{n+1} = \widetilde{T}^{n,1}, \qquad (16)$$

This operation is applied simultaneously to only one MIO. In the general case, to obtain a MMIO, including *m* fictitious dimensions, several operations of adding a dimension are consistently applied:

$$I_1(T^n, S_{n+1}) = T^n * S_{n+1} = \widetilde{T}^{n,1},$$
$$I_1(\widetilde{T}^{n,1}, S_{n+2}) = \widetilde{T}^{n,1} * S_{n+2} = \widetilde{T}^{n,2},$$
$$\dots$$
$$I_1(\widetilde{T}^{n,m-1}, S_{n+m}) = \widetilde{T}^{n,m-1} * S_{n+m} = \widetilde{T}^{n,m}. \qquad (17)$$

This is presented:

$$\widetilde{T}^{n,m} = I_m(T^n, \{S_{n+i}\}) = T^n * \{S_{n+i}\}, i = \overline{1,m}, \qquad (18)$$

where S_{n+1} determines the entry order $\widetilde{T}^{n,i-1}$ in $\widetilde{T}^{n,i}$, at the same time $T^{a,0} = T^a$.

The operation of adding a dimension allows getting MMIO of any dimension that exceeds the dimension of the original MIO. To study the operation of adding dimension, consider the process of obtaining MMIO for a uniform description of various types of spatial objects and their presentation as layers of different types (point, linear and polygonal) depending on the level of detail of spatial data on the database. Let the elementary *i* characteristic of a spatial object of any type (point, line, polygon) be described in the form MIO T^0. The point spatial object is proposed to describe MIO T_m^1 as a set of characteristics T_i^0 with scheme S_{point}^1. This scheme describes one point as a set of coordinate values *(X, Y, Z)* characterizing the location of point in the coordinate system:

$$T_m^1 = \{T_i^0\} * S_m, \; i = \overline{1, k_0}, \qquad (19)$$

where S_m is the list of various characteristics of point object, k_0 is the number of characteristics of the point object.

The linear spatial object is proposed to describe as MIO of dimension 2 T_L^2 with scheme S_L^2, which describes the line as a set of nodal points:

$$T_L^2 = \{T_m^1\}_i * S_2, \; i = \overline{1, k_1}, \qquad (20)$$

where S_2 is the list of nodal points, k_1 is the number of nodal points in the linear object, T_m^1 is MIO with scheme S_m^1. The polygonal spatial object is proposed to describe as MIO of dimension 3 T_P^3 with scheme S_P^3, which describes the polygon as a set of closed lines:

$$I_1(T_m^1, S_2) = (T_m^1) * S_2 = \widetilde{T}_m^{1,1}.$$
$$I_1(\widetilde{T}_m^{1,1}, S_3) = (\widetilde{T}_m^{1,1}) * S_3 = \widetilde{T}_m^{1,2}.$$

The result defined by (18) is:

$$I_1(T_m^1, S_2, S_3) = (T_m^1) * \{S_2, S_3\} = \widetilde{T}_m^{1,2}. \qquad (22)$$

The scheme of MMIO for point spatial objects is determined:

$$S_m^{1,2} = \{S_m^1, S_2, S_3\}. \qquad (23)$$

The MMIO $\widetilde{T}_L^{2,1}$ from T_L^2 describes linear spatial objects with fictitious dimensions S_3:

$$I_1(T_L^2, S_3) = (T_m^1) * S_3 = \widetilde{T}_L^{2,1}. \qquad (24)$$

The scheme of MMIO for linear spatial objects is determined:

$$S_L^{2,1} = \{S_L^2, S_3\}, \qquad (25)$$

For a joint description of attribute and spatial data, it is necessary to provide MIO describing attribute information for spatial objects, to the MMIO of dimension 3. In general, the attribute characteristics spatial object of any type (point, linear, polygonal) are described MIO of dimension 1.

According to (3), the attribute characteristics of a point object is described MIO of dimension 1 is T_{Am}^1 with scheme S_{Am}^1. According to (5), the attribute characteristics of a linear object is described MIO of dimension 1 – T_{AL}^1 with scheme S_{AL}^1. According to (6), the attribute characteristics of a polygonal object is described MIO of dimension 1 is T_{AP}^1 with scheme S_{AP}^1. It is necessary to enter for the attribute characteristics spatial object fictitious dimensions $\{S_2, S_3\}$ that are the same as (3)–(5).

Similarly to (22)–(24):

$$I_2(T^1_{Am}, \{S_2, S_3\}) = (T^1_{Am}) * \{S_2, S_3\} = \tilde{T}^{1,2}_{Am} \quad (26)$$

$$I_2(T^1_{AL}, \{S_2, S_3\}) = (T^1_{AL}) * \{S_2, S_3\} = \tilde{T}^{1,2}_{AL} \quad (27)$$

$$I_2(T^1_{AP}, \{S_2, S_3\}) = (T^1_{AP}) * \{S_2, S_3\} = \tilde{T}^{1,2}_{AP} \quad (28)$$

Now, describing attribute data MIO are the same type with describing spatial data MIO. Received MIO differ in only one element of the scheme is the list of attributes of a spatial object.

It is necessary to perform transformations (19)–(28) to obtain a joint description of spatial and attribute data. The result obtained allows applying the operations of combining MIO's various types.

The complete description MMIO of one point spatial object is represented:

$$\tilde{T}^3_m = \tilde{T}^{1,2}_{Am} \cup \tilde{T}^{1,2}_m, \quad (29)$$

The scheme of complete description MMIO for one point spatial object is determined:

$$S(\tilde{T}^3_m) = \{S_m, S_2, S_3, S_{Am}\}, \quad (30)$$

The complete description MMIO of one linear spatial object is represented:

$$\tilde{T}^3_L = \tilde{T}^{1,2}_{AL} \cup \tilde{T}^{2,1}_L, \quad (31)$$

The scheme of complete description MMIO for one linear spatial object is determined:

$$S(\tilde{T}^3_L) = \{S_l, S_2, S_3, S_{AL}\}, \quad (32)$$

The complete description MMIO of one polygonal spatial object is represented:

$$\tilde{T}^3_p = \tilde{T}^{1,2}_{AP} \cup \tilde{T}^3_P \quad (33)$$

The scheme of complete description MMIO for one polygonal spatial object is determined:

$$S(\tilde{T}^3_P) = \{S_p, S_2, S_3, S_{AP}\}, \quad (34)$$

In (27), (29) and (31) there S_m, S_l, S_p are lists of spatial characteristics, S_{Am}, S_{AL}, S_{AP} are lists of attribute characteristics. Combine them for each scheme and denote as S_1. Accordingly, the scheme received MMIO will look like:

$$S(\tilde{T}^3_m) = S(\tilde{T}^3_L) = S(\tilde{T}^3_P) = \{S_1, S_2, S_3\} \quad (35)$$

Since any spatial data object according to (29), (31) and (33) can be described as a MMIO of dimension 3, a separate thematic layer of the master plan can be represented a group of similar objects and their characteristics is $\tilde{T}^4$.

The layer of point objects can be represented as MMIO:

$$\tilde{T}^4_m = \{\tilde{T}^3_m\}_i * S_4, \; i = \overline{1, n_1}, \quad (36)$$

where S_4 is the list of objects on the layer, n_1 is the number of point objects on the layer.

The layer of linear objects can be represented as MMIO:

$$\tilde{T}^4_L = \{\tilde{T}^3_L\}_i * S_4, \; i = \overline{1, n_2}, \quad (37)$$

where n_2 is the number of linear objects on the layer.

The layer of polygonal objects can be represented as MMIO:

$$\tilde{T}^4_P = \{\tilde{T}^3_P\}_i * S_4, i = \overline{1, n_3}, \quad (38)$$

where n_3 is the number of linear objects on the layer.

The full description of all the spatial objects under consideration, grouped into layers with a certain level of detail and constituting a construction territory master plan of a certain scale, can be represented as MMIO of dimension 5:

$$\tilde{T}^5 = \{\tilde{T}^4\}_i * S_5, \; i = \overline{1, n_5}, \quad (39)$$

Accordingly, if the master plan of the construction territory is considered as a set of various levels of detail plans, then the information base of spatial objects can be described as a MMIO of dimension 6:

$$\tilde{T}^6 = \{\tilde{T}^5\}_i * S_6, \; i = \overline{1, n_6}, \quad (40)$$

where S_6 is the list of levels of detail, n_6 is the number of levels of detail.

III. RESULT

The description of spatial and attribute data of general planning objects based on the MIO allows to submit each type of spatial object as one MIO, achieve integrity of the layers description of different types objects, simplify the structure description of the existing databases on information processing systems, make the information data model observable and understandable. Figures 3, 4 and 5 show a graphical representations of formulas (29), (31) and (33) for the complete descriptions of spatial data each type. Fig.3 shows a graphical interpretation of MMIO $\tilde{T}^3_m$ describing point objects. Fig.4 shows a graphical interpretation of MMIO $\tilde{T}^3_L$ describing linear objects. Fig.5 shows a graphical interpretation of MMIO $\tilde{T}^3_P$ describing polygonal objects.

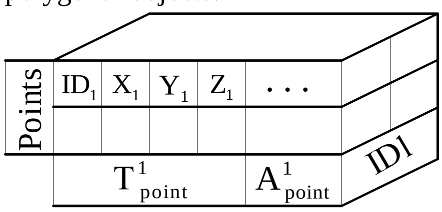

Fig.3.Graphical representation of MMIO dimension 3 $\tilde{T}^3_m$ for description point objects

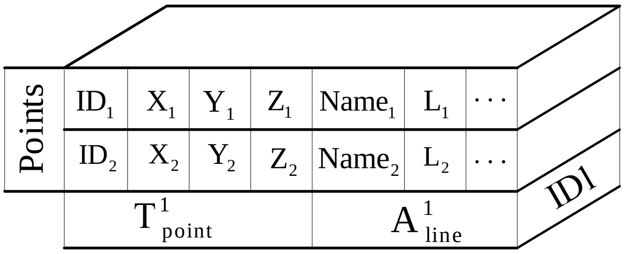

Fig.4.Graphical representation of MMIO dimension 3 $\tilde{T}_L^3$ for description linear objects

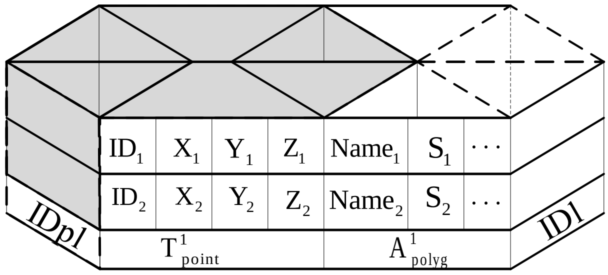

Fig.8.Graphical representation of MMIO dimension 4 $\tilde{T}_P^4$ for the layer of polygonal objects

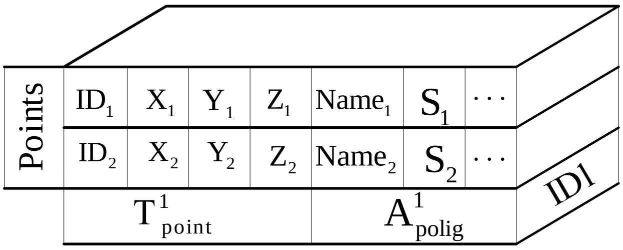

Fig.5.Graphical representation of MMIO dimension 3 $\tilde{T}_P^3$ for description polygonal objects

Figures 6, 7 and 8 show graphical representations of formulas (36), (37) and (38) for the descriptions of a similar objects group, that forms a separate layer on the master plan as MMIO.

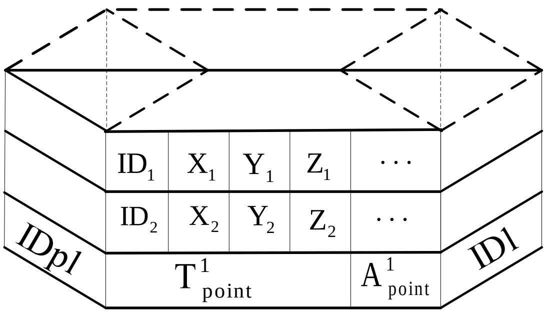

Fig.6.Graphical representation of MMIO dimension 4 $\tilde{T}_m^4$ for the layer of point objects

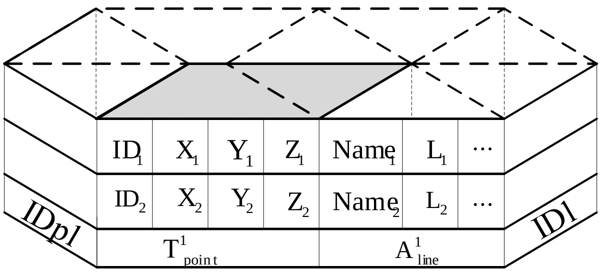

Fig.7.Graphical representation of MMIO dimension 4 $\tilde{T}_L^4$ for the layer of linear objects

IV. CONCLUSION

In the work, a description of the spatial and attribute data of the planning objects is based on the multidimensional information objects.

The results of the study have shown that multiplicative theoretical approach allows describing in one mathematical form sets of various types of spatial objects. The introduction of the additional dimension allows describing each type of spatial planning object as one separate MIO and MMIO. This is achieving the integrity of description layers of the different type's objects and simplifies the description of the existing database for the system information processing. This approach makes the information model of the planning object visible and understandable, which corresponds to the modern requirements of information modeling in the construction – BIM-technology.

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