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CREATING OF INTEGRATED SPATIAL MODEL FOR 3D GIS

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Abstract. A three dimensional (3D) model facilitates the study of the real world objects it represents. A geo-information system (GIS) should exploit the 3D model in a digital form as a basis for answering questions pertaining to aspects of the real world. With respect to the earth sciences, different kinds of objects of reality can be realized. These objects are components of the reality under study. At the present state-of the art, different realizations are usually situated in separate systems or subsystems. This separation results in redundancy and uncertainty when different components sharing some common aspects are combined. Relationships between different kinds of objects, or between components of an object, cannot be represented adequately. This thesis aims at the integration of those components sharing some common aspects in one 3D model. This integration brings related components together, minimizes redundancy and uncertainty. Since the model should permit not only the representation of known aspects of realty, but also the derivation of information from the existing representation, the design of the model is constrained so as to afford these capabilities. The tessellation of space by the network of simplest geometry, the simple network, is proposed as a solution. The known aspects of the realty can be embedded in the simple network without degrading their quality. The model provides finite spatial units useful for the representation of objects. Relationships between objects can also be expressed through components of these spatial units which at the same time facilitate various computations and the derivation of information implicitly available in the model. Since the simple network is based on concepts in geo-information science and in mathematics, its design can be generalized for n-dimensions. The networks of different dimension are said to be compatible, which enables the incorporation of a simple network of a lower dimension into dimension into another simple network of a higher dimension. Despite the GIS (Geographic Information Systems/Geospatial Information Systems) have been provided with several applications to manage the two-dimensional geometric information and arrange the topological relations among different spatial primitives, most of these systems have limited capabilities to manage the three-dimensional space. Other tools, such as CAD systems, have already achieved a full capability of representing 3D data. Despite the GIS (Geographic Information Systems/Geospatial Information Systems) have been provided with several applications to manage the two-dimensional geometric information and arrange the topological relations among different spatial primitives, most of these systems have limited capabilities to manage the three-dimensional space. Other tools, such as CAD systems, have already achieved a full capability of representing 3D data. Despite the GIS (Geographic Information Systems/Geospatial Information Systems) have been provided with several applications to manage the two-dimensional geometric information and arrange the topological relations among different spatial primitives, most of

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Key words: integrated spatial model, CAD systems, GIS, 3D modeling.

Introduction

The complexity of the 3D model full filling the requirements listed calls for a suitable construction method. The thesis presents a simple way to construct the model. The raster technique is used for the formation of the simple network embedding the representation of the known aspects of reality as constraints. The prototype implementation in a software package, ISNAP, demonstrates the simple network's construction and use. The simple network can facilitate spatial and non-spatial queries, computations, and 2D and 3D visualizations. The experimental tests using different kinds of data sets show that the simple network can be used to represent real world objects in different dimensionalities. Operations traditionally requiring different systems and spatial models can be carried out in one system using one model as a basis. This possibility makes the GIS more powerful and easy to use [1].

1. Needs for 3D GIS

We live in a three dimensional (3D) world. Earth scientists and engineers have long sought graphic expression of their understanding about 3D spatial aspects of reality in the form of sketches and drawings. Graphical descriptions of 3D reality are not new. Drawings in perspective view date from the Renaissance period [2]. 3D descriptions of reality in perspective view change with the viewing position, so their creation is quite tedious. Traditional maps overcome this problem by using orthogonal projections of the earth. However, they offer a very limited 3D impression.

These traditional drawings and maps reduce the spatial description of 3D objects to 2D. Using computing technology, however, knowledge about reality can be directly transferred into a 3D digital model by a process known as 3D modeling.

A more suitable tool for earth science applications would be a GIS providing a 3D GIS. At the time of writing, a GIS capable of providing the functions in the above list with full 3D modeling capability is not commercially available. Most GISs still limit their geometric modeling capability to 2D so that the 3D representation, analysis and visualization provided by CAD are not possible. Most endeavours to model the third dimension can be found in the representation of terrain relief and in digital terrain models (DTM). DTM can facilitate spatial analyses related to relief, including slope, aspect, height zone, visibility, cut and fill volume, and surface area, and the 3D visualization of a surface, as in a perspective view. However, the basis of DTM is a continuous surface with a single height value for every planimetric location (Figure 1.a). DTM cannot accommodate a 3D (solid) object, or a surface with multiple height values at a given planimetric location (Figure 1.b and Figure 1.c).

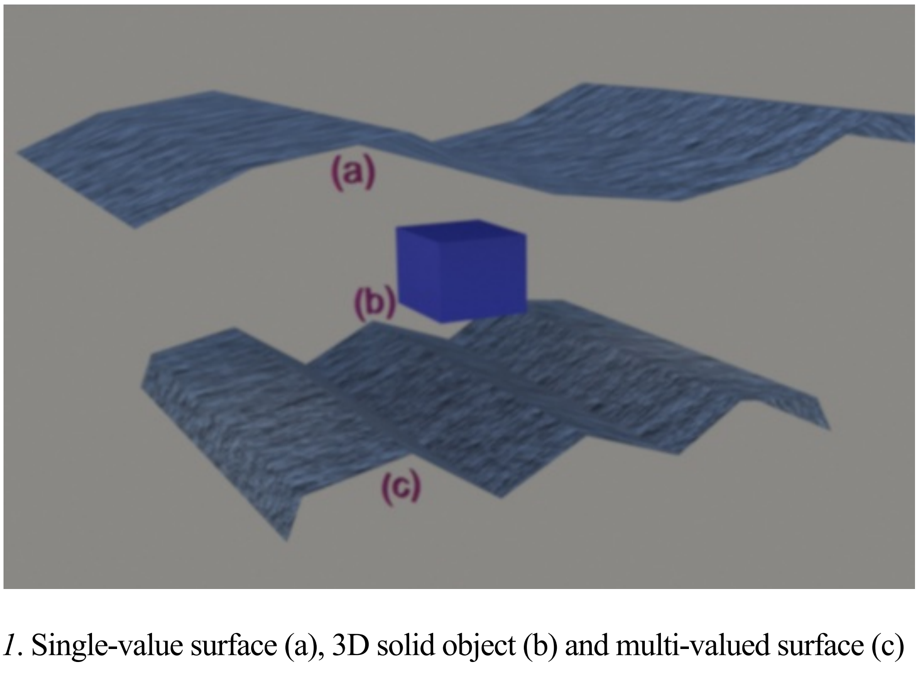

Figure 1. Single-value surface (a), 3D solid object (b) and multi-valued surface (c)

Although raster-based systems which could be regarded as 3D GISs are available, they may not be able to maintain the knowledge may be lost because of the problems of resolution and resampling. As a remedy, the original data set would have to be stored separately from the model, for example, for:

- Recreating the model if the result proves to be unsatisfactory because of unsuitable mathematical definition;
- Creating another model with different resolution;
- Merging with another data set to create a new model;

- Archiving as a reference to, or evidence of, the model.

These activities imply the need to store original data in an appropriate structure ready for future use. Necessary information about the data should be attached to each data element. In DTM for instance, information that a line is a break-line should be kept because it will have an impact on the interpolation. Similarly, other information can be attached which influence data handling strategies.

Since neither CAD nor GISs can at present fulfil the requirements of earth science applications, further research and development of a 3D GIS would seem appropriate.

In addition to the problem of creating a system capable of offering 3D modeling and functionality, there is a further problem concerning the type of 3D model chosen as the basis for 3D GIS. The model contains knowledge about reality, so we consider below the types of real world objects may be differentiated in terms of prior knowledge about their shapes and location, as shown in Figure 2. In reality, objects from the two categories coexist. Traditional GIS models the objects of each category independently with the result that two separate kinds of systems or subsystems have been developed.

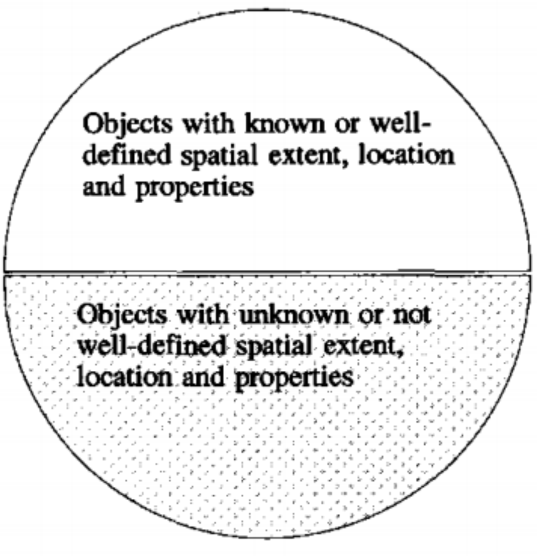

Figure 2. Two of real world objects with respect to their spatial exten

Raper [3] has also defined these two categories of objects. The first category, regarded as "sampling limited", is for objects having discrete properties and readily determined boundaries, such as buildings, roads, bridges, land parcels, fault blocks, perched aquifers.

The second category, known as "definition limited", is for objects having various properties that can be classified by grain-size distribution; moisture content, colloid or pollutant in the water by percentage ranges; carbon monoxide in the air by concentration ranges, and so forth.

Separate modelling of these two categories of objects tends to contradict the reality, which leads to difficulties in representing their relationships. Such a question as, "How many of the people working in a 50-storey office building are affected by polluted air generated by vehicles in nearby streets during rush hours"; cannot be answered until the two separate models are combined, as shown in Fig 3. Modeling them together with more accurate representation of their relationships in the 3D environment requires the integrated 3D modeling forming the general aim of this thesis.

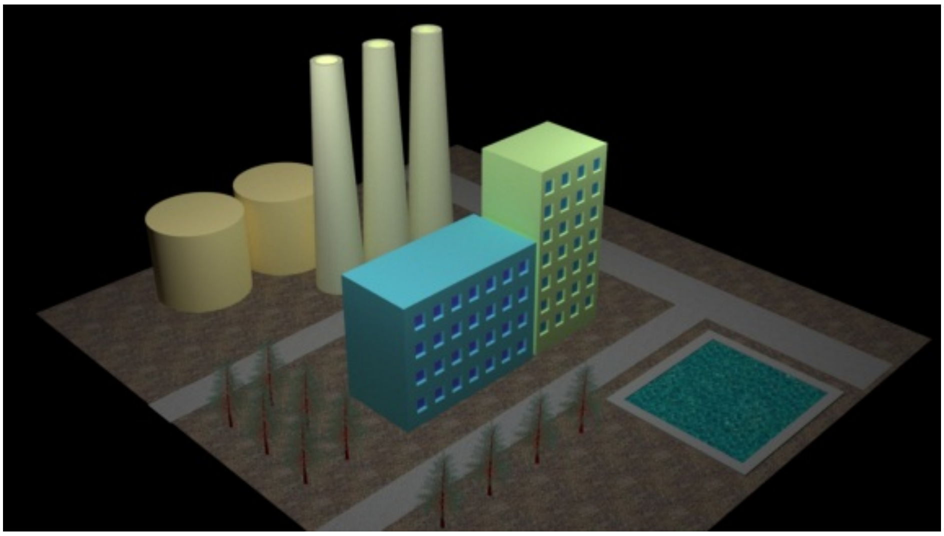

Figure 3. An example of two types of real world objects (1.Objects with discernible boundaries: roads, buildings. 2. Objects with indiscernible boundaries: moisture content of air, colloid or pollutant in the water by percentage ranges, toxins in the air)

Note also that the properties of an object may be well defined in some specific dimensions and defined in others. For example, given a DTM data set representing a surface, the planimetric extent of regions at the elevation of 100 metres above mean sea level cannot be defined until the result of interpolation based on a mathematical definition (linear interpolation) is obtained. That is to say, although the spatial extent of this region may be known in the z-dimension, the spatial extent in planimetry (x,y) has still to be discovered. The model must contain the aspect allowing the appropriate operation, such as interpolation or classification, if the required description of the properties of an object is to be obtained.

Apart from the problem of the separate modelling of the two types of objects, there remains the further problem of the separate modelling of an object's components. These components are relief and planer geometry associated with thematic properties.

This separation has resulted in independent systems and data structures, DTM and 2D GIS, respectively. The consequences are data redundancy, which may lead to uncertainty when the two data sets are combined and only one data set has been updated.

Spatial modeling is an analytical process conducted in conjunction with a geographical information system (GIS) in order to describe basic processes and properties for a given set of spatial features.

The objective of spatial modeling is to be able to study and simulate spatial objects or phenomena that occur in the real world and facilitate problem solving and planning. Spatial modeling is an essential process of spatial analysis. With the use of models or special rules and procedures for analyzing spatial data, it is used in conjunction with a GIS to properly analyze and visually lay out data for better understanding by human readers. Its visual nature helps researchers more quickly understand the data and reach conclusions that are difficult to formulate with simple numerical and textual data.

Manipulation of information occurs in multiple steps, each representing a stage in a complex analysis procedure. Spatial modeling is object-oriented with coverage and concerned with how the physical world works or looks. The resulting model represents either a set of objects or real-world process.

For example, spatial modeling can be used to analyze the projected path of tornadoes by layering a map with different spatial data, like roads, houses, the path of the tornado and even its intensity at different points. This allows researchers to determine a tornado's real path of destruction. When juxtaposed with other models from tornadoes that have affected the area, this model can be used to show path correlations and geographical factors.

In spatial modeling, the Bayesian approach has two main advantages above the frequentist methods. First, it is not based on approximation (like the penalized quasilikelihood) and thus provides exact results even for binary responses. Second, it correctly propagates the uncertainties linked to the estimation of the variogram parameters. This is not done by the frequentist approach, which uses a two-step approach: it first estimates the variogram parameters and then assumes them as known and plugs them into the linear model [4][5].

Temporal and spatial modeling of extreme precipitation in urban areas is a major challenge due to sparse data availability and huge spatial non-uniformity in precipitation. High uncertainties are associated with the short-duration precipitation events, which need to be modeled and further to be considered in the design and risk analyses. Bayesian methods provide a comprehensive way to quantify the uncertainties in the precipitation data [6]. The purpose of this study was spatial modeling of land subsidence using an RF data-mining model in Kerman Province, Iran. In order to investigate the spatial relationship between effective factors and subsidence locations, an FR bivariate statistical model was used. Also, in considering the importance of effective factors, an RF algorithm was applied. For spatial modeling, from the total subsidence locations, 70% were used for calibration and 30% for model evaluation. Validation of results showed that the RF model with an AUC value of 0.939 has excellent precision.

Therefore, based on the results of spatial modeling of a land-subsidence and susceptibility map, and also with regard to the correlation between effective factors and subsidence areas, it is possible to mitigate this hazard. Also, we can plan for managing water resources, in particular unauthorized wells and preventing extraction of groundwater which was carried out in the study area [7].

2. Importance for geo-information

In the context of earth science, the end product we seek is a model in the sense of a replica of some portion of the planet earth, and is called a geo-spatial model. Since the term “spatial model” covers a large territory over many disciplines (like the modeling of human anatomy in medicine, molecular structure in chemistry, or atomic structure in nuclear physics), we add the prefix geo to indicate the scope and purpose of this earth-related model.

For the information system to utilize the geo-spatial model, it must be constructed in digital form, so that it can be maintainted and exploited by a computer to perform certain tasks or operations that are:

Less convenient in realty; for example, a distance can be obtained from a model instead of measuring from place A to B in reality, provided that places A and B are represented in the model;

Too expensive, too difficult, or practically impossible in reality; for example, a geologist may wish to see the continuous layer of sandstone lying fifteen meters under the earth’s surface; removal of the upper soil to see this layer in realty is too expensive to contemplate.

A single-purpose model represents only single view of the reality (Figure 4).

An integrated model represents various views of the reality, so the integrated model may be considered to be of higher value, since it contains more aspects of the reality and may serve more purposes.

Before continuing this review of necessary fundamental concepts, the steps followed in geo-spatial modelling are defined. Obtaining a geo-spatial model requires two main steps: the design phase, and the construction phase (Figure 4).

Once the model is in place, maintenance forms an additional phase. The design phase includes all the abstraction processes, ranging from the conceptual design, the logical design, to the physical design. The product of the conceptual design is referred to as a conceptual model, or data model. It comprises a general scheme describing what should be included in the model.

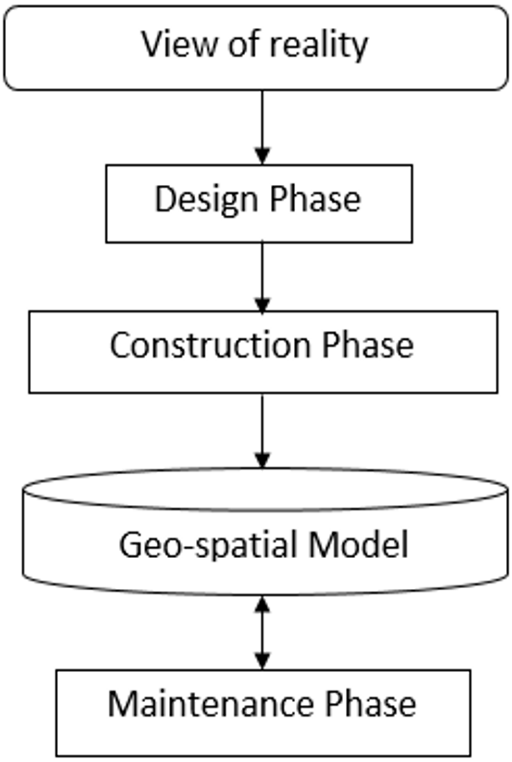

Figure 4. Geo-spatial modeling

3. Conceptual design of a geo-spatial model

The design phase deals with the abstraction of reality into the representation scheme. This phase answers two basic questions: what aspects of reality (real objects and the relationships between them) are to be modelled: how should they be represented in the model?

A geo-spatial database represents a state of reality from a specific point of view or interest at an instant in time (if the temporal aspect itself is not the subject of the model). The reality consists of a set of various objects and the relationships between them which should be capable of representation as components of the model described in the preceding section. To be manageable, it is necessary to determine a limited number of aspects of aspects of the reality (objects together with the relationships between them) during the design phase which can be represented as the first and second components of the model (Figure 5).

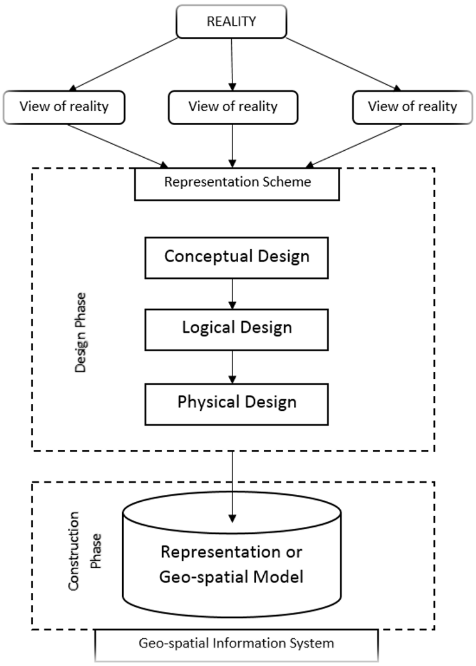

Figure 5. Design and construction phases for geo-spatial model

The conventions must operate in every design phase. In the conceptual design phase, the conventions should state the allowable type of objects and relations between them to be included in the model. In the logical design phase, the conventions should state how the representation of one objects is distinguished from another; an object should have a unique identifier. In the physical design phase, the conventions comprise a set of integrity and consistency rules for the operations that may change the state of the model; for example, the union of two areas sharing a common boundary has to yield only one area. The design of the model is followed by the design and implementation of the necessary functions and the user-interface to enable the construction and exploitation of the model. The result of this implementation is a geo-spatial information system (GIS). Having constructed the model, it must be kept valid to ensure it remains in a state comparable with the reality, which is dynamic in nature. This is the maintenance phase. The basic maintenance operations of insertion, deletion, and modification can be applied to any component of the model, that is to say object types, relations, rules, attributes and operations. A GIS should also provide functionality to maintain the geo-spatial model.

4. Spatial relations

Spatial relations are key issue in the design of a spatial model. Many extensive reviews and discussions can be found Frank and Kuhn [8], Pullar [9], Egenhofer [10], Pigot [11]. In the following paragraph, only a brief review is therefore given of some important basic concepts about spatial relations. Recall that R is a relation on a set O of objects, In general, R can be further distinguished by its different basic properties that depend on the relationships between its member elements. R is reflexive, if each element can be compared with itself (if and only if $(o1, o2) \in R$), for example 'point A' is equal to itself. R is symmetric, if and only R(o1, o2) implies R(o2 , o1). For example 'area A' is adjacent to 'area B' implies that 'area B' is adjacent to 'area A'.

R is anti-symmetric, if and only if R(o1, o2) and R(o2 , o1) implies $o1 = o2$ for all $o1, o2 \in O$, for example if $a \leq b$ and $b \leq a$, then $a = b$.

R is transitive, if and only if R(o1, o2) and R(o2, o3) implies R(o1, o3) for all $o1, o2 , o3 \in O$, for example area A < area B and area B < area C then area A < area C.

For example, given a set of real number N, $<$ is a transitive relation on N, $\leq$ is a reflexive, anti-symmetric, transitive relation on N, and $\neq$ is a symmetric relation on N. It is necessary at this stage to consider the definition of functions in mathematics used later.

Given two sets A and B, a function (or map) f from A to B, denoted f: A→B, is a subset of the Cartesian product A x B with the following properties:

For each a ∈ A, there is some b ∈ B such that (a, b) ∈ f,

If (a, b) ∈ f and (a, c) ∈ f, then b=c.

Each a ∈ A must be in relationship with exactly one b ∈ B and the relationship (a, b) ∈ f is normally written in a prefix form as b = f(a).

Comparing with relation R, every function on A is a relation R on A. However, not all relations on A are functions. Three classes of spatial relations, namely metric, order and topology, have been distinguished, based on the type of function or relation associated with a set of objects. Metric relations are built around the notion of distance function. Its mathematical description is as follows:

Given a set M with x, y, z ∈ M and a set of real number N. A metric relation d is a function d: M x M → N with the following conditions:

d(x, y) ≥ 0, Distance from x to y is more than or equal to zero.

d(x, x) = 0; d(x, y) = 0 implies x = y, Distance from x to itself equal to zero. Distance from x to y equal to zero implies that x is equal to y.

d(x, y) = d(y, x), Distance from x to y equal to distance from y to x.

d(x, y) + d(y, z) ≥ d(x, z) (triangular inequality). Distance from x to y plus distance from y to z is more than or equal to distance from x to z.

A metric space is an ordered pair (M, d) consisting of set M together with a function d: M x M → N satisfying the above four conditions. The function d is also called the metric on M. Functions d: M x M → N are called distance functions. A metric space is the Euclidean n-space (1), donated Rn, is the distance function below:

d ((x1 , . . . , xn), (y1, . . . , yn)) = $\sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$ (1)

The number ‘n’ defines the number of distance components between x and y (each one computed along an independent vector) and denotes the dimensionality of Euclidean space. The distance functions available in metric spaces are used to develop the notion of continuity crucial for the development of topology.

Conclusion.

In general, a 3D GIS should aim to integrate all the necessary elements of the spatial model and functions to create and utilize the spatial model efficiently. This research therefore analyses the definition of the direction of the related research and stimulate the development of 3D GIS that can readily be used. The research reviews some general aspects of systems for integrated 3D geo-information, their functional components, and some related and available technological developments to support their functionally with respect to the user’s perspective.

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СОЗДАНИЕ ИНТЕГРИРОВАННОЙ ПРОСТРАНСТВЕННОЙ МОДЕЛИ ДЛЯ 3D ГИС

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Аннотация. Трехмерная (3D) модель облегчает изучение объектов реального мира, которые она представляет. Геоинформационная система (ГИС) должна использовать трехмерную модель в цифровой форме как основу для ответов на вопросы, относящиеся к аспектам реального мира. Что касается наук о Земле, могут быть реализованы различные виды объектов реальности. Эти объекты являются составляющими исследуемой реальности. На современном уровне техники различные реализации обычно находятся в отдельных системах или подсистемах. Это разделение приводит к избыточности и неопределенности при объединении различных компонентов, имеющих некоторые общие аспекты. Отношения между разными типами объектов или между компонентами объекта не могут быть адекватно представлены. Этот тезис направлен на интеграцию тех компонентов, которые имеют некоторые общие аспекты в одной 3D-модели. Эта интеграция объединяет связанные компоненты, сводя к минимуму избыточность и неопределенность. Поскольку модель должна позволять не только представление известных аспектов недвижимости, но также получение информации из существующего представления, дизайн модели ограничен, чтобы предоставить эти возможности. В качестве решения предлагается тесселяция пространства сетью простейшей геометрии, простой сетью. Известные аспекты недвижимости могут быть встроены в простую сеть без ухудшения их качества. Модель предоставляет конечные пространственные единицы, полезные для представления объектов. Отношения между объектами также могут быть выражены через компоненты этих пространственных единиц, которые в то же время облегчают различные вычисления и получение информации, неявно доступной в модели. Поскольку простая сеть основана на концепциях геоинформатики и математики, ее конструкция может быть обобщена для n-мерных измерений. Сети разных измерений считаются совместимыми, что позволяет включать простую сеть более низкого измерения в размерность в другую простую сеть более высокого измерения.

Ключевые слова: интегрированная пространственная модель, САПР, ГИС, 3D моделирование.