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CLASSIFICATION OF CARTOGRAPHIC MODELS ACCORDING TO THEIR CONTENT, DIMENSIONALITY, MATERIAL OF PRODUCTION AND TYPES OF REALITY

ABSTRACT

Cartography as one of the most ancient science and practice supply users with cartographic models and deliver them with geospatial information. Now in the days of technological revolution and digital earth we cannot find clearly classification of cartographic models including the latest achievements of science, technics and methodology. Several classifications, mainly of maps are shown and critical review is done. It is visible that no standardization in this field.

Cartography as a mathematical science need classification system of its models, data and information. It is needed to everybody who make and use cartographic models. The classification system offers a possible method for selecting a suitable model that can be used to visualize a data set or theory. The point of classification is to take large number of observations and group them into data ranges or classes.

This paper represents an information about cartographic models and make attempt to classify them according to their content (general, thematic, specialized), dimensionality (2D, 2.5D, 3D, 4D, multidimensional), material of production (paper / hard base, digital, anaglyph, holographic, web), and types of reality (virtual, augmented, physical). This is done on the base of new cartographic models appeared with technical innovation and computer-aided systems used in cartography nowadays.

KEYWORDS: cartographic models, classification, dimension, virtual reality, augmented reality

INTRODUCTION

Cartography is a science that deals with the depiction of reality through various types of cartographic works. It reaches consumers by presenting geoinformation through maps, globes and others. They can all be defined as cartographic models. Ramonas [1998] wrote that a map as a complicated model of space represents a classical cartographic model and more over its properties are defined: abstractness, uniqueness, synthetic character of the view, metricity, visuality, informativeness and others. The same author includes in the category of cartographic model atlases. An atlas is a compilation of many maps, which means many cartographic models but often the atlas is in the category of complex model of the real environment. What does it mean cartographic model and modeling?

Cartographic model (CM) could be considered as a mathematically defined representation of real environment on a smaller scale than the original by generalization and symbolization of represented objects and phenomena.

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MATERIALS AND METHODS OF RESEARCHES

Cartographic modelling is a generic way of expressing and organising the methods by which spatial variables, and spatial operations, are selected and used to develop an analytical solution with a GIS [*Trodd*, 2005]. Cartographic modelling is based on the concept of data layers, operations, and procedures. Tomlin (1991) states, that “the fundamental conventions of cartographic modelling are not those of any particular GIS. On the contrary, they are generalized conventions intended to relate to as many systems as possible.”

“Modeling, is all about design”, said Trodd [2005]. He mentioned that the really useful thing about models is that they can be used to predict an unknown — either the value of something that can’t be measured directly or the future state or condition of the phenomena of interest. If a model that shows how different factors — local and global — influence weather patterns, then it could predict what is likely to happen and also what might happen if there were changes in one or more factor.

Ikonovich [2007] declares that the aim and sense of cartographic modeling is to represent essential, typical and characteristically attributes of mapping territory. She divides cartographic modeling in two phases: 1. trough theoretical modeling and creating mind models and 2. trough practical modeling and making prototype model. We will point attention on second one — practical model which can be used for many applications and for decision making in different situations.

Generally, in the cartographic literatures, there are many maps’ classifications and cartographic models which are not traditional paper maps, are classified like other cartographic publications: globes, atlases, relief maps, block-diagrams, anaglyph maps, photomaps, digital, electronic maps, map animations [*Berlyant*, 2003]. One of the first models’ classification according their use in Geographic Information System (GIS) can be found in Konečny and Rais [1985].

Srbinovski [2012] divided cartographic products on maps, atlases, globes, relief maps and models. Because we declare that all above mentioned products are cartographic models cannot agree to classify models as a type of cartographic products. Moreover, we can say that the cartographic product contains the cartographic model.

Iconovich [2006] classifies the cartographic models on maps, models in thematic cartography, atlases (complex models of geo-space) and virtual ones. This classification is not mentioned according which characters of the models they are classified.

Idrizi [2004] makes very detailed maps’ classification: according territorial coverage (space, earth, hemispheres, oceans, continents, countries, etc.); scale; content (topographic, geographic, thematic, aero-photo maps); purpose (tourist, school, informative, military, cadastre, etc.), way of use; type of content (analytic, synthetic, complex); representative form (paper, plastic, digital, color, black and white, relief, aero-photo, etc.); display of content (static, kinematic, dynamic, forecast, 2D, 3D, 4D etc.). Because this is classification of maps, we cannot find here other cartographic products, like atlases and globes.

Another details classification of maps is done by Markoski [2018]. His classification is according territorial scope (world maps, maps of land surfaces — continents, countries, regions, etc., maps of water surfaces — oceans, seas, bays, etc.); contents (geographic, topographic, thematic); scale (plans, large-scale, medium-scale, small-scale); applications (school, informative, military, …), cartographic projection, publisher, usage and other characteristics. This classification is similar to other authors but do not include that maps of hemispheres in territorial scope; it is appearing a new category according cartographic / map projection. Question about map projection could be discussed if this is really different classification of maps.

The libraries also need classification of cartographic products. But they are not according cartographical characteristic. One of proposed classification of maps and related cartographic materials in cataloging, classification, and bibliographic control, following categories are proposed: sheet maps, early and contemporary atlases, remote-sensed images such as aerial photographs and satellite images, globes, geologic sections, digital material, items on CD-ROM [*Andrew, Lansgaard*, 2000].

The new classification, including the development of the technologies in cartography came by Peng and Tsou [2003] who propose a classification of online digital maps, according to an ascending scale of the level of interactivity and of the richness of the available functions: static maps; static web maps; interact web maps and distributed GIS services. Another classification and analysis of the various types of digital maps are made by Caron et al. [2005]. They classified digital maps on static, hypermaps, dynamic maps and web-based GIS. It is difficult to say that the lasts are maps, more appropriate if they could be named cartographical products.

Classification is important for researchers to identify, group, and properly name cartographic models via standardized system, based on similarities and differences found in the models.

The next chapter proposes classification of the cartographic product by four characteristics: content, dimensionality, material of production and types of reality.

RESULTS OF RESEARCHES AND THEIR DISCUSSION

1. <u>Classification of cartographic models</u>

1.1. Classification of cartographic models by their content

Using map classification by many authors [*Berlyant*, 2003; *Penev*, 2016; *Idrizi*, 2004; *Srbinovski*, 2012] we propose similar three types of cartographic models according their content: general, thematic and specialized one.

1.1.1. <u>General cartographic model</u> — represents the totality of the elements of the area; they have universal use for studying the territory, orientation and solving scientific and practical tasks. All represented objects have one and the same visibility on the map contrary to the thematic maps where thematic objects should be more visible than basic ones.

General cartographic models provide many types of information. The following are some features that might be shown on general cartographic models: topography, bodies of water, roads, railway lines, vegetation, settlements, political boundaries, and so on. These models give a broad understanding of location and features of an area. The user may gain an understanding of the type of landscape, the location of urban places, and the location of major transportation routes all at once. Typical general cartographic models are topographic maps, nature maps, 2D and 3D city maps.

1.1.2. <u>Thematic cartographic model</u> — the most varied category of cartographic models of natural and public phenomena, their combination and complexes. The content of the model is determined by one or another theme.

A thematic model focuses on a specific theme or subject area such as physical phenomena like temperature variation, rainfall distribution and population density in an area [*Farooq*, 2002].

1.1.3. <u>Specialized cartographic model</u> — the cartographic models in this group are designed to solve a specific set of tasks or they are designed for certain circles of users.

These models have a separate function. They are result from systematic mapping in a specific area. Also, they are created for use in specific socio-economic sectors. Their drafting and issuance are approved by guidelines, instructions, rules and standards in accordance with existing regulations — laws and regulations [*Penev*, 2016].

The most common uses for specialized models in other industries or sciences are: technical infrastructure; planning of sea costs; forests; geology; ecology; navigation; soil; protected areas; cultural heritage; mineral resources; earth science and etc.

1.2. Classification of cartographic models by their dimension

Cartographers need to represent our tree-dimensional (3D) real environment on the map. Twenty years ago, we had only possibility to use map projections and map on two-dimensional plane. Now it is a time when by computer graphics we can add the third dimension, design, project and already print 3D maps. Using virtual reality, we can add the time as a fourth dimension. Including different phenomena on 4D map connected to the mapped content, we will receive multidimensional cartographic models.

1.2.1. 2D cartographic model

Mapping and analysis of 2D land-surface phenomena are performed by traditional GIS using either vector or raster approaches. Vectors more closely replicate traditional maps and diagrams, and raster system work well with some of the newer data sources, including a variety of geophysical and satellite remote sensor data.

The main use of two-dimensional cartographic model is for topographic maps. They have relatively equal scale in the x and y dimensions. From topographic sheets to atlas plates to road maps, the vast majority of maps available today are of the 2D variety [*Schobesberger, Patterson*, 2008]. These maps are used for a number of applications, from camping, hunting, fishing, and hiking to urban planning, resource management, and surveying.

The advantages of the 2D cartographic models are the shape, easy to read and interpret, and a good view of the designed area. The disadvantages are that only two dimensions can be evaluated simultaneously (for example, it is difficult to estimate the height of the surfaces), and therefore, flat representation can disturb the perception of space. Bandrova [2001] makes comparative analyses of 2D and 3D cartographic models according their practical applications on the base of thematically map contents for different users. It is discovered that second ones have better applications and representation in realistic visualization, situation of new object, full reflection of lighting and cast shadows, representation of meteorological conditions in dynamic environment and so on.

1.2.2. 2.5D cartographic model

2.5D cartographic model is a compact data representation optimized for data streaming of 3D models. Modern 2.5D cartography, known as pixel art in some contexts, integrates computer-aided design (CAD)-based photorealistic or artistic renderings into maps.

According to MacEachren [1995], “The two-and-a-half-dimensional (2.5D) map is either 2D map projected and similar techniques used to cause images or scenes to simulate the appearance of being 3D when in fact they are not, or three-dimensional one that is restricted to a two-dimensional plane with a limited access to the third dimension”.

2.5D maps, also known as perspective maps or bird’s-eye view maps, are represented in an oblique perspective [*Liang et al.*, 2016]. 2.5D maps have the potential to augment the value and extend the use of existing 3D models.

1.2.3. 3D cartographic model

3D modeling and mapping are used by a growing number and range of users for a variety of purposes such as urban planning and architecture, design and advertising, management, transportation and tourist maps. 3D provides opportunities to analyze non-personally identifiable information in 2D presentation [Bandrova, 2001].

Godchild writes about the paradox of modern cartography, giving an example of the flat 2D world view and deformation that we need to supplement with perspective views shown in recent versions of Microsoft’s Encarta Atlas. He notes that the “average” user will work with the digital globe more conveniently and easily understandably than with the digital Mercator projection.

The term 3D map, it is commonly understanding a map containing Digital Terrain Model (DTM), 2D data draped on terrain, 3D models of objects (in proper scales) and 3D symbols (expressing objects, which cannot be modeled in their real proportions) [*Hájek et al.,* 2016]. Not every 3D map of course consists of all scale levels. The most common use of 3D map is a map of urban areas (sometimes called 3D city maps). Such a map then usually consists of medium and large scales layers. The 3D cartographic models (maps, atlases, globes and others) can be used for various 3D analyses, spatial planning, 3D cadaster, Crisis Management and so on. On fig. 1 a 3D map of the avalanche zones can be seen.

The advantages of 3D cartographic models are that relative heights and depths are better conveyed in 3D, and that the relationship between design and human dimensions is easier to grasp. The disadvantages are that 3D cartographic models will be more difficult to create and modify than 2D cartographic models.

Fig. 1. 3D map of the avalanche zones in the west area of Todorka peak, Pirin Mountain, Bulgaria

1.2.4. <u>4D cartographic model</u>

4D cartographic model allows observes the dynamics of the object. Models in 4D format are created to observe the technological processes or the consequences of natural disasters. For the development of 4D models, aerospace images and plan-altitude database are used.

3D and 4D cartographic models are used in the following areas:

- spatial planning of settlements;
- management of communication networks;
- design in construction;
- modeling of natural hazards;
- others.

Aerospace images can provide reliable information even about hard-to-reach objects for which ground-based methods are not suitable.

4D representation (three spatial dimensions plus time) of time varying phenomena, i.e. thematic 4D mapping, is still widely untouched [*Resch et al.*, 2013]. These authors also mentioned that is particularly surprising as the fast rise of Google Earth since 2005 has revolutionized the Geographic Information domain through making 3D geoinformation available to inexperienced users and thus through fostering the idea of map-based information systems on the Web. This is probably due to the fact that Google Earth is mostly used to view quasi-static content such as satellite imagery, 3D city models or a variety of points of interest. Another example of using 4D cartographic models is the fact that Yano et al. [2009] include vertical and temporal dimensions to 2D models of real environment and create virtual Kyoto as 4D GIS.

In contrast to static information, the learning effect, i.e. cognitive knowledge creation by understanding a spatiotemporal process, is more complex for time-varying phenomena. It can be optimized by dual coding methods such as varying graphical variables like color, shape, intensity or the z-value extrusion.

1.2.5. Multi-dimensional cartographic model

Multi-dimensional visualization of Geographic Information System (GIS) refers to the use of 2.5D, 3D and 4D representation forms to reflect the multi-dimensional characteristics of geographical objects. Multi-dimensional visualization of geographic information is of great significance in geoscience. It has prominent methodological significance for describing objective reality dynamically, vividly, from multiple perspectives, and for virtualization research, reproduction and prediction of geo phenomena. For example, in atmospheric science, the occurrence, development and evolution of cyclones, tornadoes and precipitation clouds are expressed in the form of four-dimensional (true three-dimensional plus time dimension); in geography, it is of great scientific value and practical significance to simulate the flow, fluctuation, erosion of river embankment, and underwater condition after the break.

1.3. Classification of models by their material of production

1.3.1. Models on a paper vs the digital models

The development and using the computer devices led to considerable changes in the many fields of science and practice. Cartography is among them [*Vasilev*, 2000]. Vasilev said that "the recent applications of cartographic modelling cover more fields than classical cartography". Mapping is a timeless science as well as an art that has been around since time immemorial. It has been used by several people to identify places and find directions to destinations especially by travelers and explorers. With the development of technology, the use of paper-based topographic maps has been reduced, compared to maps in digital form. The use of smartphone applications and digital maps via GPS devices is gaining popularity.

These are some of the differences between digital maps and paper maps:

Paper maps

- accessible and available in most specialized stores;
- requires keep them in the dedicated places;
- printed on paper that can be stored anywhere and can therefore be accessed from anywhere, also you do not need a computer or internet connection to access it;
- there are cartographic symbols to represent features with specific purpose;
- cannot be updated easily;
- cannot represent all kind of features at the same time, just on aspect at a time;
- limited to specific area based on the scale of the map;
- ideal for showing boundaries of an area and for analysis of data;
- ideal for use as data storage for reference purposes when showing changes in land forms.

Digital maps

- not sold in physical shops but instead they are available online and can be downloaded for free;
- do not require physical space for storage, but require digital space;
- requires an internet connection to access them online;
- do not depend on cartographic symbols to represent features. Instead, they show the actual features and the time;
- can be updated easily because the changes will be updated automatically;
- not limited to show only a specific area based on scale. They can be widened to show the entire area;
- easier than paper maps since the features are real representations of objects of the real world;
- do not only show 2D representations of an area. They can be used to show the 3D angle of the area and also show the area overlays;
- always up to date and may therefore not be ideal for use to show changes in land forms.

Cartographic models in traditional paper format are very usable and will still be used. But the development of technologies such as multimedia and interactivity give the chance to find a new mapping representation of the study area, which could become many usable products in the future. Designing prototype models and analyzing users views of such models will help design widely used and economically successful cartographical products.

1.3.2. Anaglyph maps

There are many approaches to create and view stereoscopic images, but all of them rely on independently presenting different images to the left and right eyes. Although there are many drawbacks in anaglyph, it is the cheapest approach for creating and viewing 3D images. An anaglyph is a combination of two images into one, in such a way that they can later be separated by viewing the image through appropriately colored transparent filters. As a pair of left view and right view images are combined into a single image, a pair of color filtered glasses separates and directs the left and right images to the corresponding eyes to provide the perception of depth [*Zeng, Zeng,* 2011].

Although anaglyphs have a big advantage that they can be presented using traditional single channel media such as print, film, display, etc., a media type must be determined as a pair of images is combined into a single image to minimize retinal rivalry and stereo crosstalk. Most of anaglyph images and software to generate anaglyph pictures are optimized for display and assumed using red-cyan filtered glasses for viewing.

Most of gamut mapping methods used for ordinal printing produces serious ghost effect in printing anaglyph images optimized for display. Therefore, a gamut mapping method to produce color characterization tables for printing anaglyph images and maps is develop to solve the problem. It approximately preserves the relationship of lightness relationship of the left and right views. An anaglyph mode using such gamut mapping method makes anaglyph printing much more useful for customers.

1.3.3. Holographic maps

Holography is the only known-technique for 3D reconstruction of objects of the real world, which provides all of the required physiological characteristics of human vision system. Unlike other techniques, such as lenticular flat-panel displays, auto-stereoscopy, and volumetric systems holography is very natural for human brain while processing 3D information [*Dalkiran et al.,* 2020].

By using holography in cartography also has some limitations for now. These are:

- Low resolution;

- Lack of real colors and contrast levels;
- Hard to produce 360 degree of viewing angle;
- Need of coherent light and illumination;
- High costs.

Future maps will provide the information about n-dimensions, real-time updatable data, improved 3D symbology and geographical commenting by using artificial intelligent. These products can be categorized as digital, semi-digital and analog. Whatever it is category these products will use holographic technology in their applications.

Next decade, usage of maps will gain more importance and find more application areas. Computer aided cartography and tactile maps will become widespread. The trend of commerce will have shifted to the lane of 3D media. Most probably, holomaps will place the conventional paper maps.

1.3.4. Web maps

Cartographic communication is a highly complicated process for people have differently interpreted and expressed the view of their environment through symbols and signs. Under the influence of civilizational development, the graphically visual modeling of geo spatial data has changed. Geo space is a complex system and its demonstration is related to the creating of the model of real world. The analogue map has been the only way of showing space data visually. Being a model, its purpose has been the viewing geospatial complexity and it has served as a means of storing geospatial information. Today, information is a commodity of the highest value, including the speed of its spreading. The Web stands for the newest means of communicating geospatial information with the possibility of its versatile presentation. WWW is a global information system whose functioning essence is its universality, for every current piece of information is available and accessible to every user in real time. What differs web cartography from the traditional one is its limitation on the web as a means. The development of web cartography is directly linked with internet development as a means of communication. Web cartography studies the possibilities of creating, transferring and using cartographic information and visualizations presented on the Internet. In this way, cartography has both visual and virtual status. When creating web maps, we have to consider the features, the limitations and the possibilities of the web environment. Web cartography explores the features of web maps, also considering map contents (color, text, and symbols), map quality (size, resolution) and the map environment (interface design, web site contents). Cartographic displays are uploaded on the internet as a means of data integration, distribution and visualization on the web with the possibility of data integration from different systems in an unlimited way. The integration of spatial data from different sources on the web will make it possible for the joining of space and time during the geospatial exploration and decision, as in the future the Internet will become a unique cartographic data base.

2. Cartographic models according types of reality

2.1. Virtual reality

A concise definition of virtual reality (VR) is given by Fisher and Unwin [2002] as “the ability of the user of a constructed view of a limited digitally encoded information domain to change their view in three dimension causing update of the view presented to any viewer (the user).” The definition gives a brief summary of the essence of all visualizations that can be called virtual reality.

VR is an important tool in navigation and object manipulation as well as immersion within the designed application [*Quaye-Ballard,* 2008]. It facilitates egocentric views in which the display is constructed from the point of view of the user who may be inside the designed application as compared to desktop tools, which generally restricts the user to the outside (termed exocentric view). VR brings the promise of a much more comprehensive way of visualizing data. The user is within the middle of the plan and can directly interact with the 3D data. VR is very important in analyzing and visualizing scientific data because of the 3D and dynamic characteristics it provides.

There are several real applications of virtual reality which are used in the following areas:

- Urban and regional planning;
- Environmental planning, modelling and impact assessment;
- Scientific/geographic visualization;
- Military simulation and intelligence application;
- Geographic Information Science;
- Archaeological modelling;
- Education;
- Ecology.

The last research from Pérez and his team, was virtual reality to foster social integration by allowing wheelchair users to tour complex archeological sites realistically. The remote sensing of the site enables the production of a realistic 3D model leading to the creation of a virtual world that the user will explore [*Pérez et al.*, 2020]. The VR application has been developed to traverse one of the most important monumental buildings in Spanish Protohistory, the site of Cancho Roano (Zalamea de la Serena, Spain). Two strategies have been used in addition to the classic VR procedures. The first one is to create 3D cartographic models from 3D data gathered with a laser scanner, allowing visualization and integration into the VR application. The second strategy is to make the experience of touring the site as realistic as possible for a visitor in a wheelchair.

There is the need for 3D representation of our environment to which urban and regional planners, the environmentalist, the geographic information scientist, the military, the archaeologist, the ecologist, the educationist, the real estate agent etc. could interact. In this respect, VR can be used to assess the visual impact of different visualization schemes thereby enabling meaningful and efficient decision making, monitoring and maintenance.

2.2. Augmented reality

Augmented Reality (AR) is a variation of Virtual Environments (VE), or VR as it is more commonly called. VE technologies completely immerse a user inside a synthetic environment. While immersed, the user cannot see the real world around him. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world [*Azuma*, 1997].

AR enhances a user’s perception of and interaction with the real world. The virtual objects display information that the user cannot directly detect with his own senses. The information conveyed by the virtual objects helps a user perform real-world tasks. AR is a specific example of what Fred Brooks calls *Intelligence Amplification* (IA): using the computer as a tool to make a task easier for a human to perform. Such good example could be seen on fig. 2 where AR helps students to understand maps and represented information by easier way.

Potential areas for AR could be defined as:

- Education: interactive models for learning and training purposes, from mathematics to cartography;
- Tourism: data on destinations, sightseeing objects, navigation, and directions;
- Medicine / healthcare: to help diagnose, monitor, train, localize, etc;
- Military: for advanced navigation, marking objects in real time;
- Broadcasting: enhancing live events and event streaming by overlaying content;
- Industrial design: to visualize, calculate or model;
- Art / installations / visual arts / music [*Savova-Georgieva*, 2018].

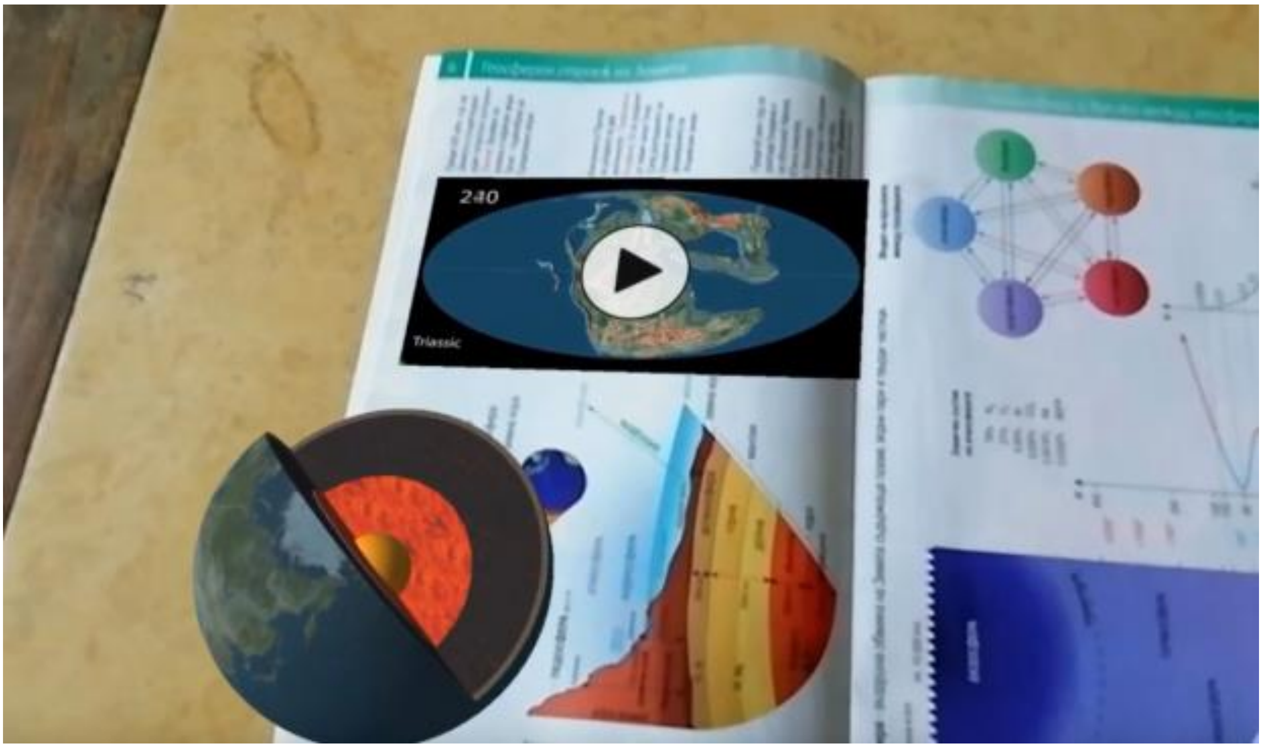

Fig. 2. AR on the base of paper school atlases [Yonov, 2019]

2.3. Physical reality

The innovation in mapping has been in shifting to a much more mobile, accessible medium (a screen instead of paper) — not in actually being more intuitive or bettering how we experience the physical world.

Most of the people have their own complex systems that affect orientation, remembering and understanding. The actually process these different systems at high level is the same: by building a cognitive model. Cognitive model are just mental representations of physical locations. It's how our brain creates a sense of place. People (and most animals) use these mental models to navigate and remember important features of the environment. Forrester (1971) states that: "The image of the world around us, which we carry in our head, is just a model. Nobody in his head imagines all the world, government or country. He has only selected concepts, and relationships between them, and uses those to represent the real system".

Sherman and Craig (2003) said that there a lot of information about physical reality from people's sense of touch, which is not currently the case in most virtual reality worlds. The lack of haptic sensation is not detrimental for many types of information gathering; however, when touch is an important aspect of an experience, relying on it heavily. Another feedback from Sherman and Craig (2018) was that in physical reality, when people interact with an object and follow through with a perceived affordance, the resultant action tells them whether that affordance was real or false. Users get immediate feedback from their action. Likewise, in virtual reality, and indeed in other computer-mediated systems, feedback is an important way for the computer interface to inform a user that their action was recognized.

The future of cartography is going to be digitized by combining multiple mixed reality models. There is an example of school atlas with augmented reality [*Yonov*, 2019]. He combined school atlas as a physical reality and 3D animations as an augmented reality for educational use.

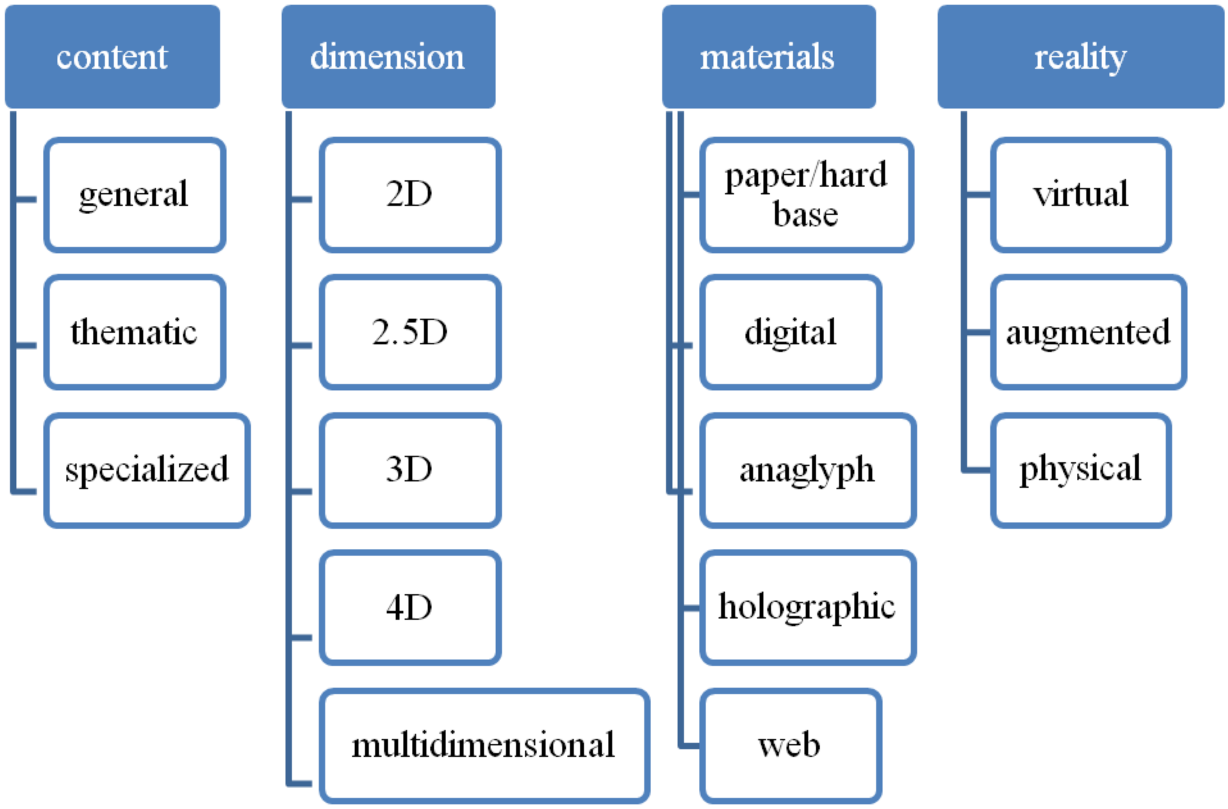

Fig. 3. Schema of classification of cartographic models

CONCLUSIONS

The classification schema (fig. 3) proposed and discussed above offers a possible method for selecting a suitable model that can be used to visualize a data set or theory. To apply the classification system and to work through the decision-tree diagram, a cartographer should, ideally, possess a clear and complete understanding of a dataset's characteristics. The point of classification is to take large number of observations and group them into data ranges or classes. Classification matters because how we group our data into classes is one of the most fundamental aspects of model generalization — the process by which we simplify the real world to fit it on to the model — and small differences in how we do that can dramatically change the look of it, and thus, its message.

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