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Real Environment 3D Model – a Base for 3D Map Making

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Abstract. 3D maps are one of the most attractive cartographical products for map users. They can present the real environment in a photorealistic, readable way, keeping enough geo-spatial information for the needs of different users. Very often users don't make a difference between 3D maps and 3D models of the real environment. The aim of this report is to clarify when we can speak of 3D maps and even to discuss the definition of a 3D map.
The article considers the cartographical elements applied in 3D mapping which help a 3D model to become a 3D map: user requirements, map contents, symbol system, accuracy, scale, projections and generalization, levels of details. The new cartographical elements are added to improve 3D maps: virtual camera, shades, lights, animation. In conclusion, the author will explain when we can speak of a 3D model and when of a 3D map.

Keywords: 3D model, 3D map, 3D symbols, 3D mapping, Cartography

1 Introduction

Cartography is one of the most ancient and, at the same time, one of the most modern sciences. The three-dimensional (3D) technologies, and the application of modern techniques give us evidence for development of cartography as a science and practice of map making. Every cartographer pays attention to users, every map should supply users with necessary information regarding the represented objects and phenomena. Many scientists (Petrovič 2001, Bonchev 2009, Stanek et al. 2010) use this new direction for cartography to identify and evaluate different user requirements and needs.

Adami and Guerra (2006) outlined the integration of the acquisition, management, and representation techniques for geo-referencing data processing. They wrote about "more representative" and "world widespread" digital cartography. This means that when reality is described and visualized, social, economic, and cultural data should also be included. Futhermore, more users can be identified from different cartographic product user groups. The author concludes that 3D maps are the most suitable products for this purpose (Adami and Guerra 2006). There are many examples of 3D maps or models of reality made by different technologies with very high usage. Some examples are given below:

- The Brisbane city 3D model, built using artificial intelligence (AI) photogrammetry method from different sources: OpenStreetMap (OSM) data, Open Source Digital elevation model (DEM) LiDAR data, Free satellite imagery, shows city development and planning processes (Snecket 2019).
- Häberling et al. (2008) explain that 3D maps can be presented on a large variety of display media. They demonstrate this by presenting a 3D map from an interactive atlas of Switzerland consisting of topographic

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3D model stvarnog okoliša – osnova za izradu 3D karata

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Sažetak. 3D karte su za korisnike karata jedan od najatraktivnijih kartografskih proizvoda. Mogu prikazati stvarno okruženje na fotorealističan, čitljiv način, čuvajući dovoljno geoprostornih informacija za potrebe različitih korisnika. Vrlo često korisnici ne prave razliku između 3D karata i 3D modela stvarnog okruženja. Cilj je ovog izvješća razjasniti kada možemo govoriti o 3D kartama, pa čak i raspraviti o definiciji 3D karte.
U članku se razmatraju kartografski elementi primijenjeni u 3D kartiranju koji pomažu 3D modelu da postane 3D karta: korisnički zahtjevi, sadržaj karte, sustav znakova, točnost, mjerilo, projekcije i generalizacija, razine detalja. Dodani su novi kartografski elementi za poboljšanje 3D karata: virtualna kamera, sjene, svjetla, animacija. U zaključku će autorica objasniti kada se može govoriti o 3D modelu, a kada o 3D karti.

Ključne riječi: 3D model, 3D karta, 3D kartografski znakovi, 3D kartiranje, kartografija

1. Uvod

Kartografija je jedna od najstarijih, a ujedno i jedna od najmodernijih znanosti. Trodimenzionalne (3D) tehnologije i primjena suvremenih tehnika svjedoče o razvoju kartografije kao znanosti i praktičnoj izradi karata. Svaki kartograf obraća pažnju na korisnike, svaka karta treba korisnicima pružiti potrebne informacije o prikazanim objektima i pojavama. Mnogi znanstvenici (Petrovič 2001, Bonchev 2009, Stanek i dr. 2010) koriste taj novi smjer u kartografiji za prepoznavanje i procjenu različitih korisničkih zahtjeva i potreba.

Adami i Guerra (2006) opisali su integraciju tehnika prikupljanja, upravljanja i prikazivanja za obradu georeferenciranih podataka. Pisali su o "reprezentativnijoj" i "svjetski raširenoj" digitalnoj kartografiji. To znači da kada se realnost opisuje i vizualizira, treba uključiti i društvene, ekonomske i kulturne podatke. Nadalje, iz različitih skupina korisnika kartografskih proizvoda može se identificirati više korisnika. Autorica zaključuje da su 3D karte najprikladniji proizvodi za tu svrhu (Adami i Guerra 2006). Postoji mnogo primjera 3D karata ili modela stvarnosti izrađenih različitim tehnologijama s vrlo raširenom upotrebom. U nastavku su navedeni neki primjeri:

- 3D model grada Brisbanea, izrađen upotrebom metode fotogrametrije umjetne inteligencije (AI) iz različitih izvora: podatci OpenStreetMapa (OSM), podatci digitalnog elevacijskog modela otvorenog koda (DEM) LiDAR-a, besplatne satelitske slike, prikazuje razvoj grada i procese planiranja (Snecket 2019).

content, draped semi-transparent satellite imagery and hypsographic colouring.

- Ski trail maps in North America are represented mainly by painting, illustrated maps, annotated photos and only 3% by computer rendering (Tait 2008). In the same research, it is mentioned that for all ski areas, 17.8% of websites had an interactive map.
- Yonov and Bandrova (2018) represent a 3D map of a sport area and symbols and consider cartographical aspects in the map making process.
- There are many other examples showing 3D map applications whose number is rising very fast – Microsoft's Earth View-Map 3D, Earth 3D Map, 3D Imagery in Google Earth, Satellite Maps 3D Scene of NOAA, Google Cities in 3D Program, and others.

One more example is an application of 3D modelling of mountain territory which is not developed enough. Despite the development of digital technologies, many traditional paper-based cartographic tools are still in use for different purposes (Stanek et al. 2010).

In this paper, by creating a 3D model, the author demonstrates how cartography can be developed to suit the production of 3D maps or when a 3D model can be called a 3D map. The major advantage of 3D cartographic modelling is that once a three-dimensional model is created it can be used for different purposes. It can be seen as a database and source material for the production of various types and functional applications, targeted to different areas of interest.

Next sections will consider different kinds of users of 3D mapping, definition of a 3D map, content, accuracy, generalization, symbol system and scale as cartographic elements applied into 3D map theory and practice. The main topic of the difference between 3D models and 3D maps will also be discussed.

2 Users of 3D Mapping

The major advantage in 3D cartographic modelling is that once created, a 3D model/map can be used for different purposes. It can be considered as a database and source for creation of various applications with different functionalities used in different areas of interest.

In the past, users worked using only 2D maps and media to depict real phenomenon at their disposal, which restricted the analysis of the processes, relationships and behaviour of real objects. Recent developments in hardware and software technology have shown encouraging results in the storage and maintenance of large amounts of data. This has let us to expect 3D images to dominate this millennium. The survey of use of 3D Maps among 15 Bulgarian companies showed that 94% of them think that a 3D symbol system is a very important part of 3D maps (Zlatanova and Bandrova, 1998). This survey showed that 3D maps should be considered a cartographical product with all aspects of map making: accuracy, generalization, symbology, location, scale, etc. Now, almost 25 years later, we already use 3D maps every day, everywhere – as navigation systems in motor vehicles, as base information for decision making, in the education process, in advertisement, for engineering purposes and design.

Users of 3D maps can be found in different fields of science, industry and communications. Their number is much bigger than users of 2D maps. When the third dimension is included in cartographic representation and products, the analyses become deeper and more accurate, even possible in some new areas of research, where it had not been possible to use the 3rd dimension so far.

- City planning and architecture – engineers and architects need photo-realistic models of buildings and cartographic models of city environments to design and visualize new ones that can be entered into new 3D maps. 3D maps can be used for collecting information with the aim of restoring unique facades of buildings (Bayanova and Bandrova 2012, Girindran et al. 2020)
- Teaching in schools and universities – some students find it difficult to use school atlases and wall maps in geography, history, and earth sciences. Multimedia education that includes the 3rd dimension of maps, diagrams, sound, video, and others can improve the quality of the teaching as well as increase students' interest in subjects (Šašinka et al. 2019, Niedomysl et al. 2013)
- Design and advertising – 3D tourist maps will give a more realistic impression of a city than 2D maps (Wu et al. 2022)
- Telecommunications – Telecommunications companies could use 3D maps and data to calculate and visualize radio signal propagation predictions in urban environments. 3D maps enable easy analysis and design (Krijestorac et al. 2021)
- Transport – 3D maps are useful for simulating urban traffic and enable better planning of different kinds of transport schedules (Rubin et al. 2021)
- Environmental pollution – 3D maps can be used to illustrate the distribution of different kinds of pollution, simulate global warming and noise distributions (Li et al. 2017, Kurakula and Kuffer 2008)
- Tourism – Tourism companies could present more realistic city views for different tourism proposals. They could suggest interactive virtual rambles through such 3D maps (Dymkova and Dymkov 2021).

- Häberling i sur. (2008) objašnjavaju da se 3D karte mogu prikazati na velikom broju medija za prikaz. Oni to pokazuju prikazivanjem 3D karte iz interaktivnog atlasa Švicarske koja se sastoji od topografskog sadržaja, poluprozirnih satelitskih slika i hipsografskih boja.
- Karte skijaških staza u Sjevernoj Americi prikazane su uglavnom slikama, ilustriranim kartama, fotografijama s bilješkama i samo 3% računalnim renderiranjem (Tait 2008). U istom se istraživanju navodi da je za sva skijališta 17,8% web stranica imalo interaktivnu kartu.
- Yonov i Bandrova (2018) prikazuju 3D kartu sportskog područja i znakova te razmatraju kartografske aspekte u procesu izrade karte.
- Postoje mnogi drugi primjeri koji pokazuju primjene 3D karte čiji broj vrlo brzo raste – Microsoftov Earth View-Map 3D, Earth 3D Map, 3D Imagery u Google Earthu, Satellite Maps 3D Scene NOAA-e, Google Cities in 3D Program, i drugi.

Još je jedan primjer nedovoljno razvijena primjena 3D modeliranja planinskog područja. Unatoč razvoju digitalnih tehnologija, mnogi tradicionalni kartografski alati koji se temelje na papiru još uvijek se koriste u različite svrhe (Stanek i dr. 2010).

U ovom radu autorica pokazuje kako se kartografija može razviti tako da odgovara izradi 3D karata, odnosno kada se 3D model može nazvati 3D kartom. Glavna je prednost 3D kartografskog modeliranja ta što se trodimenzionalni model jednom kreira, a može koristiti u različite svrhe. Može se promatrati kao baza podataka i izvorni materijal za proizvodnju različitih vrsta i funkcionalnih aplikacija usmjerenih na različita područja interesa.

U sljedećim će se poglavljima razmatrati različite vrste korisnika 3D karata, definicija 3D karte, sadržaj, točnost, generalizacija, sustav kartografskih znakova i mjerilo kao kartografski elementi primijenjeni u teoriji i praksi 3D karte. Također će se raspravljati o glavnoj temi: razlici između 3D modela i 3D karata.

2. Korisnici 3D kartiranja

Glavna je prednost 3D kartografskog modeliranja ta što se jednom izrađeni 3D model/karta može koristiti u različite svrhe. Može se smatrati bazom podataka i izvorom za izradu različitih aplikacija s različitim funkcionalnostima koje se koriste u različitim područjima interesa.

U prošlosti su korisnici upotrebljavali samo 2D karte i medije da bi prikazali stvarne fenomene koji su im bili na raspolaganju, što je ograničavalo analizu procesa, odnosa i ponašanja stvarnih objekata. Nedavni razvoj hardverske i softverske tehnologije pokazao je ohrabrujuće rezultate u pohranjivanju i održavanju velikih količina podataka. Stoga očekujemo da će u ovom tisućljeću dominirati 3D slike. Istraživanje upotrebe 3D karata među 15 bugarskih tvrtki pokazalo je da 94% njih misli da je sustav 3D kartografskih znakova vrlo važan dio 3D karata (Zlatanova i Bandrova 1998). To je istraživanje pokazalo da 3D karte treba smatrati kartografskim proizvodom sa svim aspektima izrade karata: točnost, generalizacija, simbologija, lokacija, mjerilo itd. Sada, gotovo 25 godina kasnije, svakodnevno i posvuda koristimo 3D karte – kao navigaciju sustava u motornim vozilima, kao temeljne informacije za donošenje odluka, u obrazovnom procesu, u oglašavanju, za inženjerske svrhe i projektiranje.

Korisnici 3D karata nalaze se u različitim područjima znanosti, industrije i komunikacija. Njihov je broj puno veći od broja korisnika 2D karata. Kada se treća dimenzija uključi u kartografski prikaz i proizvode, analize postaju dublje i točnije, čak moguće i u nekim novim područjima istraživanja u kojima do sada nije bilo moguće koristiti treću dimenziju.

- Urbanističko planiranje i arhitektura – Inženjeri i arhitekti trebaju fotorealistične modele zgrada i kartografske modele gradskih sredina za dizajn i vizualizaciju novih koji se mogu unijeti u nove 3D karte. 3D karte mogu se koristiti za prikupljanje informacija s ciljem obnove jedinstvenih fasada zgrada (Bayanova i Bandrova 2012, Girindran i dr. 2020).
- Nastava u školama i na sveučilištima – nekim je učenicima teško koristiti školske atlase i zidne karte u geografiji, povijesti i znanostima o Zemlji. Multimedijsko obrazovanje koje uključuje 3. dimenziju karata, dijagrama, zvuka, videa i drugo može poboljšati kvalitetu nastave kao i povećati interes učenika za predmete (Šašinka i sur. 2019, Niedomysl i sur. 2013).
- Dizajn i oglašavanje – 3D turističke karte dat će realističniji dojam grada nego 2D karte (Wu i dr. 2022).
- Telekomunikacije – Telekomunikacijske tvrtke mogle bi koristiti 3D karte i podatke za računanje i vizualizaciju predviđanja širenja radio signala u urbanom okruženju. 3D karte omogućuju jednostavnu analizu i dizajn (Krijestorac i dr. 2021).
- Promet – 3D karte korisne su za simulaciju gradskog prometa i omogućuju bolje planiranje različitih vrsta prijevoza (Rubin i dr. 2021).
- Onečišćenje okoliša – 3D karte mogu se koristiti za ilustraciju distribucije različitih vrsta onečišćenja, simulaciju globalnog zatopljenja i distribuciju buke (Li i dr. 2017, Kurakula i Kuffer 2008).
- Turizam – Turističke bi tvrtke mogle predstaviti realističnije poglede na grad za različite turističke ponude. Mogle bi predložiti interaktivno virtualno lutanje kroz takve 3D karte (Dymkova i Dymkov 2021).

Some scientists even researched how users will deal with interactive and static 3D maps and found that interactive 3D maps are better for users than static ones in several aspects: more accurate solutions require less time, they are suitable for complex tasks and for geo-experts (Herman et al. 2018).

Still many other users of 3D maps could be shown – mobile mapmakers (Rakkolainen and Vainio 2001), decision makers in early warning and crises management (Jiping et al. 2021), for landscape simulations (Dinkov and Vatseva 2016), for web-based applications (Dinkov and Bonchev 2020) and many others. Generally, every field where spatial data should be represented is a potential user of 3D map. User requirements are directed to readable and clear data representation, strict accuracy, generalization and appropriate symbolization. All these user requirements came from long time usage of traditional 2D maps. There is even research where authors show that there is no evidence for user preferences to a 3D globe when need to solve cartographic tasks (Wilkening and Fabrikant 2013).

The use of 2D and 3D cartographic products gives enormous information to our users in many fields shown above. Coming from the users' point of view, we can find different definitions of a 3D map. Here a definition of the 3D map is given on the base of a 2D map including the 3rd dimensionality and a new aspect of a 3D mapmaker.

3 Definition of 3D Map

Many authors talk about 3D maps and give different definitions: Jenny speaks about 3D maps as "commonly known as landscape panoramas or bird's-eye views" (Jenny 2011). Artimo (1994) defines 3D maps as a combination of digital cartographic data and methods for representation. Here we should make a difference between 2.5D and 3D maps. 2.5D map is designed on a 2D base map with inclusion of the height as an attribute, while on a real 3D map every point should be represented by 3 co-ordinates (Petrovič 2003).

Another definition says that a 3D map is a computer, mathematically defined, three-dimensional virtual representation of the Earth surface or another celestial body, objects and phenomena in nature and society. Represented objects and phenomena are classified, designed and visualized for a particular purpose (Bandrova 1997).

Nowadays when cartography has a new dimension as a science, practice and technology, the working group on the Cartographic Body of Knowledge (International Cartographic Association) presented a new map definition: "*The map* is a medium designed for communication of generalized spatial information and relationships" (Lapaine et al. 2021). Having this definition, we do not need to specially define a 3D map, because all modern type variants of a map are included – not only traditional one, but digital, animated, 3D and multi-dimensional, web map, even holographic one.

Now my task will be to distinguish the 3D model of the real environment from a 3D map and to explain when a 3D model of the real environment will become a 3D map. The start will be with the content of a 3D map which is described below.

4 Content of 3D Map

The concrete content of a 3D map is designed after the definition of objects and phenomena that will be included. It could be subdivided into three themes:

- *Main content* – large topographic or landscape objects such as relief bodies, roads, buildings etc. Most designed 3D maps, presented by different companies in the world, represent it.
- *Secondary content*, carrying the basic information. For example, in 3D urban maps – "small" objects, represented by symbols – traffic signs, facilities, transport elements, information signs, trees, etc.
- *Additional content*, providing the qualitative and quantitative information about objects, often created as a textual database, regarding each of the designed objects or the map as a whole.

Since objects from the main content are usually represented in real size and often they are phototextured, we can consider them as a 3D model of the real environment/city. The symbol system is represented in secondary content and more qualitative and quantitative information about represented objects and phenomena could be found in additional content. We can consider that a 3D map contains all three types of content: main, secondary and additional. In addition, for every cartographical product, such as a 3D map, accuracy, scale and generalization are important elements.

5 Accuracy of a 3D Map

The design of a 3D map cannot reduce the accuracy of the output data obtained by digitization, direct measurements, and satellite images. The accuracy of referencing an object can reach 0.1 mm, which would satisfy the users of this type of map. The localization of objects or symbols on a 3D map is done using the coordinates X, Y, Z in a local coordinate system or relative local coordinates x, y, z, relative to a predetermined starting point. The accuracy in the use of a symbol system for 3D maps can be considered in 3 aspects:

1. Positional accuracy (accuracy of referencing)

Neki su znanstvenici istraživali kako će se korisnici nositi s interaktivnim i statičnim 3D kartama i otkrili da su interaktivne 3D karte bolje za korisnike od statičnih u nekoliko aspekata. Točnija rješenja zahtijevaju manje vremena, prikladna su za složene zadatke i za geostručnjake (Herman i dr. 2018).

Mogli bi se prikazati i mnogi drugi korisnici 3D karata – mobilni izrađivači karata (Rakkolainen i Vainio 2001), donositelji odluka u ranom upozoravanju i upravljanju krizama (Jiping L i dr. 2021), za simulacije krajolika (Dinkov i Vatseva 2016), za web aplikacije (Dinkov i Bonchev 2020) i mnoge druge.

Općenito, svako je područje u kojem se susreću prostorni podatci potencijalni korisnik 3D karte. Zahtjevi korisnika usmjereni su na čitljiv i jasan prikaz podataka, strogu točnost, generalizaciju i odgovarajuću primjenu kartografskih znakova. Svi ovi zahtjevi korisnika proizašli su iz dugotrajne upotrebe tradicionalnih 2D karata. Postoji čak i istraživanje u kojem autori pokazuju da nema dokaza o preferencijama korisnika prema 3D globusu kada je potrebno riješiti kartografske zadatke (Wilkening and Fabrikant 2013).

Upotreba 2D i 3D kartografskih proizvoda daje golemu količinu informacija našim korisnicima u mnogim područjima. S gledišta korisnika možemo pronaći različite definicije 3D karte. Ovdje je dana definicija 3D karte na temelju 2D karte uključujući trodimenzionalnost i novi aspekt 3D kartografa.

3. Definicija 3D karte

Mnogi autori govore o 3D kartama i daju različite definicije: Jenny govori o 3D kartama kao o "općepoznatim kao pejzažne panorame ili pogledi iz ptičje perspektive" (Jenny 2011). Artimo (1994) definira 3D karte kao kombinaciju digitalnih kartografskih podataka i metoda prikazivanja. Ovdje treba napraviti razliku između 2.5D i 3D karata. 2.5D karta dizajnirana je na 2D osnovnoj karti s uključivanjem visine kao atributa, dok na pravoj 3D karti svaka točka treba biti prikazana s trima koordinatama (Petrovič 2003).

Druga definicija kaže da je 3D karta računalni, matematički definiran, trodimenzionalni virtualni prikaz površine Zemlje ili nekog drugog nebeskog tijela, objekata i pojava u prirodi i društvu. Prikazani objekti i pojave klasificiraju se, dizajniraju i vizualiziraju za određenu svrhu (Bandrova 1997).

U današnje vrijeme, kada kartografija ima novu dimenziju kao znanost, praksa i tehnologija, radna skupina Kartografskog korpusa znanja (International Cartographic Association) predstavila je novu definiciju karte: „*Karta* je medij dizajniran za komunikaciju generaliziranih prostornih informacija i odnosa." (Lapaine i dr. 2021) Imajući tu definiciju, ne trebamo posebno definirati 3D kartu jer su uključene sve moderne tipske varijante karte – ne samo tradicionalne, već i digitalne, animirane, 3D i višedimenzionalne, web karte, čak i holografske.

Zadatak je autorice članka razlikovanje 3D modela stvarnog okoliša od 3D karte te objasniti kada će 3D model stvarnog okoliša postati 3D karta.

4. Sadržaj 3D karte

Konkretan sadržaj 3D karte osmišljava se nakon definiranja objekata i pojava koji će biti uključeni. Može se dalje podijeliti u tri teme:

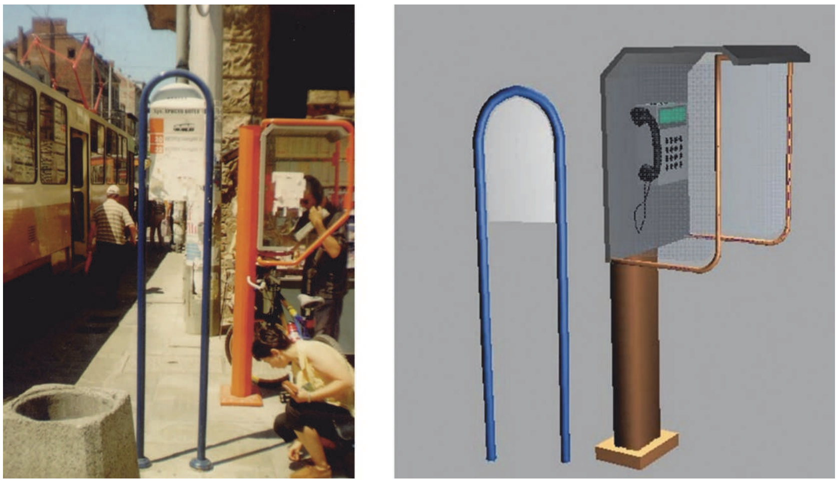
- *Glavni sadržaj* – veliki topografski ili krajobrazni objekti kao što su dijelovi reljefa, ceste, zgrade itd. Prikazuje ih većina 3D karata koje su izradile različite tvrtke.
- *Sekundarni sadržaj* – nosi osnovne informacije, na primjer, u 3D urbanim kartama to su "mali" objekti, prikazani kartografskim znakovima: prometni znakovi, objekti, prometni elementi, informativni znakovi, drveće itd.
- *Dodatni sadržaj* – pruža kvalitativne i kvantitativne informacije o objektima, često kreiran kao tekstualna baza podataka, za svaki od projektiranih objekata ili kartu u cjelini.

Budući da su objekti iz glavnog sadržaja obično prikazani u stvarnoj veličini i često su oblikovani s pomoću fotografija, možemo ih smatrati 3D modelom stvarnog okoliša/grada. Sustav kartografskih znakova prikazan je u sekundarnom sadržaju, a više kvalitativnih i kvantitativnih informacija o prikazanim objektima i pojavama može se pronaći u dodatnom sadržaju. Možemo smatrati da 3D karta sadrži sve tri vrste sadržaja: glavni, sekundarni i dodatni. Osim toga, za svaki su kartografski proizvod, poput 3D karte, važni elementi točnost, mjerilo i generalizacija.

5. Točnost 3D karte

Dizajn 3D karte ne može smanjiti točnost izlaznih podataka dobivenih digitalizacijom, izravnim mjerenjima i satelitskim slikama. Točnost referenciranja objekta može doseći 0,1 mm, što bi zadovoljilo korisnike te vrste karata. Smještaj objekata ili kartografskih znakova na 3D karti obavlja se s pomoću koordinata X, Y, Z u lokalnom koordinatnom sustavu ili relativnih lokalnih koordinata x, y, z, u odnosu na unaprijed određenu početnu točku. Točnost u upotrebi sustava kartografskih znakova za 3D karte može se promatrati u trima aspektima:

1. Položajna točnost (točnost referenciranja)



Slika 1. Fotorealistični dizajn 3D znakova vizualizira stvarne gradske objekte korištene u sustavu kartografskih znakova za 3D kartu: lijevo – fotografija stvarnih objekata okoliša; desno – znakovi dvaju objekata.

Fig. 1 Photorealistic design of 3D symbols visualized real city objects used in a symbol system for a 3D map: left – photo of real environmental objects; right – symbols of two of the objects.

2. Thematic accuracy and
3. Semantic accuracy.

Positional accuracy refers to the actual location of the object on the ground. It is influenced by:

- Accuracy of measurements and data collection
- Scale of the basic 2D map
- Hardware and method of input data processing.

The accuracy of the thematic information to be displayed on the map depends on:

- The data used (e.g. quality of the statistics, collection and processing methods) and
- Transformation of data (selection, classification and assignment of data to other data).

The way in which the data on the map is symbolized and visualized is part of the thematic accuracy. The data can be displayed on a map as basic structure, such as a map showing population density by district. In reality, however, the calculated density can be attributed to one part of this area, while another part does not have the same density (Sijmons 1995).

Semantic accuracy is the accuracy with which symbols define the objects. Depending on the purpose and use of the map, the symbols must be designed in such a way that the user imagines the objects as they are in reality. The problem with the semantic accuracy of 2D maps has been overcome by 3D modelling methods, which give extremely high photorealistic visualization of real-world objects (Figure 1).

Another issue in this topic could be the difference in accuracyon the X and Y coordinates and H ones. The difference will come from different sources for 3D map creation. Usually, the accuracy on the X and Y coordinates will be relevant to the sources: 2D cadastral, topographic map or measurements. The 3rd coordinate H could be received by other types of measurements, architectural plans or others. In this case, the accuracy on the H coordinate could be higher than on X and Y. The accuracy will also be influenced by generalization or levels of detail.

6 Generalization and Levels of Detail

The traditional cartographic generalization does not explore all aspects of generalization in computer graphics, which is a powerful tool in creating this new type of cartographic model - 3D maps. The following can be added to the traditional cartographic generalization:

- Automatic generalization
- Dynamic generalization and
- Interactive generalization.

Automatic generalization, as Berlyant writes, manifests itself in "formalized selection, smoothing and filtering of the image in accordance with certain formal criteria". Smoothing can be used to simplify curved contours when creating symbols or on highly dissected surfaces. "The process of automatic generalization is well manageable, but it is difficult to introduce informal assessments, parameters of content value" (Berlyant 1996).

We have a dynamic generalization when we use 3D maps to create an animated map for a given territory or to track the development of a given phenomenon in space

2. Tematska točnost i
3. Semantička točnost.

Položajna se točnost odnosi na stvarni položaj objekta na tlu. Na nju utječu:

- Točnost mjerenja i prikupljeni podatci
- Mjerilo osnovne 2D karte
- Hardver i metoda obrade ulaznih podataka.

Točnost tematskih informacija koje će se prikazati na karti ovisi o:

- upotrijebljenim podatcima (npr. kvaliteta statistike, metode prikupljanja i obrade) i
- transformaciji podataka (odabir, klasifikacija i dodjela podataka drugim podatcima).

Način na koji su podatci na karti prikazani kartografskim znakovima i vizualizirani dio je tematske točnosti. Podatci se mogu prikazati na karti kao osnovna struktura, kao što je karta koja prikazuje gustoću naseljenosti po okrugu. U stvarnosti, međutim, izračunana gustoća može se pripisati jednom dijelu područja, dok drugi dio nema istu gustoću (Sijmons 1995).

Semantička je točnost točnost kojom kartografski znakovi definiraju objekte. Ovisno o namjeni i upotrebi karte, znakovi moraju biti oblikovani tako da korisnik zamišlja objekte onakvima kakvi su u stvarnosti. Problem sa semantičkom točnošću 2D karata prevladan je metodama 3D modeliranja koje daju iznimno visoku fotorealističnu vizualizaciju objekata iz stvarnog svijeta (slika 1).

Drugi bi problem u ovoj temi mogla biti razlika u točnosti koordinata X, Y i H. Razlika će se pojaviti zbog različitih izvora za izradu 3D karte. Obično će točnost X i Y koordinata biti relevantna za izvore: 2D katastar, topografsku kartu ili mjerenja. Treća se koordinata H može dobiti drugim vrstama mjerenja, s arhitektonskih planova ili na neki drugi način. U ovom slučaju, točnost H koordinate mogla bi biti veća od točnosti X i Y. Na točnost će također utjecati generalizacija ili razine detalja.

6. Generalizacija i razine detalja

Tradicionalna kartografska generalizacija ne istražuje sve aspekte generalizacije u računalnoj grafici koja je moćan alat u stvaranju ove nove vrste kartografskog modela – 3D karte. Tradicionalnoj kartografskoj generalizaciji može se dodati:

- automatska generalizacija
- dinamička generalizacija i
- interaktivna generalizacija.

Automatska generalizacija, kako piše Berlyant, očituje se u "formaliziranom odabiru, izglađivanju i filtriranju slike u skladu s određenim formalnim kriterijima". Zaglađivanje se može koristiti za pojednostavljenje zakrivljenih kontura pri kreiranju kartografskih znakova ili na jako isječenim površinama. "Procesom automatske generalizacije je dobro upravljati, ali je teško uvesti neformalne procjene, parametre vrijednosti sadržaja." (Berlyant 1996).

Kada koristimo 3D karte za izradu animirane karte za određeni teritorij ili za praćenje razvoja određenog fenomena u prostoru i vremenu, imamo dinamičku generalizaciju. Zatim se slika generalizira, promatraju se glavni, vremenski stabilni, tipični i dugoročni trendovi razvoja pojava uvođenjem brzine kao norme generalizacije. "Načela generalizacije određena su brzinom fluktuacije materijala, učinak koje još nije proučavan. Razlika između uobičajene i brze projekcije filmova je sasvim drugačija: od 24 do nekoliko tisuća sličica u sekundi. " (Berlyant 1996) Ta generalizacija uvodi vremenski efekt u 3D karte ili stvara, kako su ih mnogi znanstvenici nazvali, 4D karte.

Interaktivna generalizacija kombinira tradicionalnu kartografsku generalizaciju s automatskom i vremenskom generalizacijom. Interaktivna intervencija opet subjektivizira proces sveukupne generalizacije izvedene na 3D kartama. Jasno je da će geometrijski oblik objekata prikazanih kartografskim znakovima, prikaz njihovih kvantitativnih i kvalitativnih karakteristika, kao i novouvedeni dinamički aspekti kroz vremensku ili dinamičku generalizaciju, odrediti sadržaj svake 3D karte.

Generalizacija je vrlo često povezana s razinama detalja u konceptu 3D kartiranja. 3D karte mogu se izraditi na nekoliko različitih načina. Ovisno o razinama detalja, to će uzrokovati nedosljednu sliku, a mogu se pojaviti i problemi s generalizacijom i upotrebom znakova. To je otežano pri stalno mijenjajućem mjerilu (Bandrova 2001). Zbog složenosti kartografske vizualizacije i relativnosti izražene razlikama u potrebama potrošača ne može se izgraditi precizan model razine detalja koji bi jednako dobro funkcionirao za različite teritorije. Na primjer, kad se stvara trodimenzionalni model kartografskog terena, potrebne razine detalja su radikalno različite od urbanog okruženja. Razine detalja također mogu varirati ovisno o namjeni karte.

7. Sustav kartografskih znakova za izradu 3D karata

Sistematizacija i klasifikacija objekata i dizajn kartografskih znakova temelji se na nizu uvjeta koji se uzimaju u obzir pri sastavljanju karata: sadržaj, namjena, priroda uporabe, značajke vizualne percepcije, estetski zahtjevi, hardverske i softverske mogućnosti. Uzimajući u obzir cjelokupnu složenost kombiniranja navedenih uvjeta, koraci u izradi znakova za 3D karte razlikuju se kako slijedi:

a) *Prikupljanje informacija* o objektu (kvalitativne i kvantitativne karakteristike, slike, teksture) and time. Then the image is generalized, we observe the main, stable in time, typical and long-term trends for the development of phenomena by introducing speed as the generalization norm. "The principles of generalization are determined by the speed of staff turnover, the effect of which has not yet been studied. The difference between the usual and high-speed screening of films is quite different: from 24 to several thousand frames per second " (Berlyant 1996). This generalization introduces the time effect into 3D maps or creates 4D maps, as many scientists have called them.

Interactive generalization combines traditional cartographic generalization with automatic and temporal generalization. The interactive intervention again subjectivizes the process of overall generalization performed in 3D maps. It is clear that the geometric shape of the objects depicted by symbols, the representation of their quantitative and qualitative characteristics, as well as the newly introduced dynamic aspects through temporal or dynamic generalization will determine the content of every 3D map.

Generalization is very often connected to levels of detail in the concept of 3D mapping. 3D maps can be created in several different ways. Depending on the levels of detail, this will cause an inconsistent image, and problems with generalization and symbology can occur. This is made more difficult due to the continuously changing scale (Bandrova 2001). Due to the complexity of cartographic visualization and the relativity expressed by differences in consumer needs, a precise model of the level of detail cannot be built, which would work equally well for different territories. For example, when creating a three-dimensional model of cartographic terrain, the levels of detail required would be radically different from the urban environment. The levels of detail may also vary depending on the purpose of the map.

7 Symbol System for 3D Map Making

The systematization and classification of objects and the design of cartographical symbols is based on a number of conditions considered when compiling maps: content, purpose, nature of use, features of visual perception, aesthetic requirements, hardware and software capabilities. Considering the whole complexity of combining the listed conditions, the steps in creating symbols for 3D maps are distinguished as follows:

a) *Gathering information* about an object (qualitative and quantitative characteristics, images, textures)
b) *Analysing information* and collecting data about each object
c) *Designing symbols* by visual and metric analysis and then applying computer graphics techniques
d) *Visualizing symbols* in the virtual environment
e) Obtaining synthesized information for an object.

The theoretical base of the cartographic symbol system in 3D modelling has been developed by Bandrova (2001). This is a result of extensive investigations that demonstrate the lack of a formally defined 3D symbol system. The requirements and stages for symbol design are specified. They provide cartographers with a standard approach for developing symbol systems for 3D city maps. Cartographic symbols could be used for representing all “small” objects, represented on the maps. Usually, they do not need to be represented with their real shape and dimensions depending on user needs and purpose of the map. On Figure 2 churches, fences, grass, trees, streetlamps and the north symbol are represented by cartographic symbols on a 3D map.

The choice of which objects will be represented by symbols, and which will be in real sizes, shapes and textures depends on the author of the map and as well the map scale.

8 Scale in 3D Maps and Projections

The term "Scale" in 3D maps has a more complicated interpretation/meaning than in 2D maps. The range of scale that can be generated in a 3D map is huge. At the highest magnification of a section of the map or symbol, details in real size can be seen (scale 1:1). However, this can be useful in extremely few cases, e.g. for more accurate positioning. The computer screen will limit us in the size of the map we will handle. In this case, not only the dimensions of the objects are scaled, but also the distances from their reference points to the centre of the scaling. Otherwise, each individual object or character can be scaled against its own reference point. Then the distances between the reference or reference points of the objects and the symbols remain unchanged. A third case can be used, of volume scaling with the same properties relative to the origin of a coordinate system.

In research with map users on the interpretation of scale in 3D maps, most of the respondents (46.7%) answered that 3D maps can be divided into three categories: large, medium and small-scale, depending on the area of the visualized territory. 40% of the respondents marked "Yes, scale depends on zooming", another 40% marked "Yes, scale depends on levels of detail". Only two people (13.3%) answered "Yes, scale depends on the data source" (Bandrova and Bonchev 2013). This shows that the map users try to connect the scales in 3D maps to concept of the 2D maps’ scale, even some of them make some differentiations.

Because 3D map visualization is very frequently made in perspective projection, the visualization of scale

Slika 2. Kartografski znakovi prikazani na 3D karti (sliku je izradila studentica Mariela Nazlumova (https://skfb.ly/6SKXv) pod vodstvom T. Bandrove).

Fig. 2 Cartographic symbols represented on a 3D map. The figure is made by diploma student Mariela Nazlumova (https://skfb.ly/6SKXv) with leadeship of T. Bandrova.

b) *Analiziranje informacija* i prikupljanje podataka o svakom objektu
c) *Dizajniranje kartografskih znakova* vizualnom i metričkom analizom i potom primjenom tehnika računalne grafike
d) *Vizualiziranje kartografskih znakova* u virtualnom okruženju
e) Dobivanje sintetizirane informacije za objekt.

Teorijsku osnovu sustava kartografskih znakova u 3D modeliranju razvila je Bandrova (2001). To je bio rezultat opsežnih istraživanja koja su pokazala nedostatak formalno definiranog sustava 3D znakova. Navedeni su zahtjevi i faze za dizajn znakova. Oni kartografima pružaju standardni pristup za razvoj sustava znakova za 3D karte gradova. Kartografskim znakovima mogu se prikazati svi "mali" objekti prikazani na kartama. Obično ih nije potrebno prikazivati njihovim stvarnim oblikom i dimenzijama, nego to ovisi o potrebama korisnika i namjeni karte. Na slici 2 kartografskim su znakovima na 3D karti prikazane crkve, ograde, trava, drveće, ulične svjetiljke i znak za sjever.

Odabir objekata koji će biti prikazani znakovima, a koji će biti u stvarnim veličinama, oblicima i teksturama, ovisi o autoru karte, ali i o mjerilu karte.

8. Mjerilo i projekcije 3D karata

Pojam "mjerilo" 3D karata ima kompliciraniju interpretaciju/značenje nego kod 2D karata. Raspon mjerila koji se može generirati na 3D karti je ogroman. Pri najvećem povećanju dijela karte ili znakova mogu se vidjeti detalji u stvarnoj veličini (mjerilo 1:1). Međutim, to može biti korisno u vrlo malom broju slučajeva, npr. za točnije pozicioniranje. Ekran računala će nas ograničiti u veličini karte koju ćemo koristiti. U tom se slučaju ne mijenja samo mjerilo dimenzija objekata, već i udaljenosti od njihove referentne točke do središta promjene mjerila. Svaki pojedinačni objekt ili lik može promijeniti mjerilo u odnosu na vlastitu referentnu točku. Tada udaljenosti između referentnih točaka objekata i kartografskih znakova ostaju nepromijenjene. Može se koristiti i treći slučaj – promjena volumena s istim svojstvima u odnosu na ishodište koordinatnog sustava.

U istraživanju s korisnicima karata o interpretaciji mjerila 3D karata, većina je ispitanika (46,7%) odgovorila da se 3D karte mogu podijeliti u tri kategorije: velike, srednje i male, ovisno o površini vizualiziranog teritorija. "Da, mjerilo ovisi o zumiranju", procijenilo je 40% ispitanika, a drugih je 40% ocijenilo: "Da, mjerilo ovisi o razinama detalja." Samo dva ispitanika (13,3%) odgovorila su: Da, mjerilo ovisi o izvoru podataka." (Bandrova i Bonchev 2013). To pokazuje da korisnici karata pokušavaju povezati mjerila 3D karata s konceptom mjerila 2D karata, a neki od njih uočavaju razlike.

Budući da se 3D vizualizacija karte vrlo često radi u perspektivnoj projekciji, vizualizacija mjerila može biti samo orijentacijska (slika 3). Da bi se koristila za metričke potrebe, morali bismo vizualizirati kartu u paralelnoj projekciji (slika 4). Naravno, najbolji način za pozicioniranje prikaza mjerila je dinamička promjena u modelu da bi se dobilo ispravno mjerilo na mjestu postavljanja. U svakom slučaju, bit će vizualizirano za orijentaciju korisnika, a mjerenja bi se mogla obaviti elektronički.

could be only for orientation (Figure 3). To be used for metric needs, we can visualize a map in a parallel projection (Figure 4). Of course, the best way to position the scale display is to dynamically change the model to get the correct scale at the placement location. Anyway, it will be visualized for users' orientation and measurements could be done electronically.

9 3D Model and 3D Map – Conclusions

The terms 3D map and 3D model (urban, mountain, etc.) can be considered similar, where the second concept can be defined as an abbreviated version of the first concept. It is true that every map is a model of the real environment, of certain real objects or phenomena, but not every model is a map. The question of which 3D model exactly is a map needs to be clearly defined?. The answer to this question lies in the history of modern cartography. 3D topographic mapping marks the beginning of this new section of cartography, used mainly for military purposes. Tempfli (1998) defines it as extracting information about topographic objects from images or their digital representation in the form of geometric, semantic and radiometric properties of objects. Geometry gives shape, size, location and topology. Location is defined in a three-dimensional Cartesian coordinate system (e.g. topocentric). Topology is described by the spatial relationships between objects and their components. Goodchild (1999) writes about the paradox of modern cartography, giving an example of the flat 2D view of the world and the distortions that must be supplemented by perspective views shown in the latest versions of the Atlas Encarta from Microsoft. He notes that the "average" user will work with the digital globe more conveniently and easily than with the digital Mercator projection, "and children understand this globe more easily than its earlier projection version". In Berlyant's definitions we find the modern view of cartography and the map, and when they are globally established, it will not make sense to consider the 3D map as a kind of a new type of a cartographic model, as well as its separate definition. He wrote "cartography is considered as a science of systematic information – cartographic modelling and exploration of geosystems, and the map - as a figurative-symbolic geo-information model of reality" (Berlyant 1996). Here it can be summarized that a 3D map should be considered as a cartographic model of the reality. The concept of a 3D model only gives direction in the large classification order of cartographic works regarding their dimensionality but does not determine the essence of the map. *The 3D model of the real environment will become a 3D map when all the elements of 3D mapping are applied to it.*

3D maps represent well urban or rural environments, objects, phenomena and territories. In addition to the materials used, such as photogrammetric or remote sensing data, a variety of often-input data can also be used for this purpose. Such information is automatically imported into most modelling systems, which facilitates the repeated usage of such data in 3D maps.

The input of a symbol system, accuracy, generalization, and other cartographical elements will help the compilers as well as users of 3D maps. Their existence will standardize 3D maps. The next step is to make research about the qualitative and quantitative features of the maps, using 3D GIS, extract data for them and solve different kinds of managers' and engineers' tasks. It will also be necessary to analyse and test 3D maps with different groups of users.

Every 3D map consists of 3D geometry, topographic information and photorealistic texturing, 3D symbols, which contain quantitative and qualitative information about the objects, north direction and coordinate datum, scale, level of details, generalization, accuracy, toponyms, legend and title. All these cartographical elements will make possible for a 3D model of the real environment to be considered a 3D map. Virtual cameras, shades, lights, animation are new cartographical elements which should be added to 3D maps and should be discovered for future needs.

References / Literatura

Adami A, Guerra F (2006) 3D digital maps: New development in cartography for cultural heritage. e-Perimetron, Vol.1, No 2, pp 164–169

Artimo K (1994) Visualization in Modern Cartography. Ed. by Alan M, MacEachren. Vol 2, USA

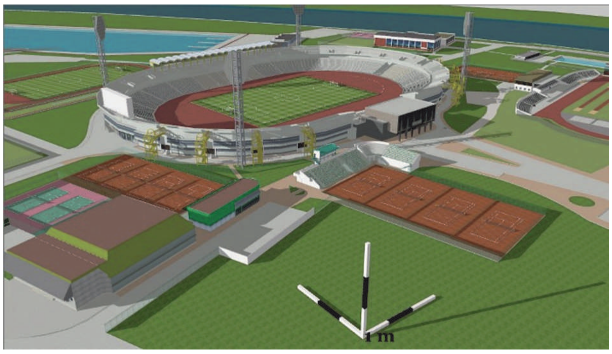
Bandrova T (1997) Creating of Tree-Dimensional Symbol System. International Symposium "Modern Technologies in the Cadastre", Proceedings, Sofia, Bulgaria pp 132–138 (In Bulgarian)

Bandrova T (2001) Designing of Symbol System for 3D City Maps. 20th International Cartographic Conference. Vol. 2, pp 1002–1010, Beijing, China

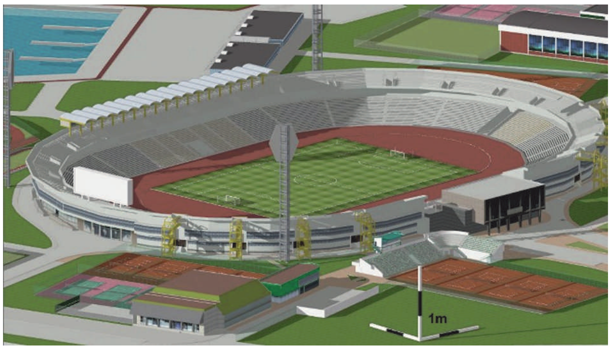
Bandrova T, Bonchev S (2013) 3D maps – scale, accuracy, level of details, 26th International Cartographic Conference, Dresden, Germany, On-line Proceedings, ISBN 978-1-907075-06-3

Berlyant A M (1996) Geoikonika, Moscow, Astreya Company

Bonchev S (2009) Development of a three-dimensional map of a mountain resort for tourist purposes, International Conference UACEG2009: Science & Practice, CD Proceedings, Sofia (In Bulgarian)



Slika 3. Prikaz mjerila u perspektivnoj projekciji 3D karte. Sliku je izradio student Nikola Yonow (https://skfb.ly/6SKXv) pod vodstvom T. Bandrove.
Fig. 3 Scale representation in perspective projection of a 3D map. The figure is made by diploma student Nikola Yonow (https://skfb.ly/6SKXv) with leadership of T. Bandrova.



Slika 4. Prikaz mjerila u paralelnoj projekciji 3D karte.
Fig. 4 Scale representation in parallel projection of a 3D map.

9. 3D model i 3D karta - zaključci

Pojmovi 3D karta i 3D model (urbani, planinski itd.) su slični, pri čemu se drugi koncept može definirati kao skraćena verzija prvoga. Istina je da je svaka karta model stvarnog okoliša, određenih stvarnih objekata ili pojava, ali nije svaki model karta. Treba jasno definirati pitanje koji je točno 3D model karta. Odgovor na to pitanje nalazi se u povijesti moderne kartografije. 3D topografsko kartiranje označava početak ovog novog dijela kartografije koji se uglavnom koristio u vojne svrhe. Tempfli (1998) to definira kao izvlačenje informacija o topografskim objektima iz slika ili njihove digitalne reprezentacije u obliku geometrijskih, semantičkih i radiometrijskih svojstava objekata. Geometrija daje oblik, veličinu, položaj i topologiju. Položaj je definiran u trodimenzionalnom kartezijevom koordinatnom sustavu (npr. topocentričnom). Topologija je opisana prostornim odnosima između objekata i njihovih komponenti. Goodchild (1999) piše o paradoksu moderne kartografije dajući primjer ravnog 2D pogleda na svijet i distorzija, što mora biti nadopunjeno perspektivnim prikazima u najnovijim verzijama Atlasa Encarta iz Microsofta. On napominje da će "prosječni" korisnik s digitalnim globusom raditi pogodnije i lakše nego s digitalnom kartom u Mercatorovoj projekciji, "a djeca taj globus lakše razumiju nego njegovu raniju projekcijsku verziju". U Berlyantovim definicijama nalazimo suvremeni pogled na kartografiju i kartu, a kada se one globalno uspostave, neće imati smisla 3D kartu smatrati nekom novom vrstom kartografskog modela, kao ni njezinu zasebnu definiciju. Napisao je da se "kartografija smatra znanošću o sustavnim informacijama – kartografskom modeliranju i istraživanju geosustava, a karta – figurativno-simboličkim geoinformacijskim modelom stvarnosti" (Berlyant 1996). Ovdje se može sažeti da 3D kartu treba promatrati kao kartografski model stvarnosti. Koncept 3D modela daje samo smjernice u velikom klasifikacijskom poretku kartografskih djela u pogledu njihove dimenzionalnosti, ali ne određuje bit karte. *3D model stvarnog okoliša postat će 3D karta kada se na njega primijene svi elementi 3D kartografiranja.*

3D karte dobro prikazuju urbane ili ruralne sredine, objekte, pojave i teritorije. Osim korištenih materijala, kao što su fotogrametrijski podatci ili podatci daljinskih istraživanja, u tu se svrhu mogu koristiti i različiti drugi podatci koji se automatski unose u sustave modeliranja, što olakšava ponovnu upotrebu takvih podataka u 3D kartama.

Unos sustava kartografskih znakova, točnost, generalizacija i drugi kartografski elementi pomoći će sastavljačima, kao i korisnicima 3D karata. Njihovo će postojanje standardizirati 3D karte. Sljedeći je korak istraživanje kvalitativnih i kvantitativnih značajki karata, korištenjem 3D GIS-a, izdvajanje podataka za njih i rješavanje različitih vrsta zadataka menadžera i inženjera. Osim toga bit će potrebno analizirati i testirati 3D karte u različitim skupinama korisnika.

Svaka 3D karta sastoji se od 3D geometrije, topografskih informacija i fotorealističnih tekstura, 3D kartografskih znakova koji sadrže kvantitativne i kvalitativne informacije o objektima, smjera sjevera i koordinatnog datuma, mjerila, razine detalja, generalizacije, točnosti, toponima, legende i naslova. Svi ti kartografski elementi omogućit će da se 3D model stvarnog okoliša smatra 3D kartom. Virtualne kamere, sjene, svjetla i animacije novi su kartografski elementi koji se mogu dodati 3D kartama.

Boyanova K, Bandrova T (2012) 3D Mapping for Needs of Architecture. Proceedings vol. 1, 4th International Conference on Cartography and GIS, June, 18-22, Albena Bulgaria, pp 201–210

Dinkov D, Vatseva R (2016) 3D Modelling and Visualization for Landscape Simulation. Proceedings, 6th International Conference on Cartography and GIS, Bulgaria, ISSN 1314-0604. pp 320–333

Dinkov D, Bonchev S (2020) 3D Historical Reconstractions with Interactive Web-Based Application. Proceedings Vol 1. 8th International Conference on Cartography and GIS, Bulgaria, ISSN 1314-0604. pp 656–667

Dymkova S S and Dymkov A D, (2021) Multifactorial methodology of cycling routes time calculation based on 3D maps, Systems of Signals Generating and Processing in the Field of on Board Communications, pp 1–8, doi.org/10.1109/IEEECONF51389.2021.9416046.

Girindran R, Boyd D S, Rosser J, Vijayan D, Long G, Robinson D (2020) On the Reliable Generation of 3D City Models from Open Data. Urban Sci., 4, 47. doi.org/10.3390/urbansci4040047

Goodchild M F (1999) Cartographic Futures on a Digital Earth. 19th International Cartographic Conference. Proceedings, CD- ISBN 0-919088-54-6, Ottawa, Canada

Häberling C, Bär H, Hurni L (2008) Proposed Cartographic Design Principles for 3D Maps. A Contribution to an Extended Cartographic Theory. Cartographica: The International Journal for Geographic Information and Geovisualization, Vol. 43, Issue 3, pp 175–188, doi: 10.3138/carto.43.3.175

Herman L, Jurik V, Stachon Z, Vrbik D, Russnak J, Reznik T (2018) Evaluation of User Performance in Interactive and Static 3D Maps. ISPRS International Journal of Geo-Information, MPDI, 7, 415; doi:10.3390/ijgi7110415, https://mdpi-res.com/d_attachment/ijgi/ijgi-07-00415/article_deploy/ijgi-07-00415.pdf (Accessed 1 Apr 2022)

Jenny H M (2011) Geometric Design Alternatives for Computer-generated 3D Maps Inspired by Hand-painted Panoramas. PhD Theses, Diss ETH No 19790

Jiping L, Konecny M, Du Q, Xu S, Ren F, Che X (2021) International Journal of Image and Data Fusion. Vol. 12, Issue 4: Special Issue on Data Fusion for Integrated Disaster Reduction. Taylor&Frances. Pp. 265-267. doi.org/10.1080/19479832.2021.1970931

Krijestorac E, Hanna S, Cabric D (2021) Spatial Signal Strength Prediction using 3D Maps and Deep Learning, ICC 2021 - IEEE International Conference on Communications, pp 1–6, doi.org/10.1109/ICC42927.2021.9500970

Kurakula V K, Kuffer M (2008) 3D Noise Modeling for Urban Environmental Planning and Management, Real CORP 008 Proceedings / Tagungsband Vienna, May 19-21 2008, www.corp.at, ISBN: 978-39502139-4-2 (CD-ROM); ISBN: 978-39502139-5-9 (Print) Editors: Schrenk M, Popovich V V, Engelke D, Elisei P

Lapaine M, Midtbø T, Gartner G, Bandrova T, Wang T, Shen J (2021) Definition of the Map. Advances in Cartography and GIScience of the International Cartographic Association, 3, 2021. 30th International Cartographic Conference (ICC 2021), 14–18 December 2021, Florence, Italy. This contribution underwent double-blind peer review based on the full paper. www.researchgate.net/publication/356615365_Definition_of_the_Map Accesed 5 Apr 2022

Li X-B, Dong-Sheng Wang D-S, Lu Q-C, Peng Z-R, Lu S-J, Li B, Li C (2017) Three-dimensional investigation of ozone pollution in the lower troposphere using an unmanned aerial vehicle platform, Environmental Pollution, Vol. 224, pp 107–116, ISSN 0269-7491, doi.org/10.1016/j.envpol.2017.01.064

Niedomysl T, Elldér E, Larsson A, Thelin M, Jansund B (2013) Learning Benefits of Using 2D Versus 3D Maps: Evidence from a Randomized Controlled Experiment, Journal of Geography, 112:3, 87-96, doi.org/10.1080/00221341.2012.709876

Petrovič D (2001) Three-dimensional mountain map. ICA-CMC-Session, Beijing, China

Petrovič D (2003) Cartographic Design in 3D Maps. Proceedings of the 21st International Cartographic Conference, ISBN: 0-958-46093-0, Durban, South Africa https://icaci.org/files/documents/ICC_proceedings/ICC2003/Papers/248.pdf (Accessed 5 Apr 2022)

Rakkolainen I, Vainio T (2001) A 3D City Info for mobile users. Computer&Graphics, Vol. 25, Issue 4, Elsevier, pp 619–625

Rubin S, Agrawal A, Stegmaier J, Krief S, Felsenthal N, Svorai J, Addadi Y, Villoutreix P, Stern T, Zelzer E (2021) Application of 3D MAPs pipeline identifies the morphological sequence chondrocytes undergo and the regulatory role of GDF5 in this process. Nat Commun 12, 5363, doi.org/10.1038/s41467-021-25714-0

Šašinka Č, Stachoň Z, Sedlák M, Chmelík J, Herman L, Kubíček P, Šašinková A, Doležal M, Tejkl H, Urbánek T, Svatoňová H, Ugwitz P, Juřík V (2019) Collaborative Immersive Virtual Environments for Education in Geography. ISPRS International Journal of Geo-Information. 8(1):3. doi.org/10.3390/ijgi8010003

Sijmons K (1995) Introduction to GIS and Cartography, ITC, The Netherlands

Snecker J (2019) Architecture – 3D Cities / Cityscapes 3D Models https://www.3dcadbrowser.com/3d-model/brisbane-city-australia-2019 (Accessed on 8 May 2022)

Stanek K, Friedmannova L, Kubicek P and Konecny M (2010) Selected issues of cartographic communication optimization for emergency centers. International Journal of Digital Earth, Vol. 3, Issue 4, pp 316–339

Tait A (2008) Mountain Ski Maps of North America. 6th ICA Mountain Cartography Workshop, 2008. Lenk, Switzerland

Tempfli K (1998) 3D Topographic Mapping., Lecture Notes PHM 112, Geoinformatics, The Netherlands

Wilkening J, Fabrikant S I (2013) How Users Interact with a 3D Geo-Browsers under Time Pressure. Cartography and Geographic Information Science. Vol. 40, Issue 1, pp 40–52

Wu D-Y, Lin J-H T, Bowman ND (2022) Watching VR advertising together: How 3D animated agents influence audience responses and enjoyment to VR advertising, Computers in Human Behavior, Vol. 133, 107255, ISSN 0747-5632, doi.org/10.1016/j.chb.2022.107255

Yonov N, Bandrova T (2018) 3D Maps Cartographic Aspects. Proceedings, 7th International Conference on Cartography and GIS, Bulgaria, pp. 452-463, ISSN: 1314-0604

Zlatanova S, Bandrova T (1998) User requirements for the Third Dimensionality. E-mail Seminar of Cartography. Sofia, Bulgaria, pp 61–72