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# 3DISCWORLD: AUTOMATIC PREPARATION AND VISUALIZATION OF 3D SPATIAL DATA WITH USE OF PLANAR DATA

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## ABSTRACT

The paper is focused on a method of automatic transfer of 2D to 3D geographic data on the base of its geometric and/or attributes information as a cheap and fast alternative for high precise methods such as laser scanning or stereophotogrammetry. The process of automatic preprocessing and visualization of 3D geographic data on the base of two-dimensional data brings sufficient basis for both 3D spatial analysis and preparation of 3D maps, as a visual output of virtual scenes. The research resulted in ArcGIS Desktop extension that allows automatic transfer of 2D spatial data into Multipatch format developed by ESRI for storing complex 3D data.

## INTRODUCTION

Because the world is the three-dimensional reality, the perception of 3D information is more natural and therefore, in some cases, the 3D visualization is more effective than 2D. 3D visualization appears in many sectors of human activities - entertainment, architecture, education, science or civil defense. 3D visualization brings more engaging means of presentation of our work, and of course, the great potential can be seen in wide possibilities of modeling and analyses with 3D data, which are valuable for decision support.

The more detailed and accurate the input data, the more trustful analyses results and more reliable 3D scenes are. High precision data carry high financial and time costs of their preparation, and because it is the money that play one of the most important roles in every project, our goal was to utilize the potential of easily (and inexpensively) attainable 2D geographic data for the preparation of 3D data which would describe the part of the landscape with enough exact level of detail.

## THE THIRD DIMENSION PERCEPTION

In the article we deal with terms 3D visualization, 3D data or 3D models. Among specialists the perception of dimensions is heterogenous [2]. Therefore it is necessary to specify the meaning of what we will use in the article.

Dimension, as such, can be understood as an expression of the character of measurable phenomenon. According to the number of monitored characteristics the number of data dimensions is derived.

In our case we deal with spatial data and because of that we perceive dimensions as an expression of spatial location within X, Y and Z axes.

3D spatial data are quite clearly definable by a pair of X and Y coordinates, which at least one value of spatial Z coordinate belongs to. In the field of Geoinformatics and Cartography we also encounter with the term 2.5D, which is often and wrongly called 3D [2]. Two-and-half dimensional data are usually used for the expression of digital terrain models. The definition of 2.5D says that for each X and Y coordinate pair belongs just one Z value [12].

More complicated is the definition of the third dimension in the case of visualization. There are two types of media through which the visualization can be transmitted – 2D medium (paper or screen) and 3D media (the material by which the 3D object is modeled on a specific scale in relation to the real object). Considering the 3D object cannot be physically presented through 2D media, then the true 3D visualization is the one, that is allowed within the scope of the three-dimensional imaging environment.

The human brain has an impressive capacity for the understanding and assimilation of graphically presented information [14]. The possibility of the visualization of 3D data in the computer environment (or on computer monitor) is always based on the user experience and on capabilities of human eyes to perceive the perspective and determine which objects are closer or more distant. In this case it is not about the real 3D visualization, but 3D effect in 2D. Figure 1 shows the relationship between the real-world objects, the possibilities of their data representation, visualization environment and capabilities of perceptions of their visualization. 2D visualization environment, commonly used in cartography, allows three types of outputs. The first is represented by common 2D maps - paper or digital. In the latter case it is the 3D visual effects, exemplified, for instance, with shaded relief maps, anaglyphs, or outside the field of cartography 3D movies. This 3D effect displayed in 2D is used only for viewing. In contrast, the third option provides a virtual 3D environment inside the physical 2D environment that the user is able to navigate through and interact with [13]. Representatives of this option can be for instance virtual globes (Google Earth, World Wind, Skyline Globe, etc.) that can be regarded as the most effective environment for visualizing 3D data. Virtual globes attracted widespread public use and attention due to its ability to view landscapes in fairly realistic three dimensions, using a combination of digital elevation models, satellite imagery, and 3D building envelopes (in some selected cities) [10]. The use of VR and the construction of virtual environments exploit navigational and behavioral realism, but become most useful when combined with abstracted representations embedded in a 3D space [9]

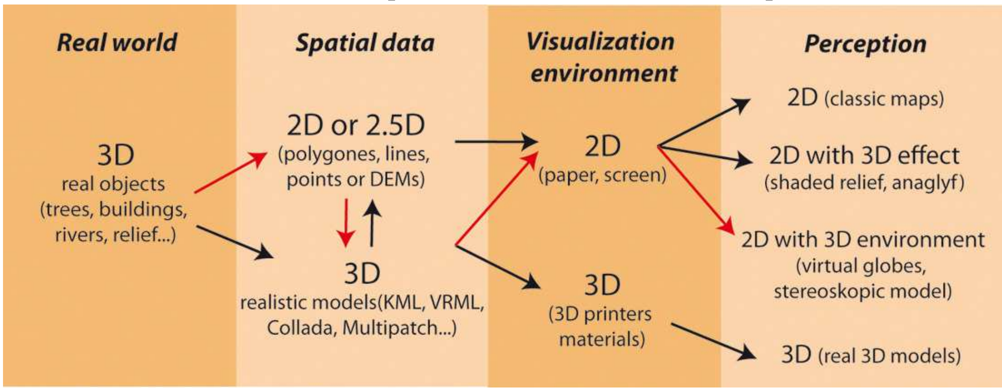


*Figure 1 The diagram illustrates the relationship between real-world objects, the possibilities of data representation, visualization environment and perceptions of their visualization capabilities. Key relationships in this research are shown with red arrows.*

## 3D MODELLING APPROACHES

Several approaches of 3D data preparation exist. Below the most dominant of them are described according the principal paradigm.

### *1. Geometric based 3D modelling*

In the geometric 3D modeling paradigm, the landscape model consists of an explicit three dimensional geometric model, which typically includes a range of semantic and representation properties [3]. Such an explicit 3D model must first be reconstructed or generated based on real-world information before it can be used for visualization or analysis purposes [5]. The Z coordinate generally expresses the height of the object.

Today's 3D landscape models are predominantly derived using photogrammetric airborne imagery or airborne LIDAR data. Point clouds from static terrestrial laser scanners are increasingly being used as an input for the detailed modeling of individual landmarks or buildings [5]. Modern photogrammetric image processing and 3D visualization software tools enable us to generate synthetic landscapes of high accuracy and a high degree of immersivity [8]. Many operational modeling procedures additionally rely on ground-based data, e.g., objects footprints from cadastral data. This method is in focuse of our research.

### *2. Image-based 3D modelling*

In the image-based modeling paradigm, the 3D urban environment is represented by georeferenced 2D images or 2D videos instead of explicit geometric 3D models as in the geometric 3D modeling paradigm. Therefore, there is no need for an actual 3D city model [5].

The most nowadays known example of this category is the StreetView by Google. Another attractive possibility is to store panoramatical images (belt, cylindrical or spherical) in KMZ and view them in Google Earth [6]. QuickTime VR and its sets of 360° cylindrical panoramic scenes is a representative of former solution.

The method is based on the assumption that a healthy human eye can perceive the perspective and estimate the distance ratios on the base of digital image.

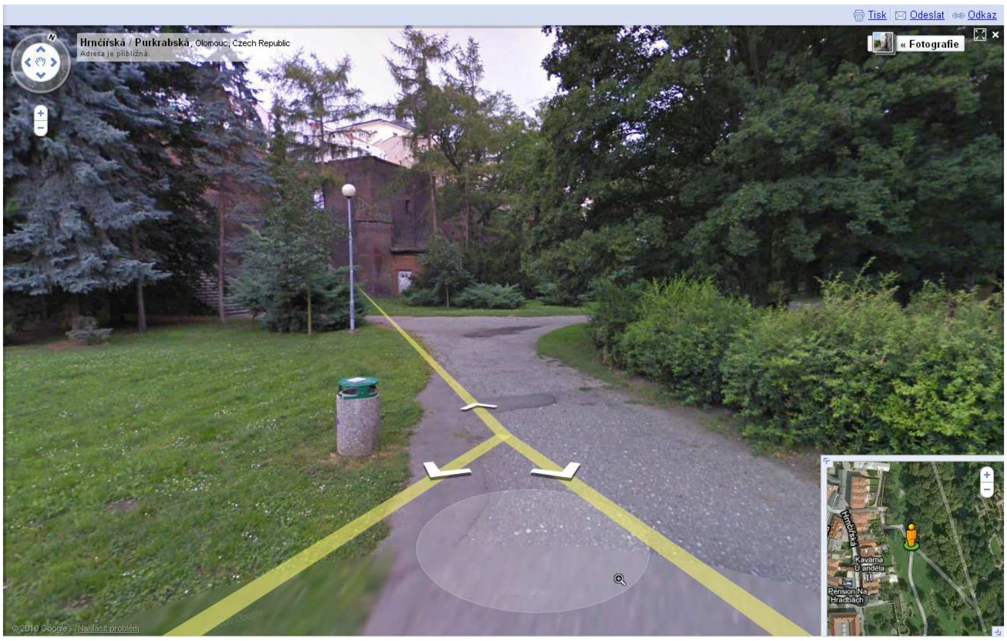


*Figure 2 Street View by Google offers virtual walkthrough hundreds world cities.*


*Figure 3 Spherical panoramatical image is one of the possibilities of image based 3D models. (Popelka, Vozenilek, 2010)*

***3. Information based 3D modelling***

Unlike the previous two methods, where the third dimension represents the parametric properties of real objects (size, shape, texture), the method of 3D models based on attribute values uses a third dimension to highlight some nonparametric characteristics of the phenomenon.

An example can be the expression of a quantitative phenomenon with a so called information landscape that is represented as colorless continuous surface [7], where the higher density of the phenomenon is expressed by a higher "altitude" elevation (Figure 4).

Analogous to the solution may be the use of the prism maps (Figure 5).

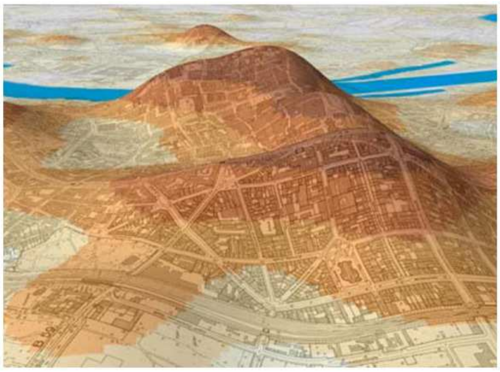 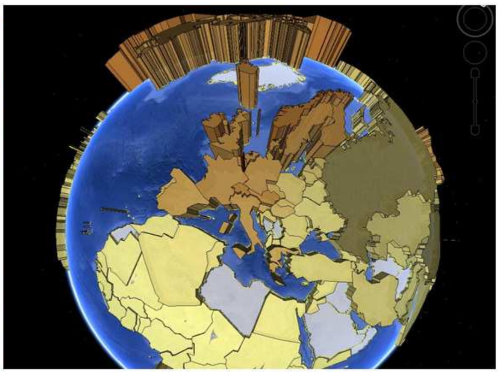

*Figure 4 Informational landscape as a representation of robbery density. The surface is overlaid with additional textures – classified choropleth map and georeferenced city map [7].*

*Figure 5 Representation of GDP per capita (2004) with use of prism map in the environment of virtual globe of Google Earth. That method is impressive, but it cannot be considered as a good source of quick information.*

The two latter methods of the preparation of the 3D information can be considered as more interesting, and effective ways of the information visualization. Only the first method produces the 3D data that are more or less authentic picture of the real world and can be used both for visualization and for the purpose of spatial analysis and modeling. In this way the article continues.

**SOFTWARE SOLUTION FOR AUTOMATIC PREPARATION 3D SPATIAL DATA WITH USE OF PLANAR DATA**

There are many ways of preparing high-quality 3D data, but financial and time costs are often higher than the actual usability of these data. The aim of our project was to prepare a software solution for automatic conversion of 2D spatial data into full 3D format. Existing graphics programs (e.g. 3ds Max, Maya, and SketchUp) support 3D modeling and visualization well, but their disadvantage is missing environment for further geographic analyses, searching data according attribute information, filter data, create topology, define relationships among features etc. [11]. Administration and particularly the preparation of 3D data in GIS software are implemented peripherally.

Our decision was to create an extension for ArcGIS Desktop. It has been supported by the fact that ArcGIS is probably one of the most powerful GIS software that is proved by multitude of users from around the world. ArcGIS has a long tradition and it is clear that it will evolve in the coming years and his popularity will not descend. The new version (ArcGIS10) did not bring significant improvements of the creation of 3D data; therefore the result of our work could be welcomed by many of interested specialists.

The extension was named „3Disworld“. The name is the combination of the term „3D“, which is the focal theme of this research, and „Discworld“, which was taken from the writer Terry Pratchett and expresses a fantastic world in the shape of a flat disc. The combination of these two terms reflects the relation ship between 2D planar data (Discworld) and three-dimensional visualization (3D).

**3D VISUALIZATION IN ESRI PRODUCTS**

ESRI has three products to view 3D models: ArcScene, ArcGlobe, and ArcGIS Explorer. ArcScene and ArcGlobe are 3D authoring and analysis desktop tools, while ArcGIS Explorer is a lighter weight tool for consuming content from ArcGIS Server.

ArcScene and ArcGlobe offer two kinds of 3D visualization.

The first one is done by setting the point data layer properties displayed in the active window under the Symbology tab. To determine the appearance of 3D representation of point objects can be used the *.3ds, *.DAE, *.flt, *.skp and *.wrl format. The user chooses the size and orientation of the 3D symbol. This method doesn't create real 3D data; it is just a visual representation.

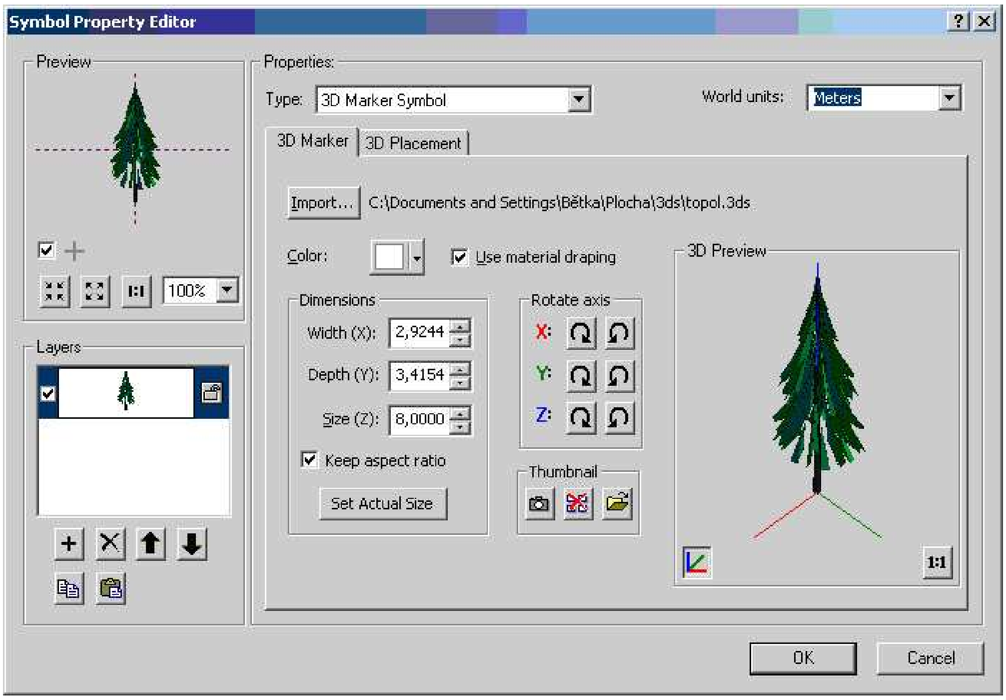


*Figure 6 Symbol Property Editor in ArcGIS – settings of 3D symbol appearance.*

The second method is to display true 3D data. The most common and simplest approach is to set the base altitude and total height of the object for the Z-enabled data type (polygonZ, polylineZ, pointZ). A more realistic appearance can be achieved by displaying Multipatch objects. The disadvantage is that there is no implemented ArcGIS interface, where would be possible to create these objects.

Multipatch features can be created through the ArcObjects programming method, which is not a nice solution for each user, or by using the Import 3D Files tool (3D Analyst) to import a 3D object created in one of the supported formats (*. 3ds, *. flt, * . skp, *. wrl). In any case it is necessary to model and displayed each object separately. Extension 3Discworld resolves the discomfort automatically. The user selects the 2D reference layer (polygon, line or point), the 3D representation and the consistency with which the 3D object will be placed within the 2D reference layer.

Both of the described methods are visually indistinguishable. A common problem is that the visualization of large volumes of data can significantly slow down computer functions.

The main and very important difference is that using the first method (the Symbology layer property), we get only the 3D perception, not the 3D data. With the use of 3Discworld we obtain real 3D data, which are ready to use in spatial analyses and exportable to another 3D format.

*Table 1 Possibilities of import and export of different 3D data formats to/from ArcGIS.*

| | X3D | VRML | SketchUp | KML | OpenFlight | Collada | CityGML | 3DS |
|---|---|---|---|---|---|---|---|---|
| **Import** | × | ✓ | ✓ | × | ✓ | × | × | ✓ |
| **Export** | × | ✓ | × | ✓ | × | × | × | × |

The export of 3D Multipatch objects from ArcGIS is available only to KML and VRML. Unfortunately, any export option does not preserve the visual quality of Multipatch objects.

ArcGIS doesn’t allow photorealistic rendering of 3D objects, such as software that are directly invented for 3D graphics.

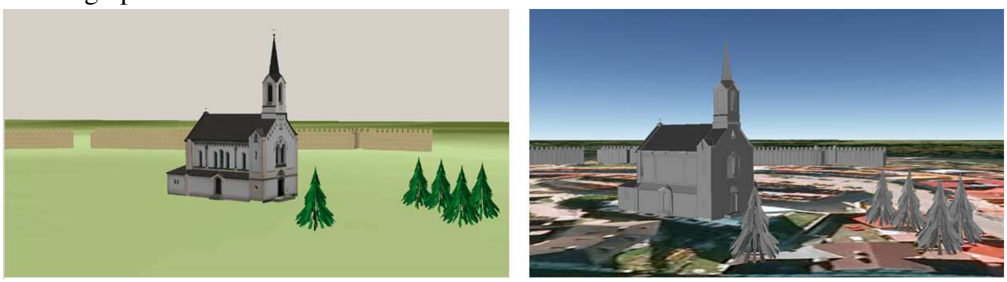

*Figure 7 Visualization of 3D Multipatch objects in ArcGIS ArcScene (left) and in Google Earth (right) after export to KML. The loss of visual quality is evident.*

## THE 3DISCWORLD EXTENSION

3Discworld is an application developed for the automatic conversion of 2D spatial data in 3D format. The user can use a set of tools to work with polygon, line and point data and convert them into realistic 3D appearance.

The application 3Discworld was developed as an extension for ESRI ArcMap ArcGIS 9.3, for which the full functionality the extensions 3D Analyst and Spatial Analyst are needed.

To build the application the VB.NET programming language and ArcObjects libraries were used.

ArcObjects technology, implemented in the ArcGIS Desktop since the version 8.0, opens up many possibilities for the development of new applications. ArcObjects are software components that were developed for use in ESRI products (ArcGIS Desktop and ArcGIS Server) [17]. With a little exaggeration, Arc Objects can be likened to Lego cubes through which they can build a variety of shapes - the same way, using ArcObjects component, software products can be developed.

From a programming perspective ArcObjects are classes programmed using C++ language, which are stored in binary format files as DLLs (dynamic linking library).

ArcObjects are a set of about 2700 classes that define methods and properties of objects that the user is working with. These objects can be ArcMap documents, map windows, cursors, toolbars, buttons for procedures calling, as well as data layers, particular line, points, polygons, or cartographic symbols and so on [15].

Using ArcObjects components standalone applications independent of ArcGIS Desktop or ArcGIS extensions can be created. The latter option was used in this project.

Development of extending applications proceeded on Microsoft Visual Studio 2008 Express Edition. Visual Studio provides an user friendly interface, advanced development tools and debugging functions. The VB.NET was chosen as a programming language, because of its simple and clear syntax and a number of tutorials and sample codes located in this language.

Extension was created as a dynamic linking library (DLL), from which ArcGIS retrieves information needed to perform procedures, whose description is contained in a DLL. The library contains a COM interface to work with ArcGIS and it is necessary to register it. This step does the installer created in Visual Studio automatically [16]. The installation file itself registers the COM interface after startup on the user's computer. The user then simply activates the extension directly in the ArcMap.

In the Google SketchUp 3D models were created. These models are intended to fill the library that is used by 3Discworld extension to replace 2D data with selected 3D model. 3D objects in SketchUp format (*.skp) were exported to ESRI Multipatch format using the Import 3D Files tool (3D Analyst Extension) and stored in Personal Geodatabase, where are ready to use in process of 2D data conversion.

## 3DISCWORLD COMPONENTS

The correct 3Discworld extension workflow provides software, database and supporting components whose interdependence is shown schematically in Figure 6.

The software components are represented by any 3D computer graphics software, which data format is applicable to conversion to ESRI Multipatch format, ArcGIS Desktop and the 3Discworld extension itself. With the use of 3D computer graphics software and ArcGIS 3D the 3D objects are created and then imported into the library of 3D objects. In the case of this research the Google SketchUp was used as 3D computer graphics software.

Metadata text file that contains information on specific 3D objects (geometry, location, name and description) presents a functional link to retrieve this information in the extension environment, where the user browses through a library and select the desired 3D appearance of the 2D object. The key information bring layers of 2D data that are loaded in ArcMap.

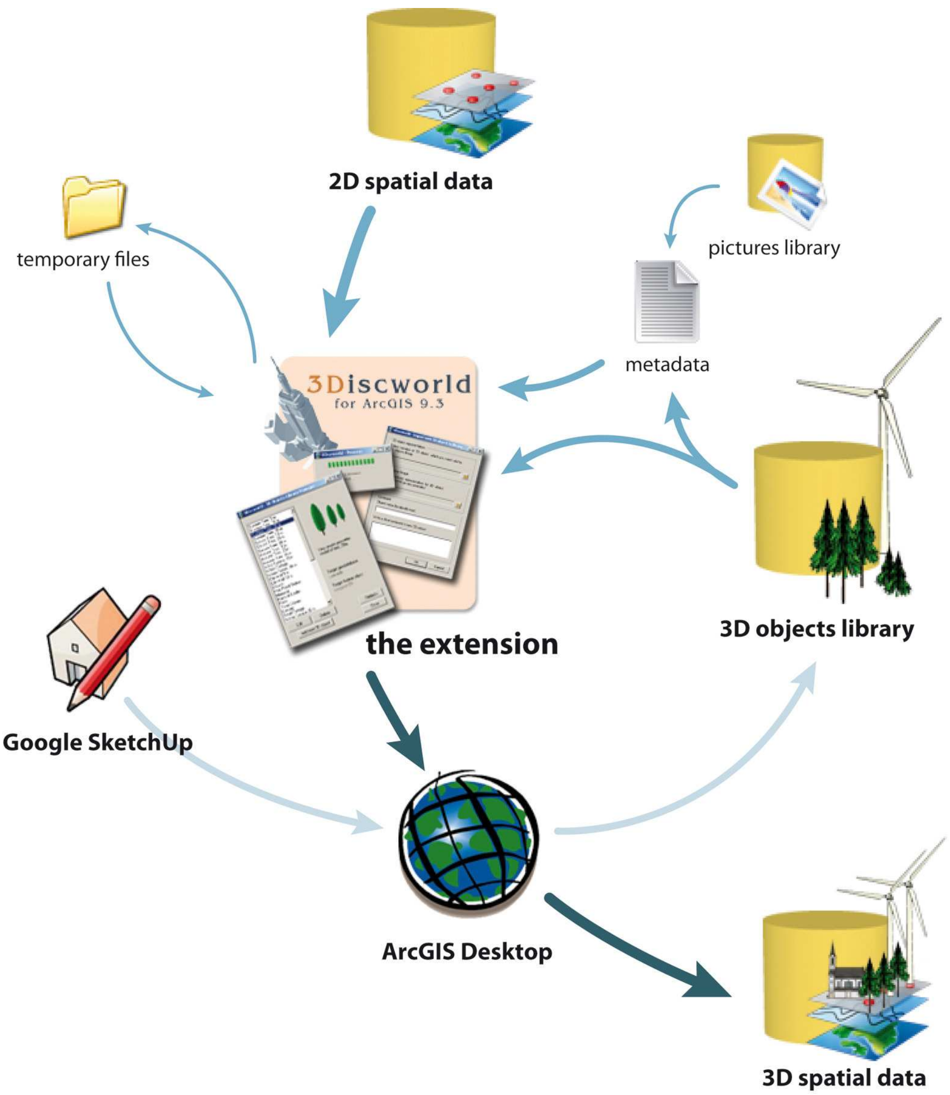


*Figure 9 3discworld extension components.*

**INPUT DATA REQUIREMENTS**

The most important condition to work with the 3Discworld extension is the input data, which may be, due to their usability, divided into two groups.

The first group includes geographic data that enter the calculations as a reference base for the 3D spatial data location. These data can be polygon, line and point layers and digital terrain models in the form of elevation grid. The level of details of input data depends on the user. One must realize that in most cases the 3D data are used for visualization of virtual reality and therefore it is necessary to take in account the degree of the data generalization.

The format of input data is limited to polygons, lines and point data supported by ArcGIS.

The extension allows the calculation of the altitude of 3D data generated by the elevation grid. The general rule is the higher resolution grid is, the more accurate is the resulting visualization.

The second category of input data represents a library of 3D objects that are according to user settings placed on the frame of the spatial location of the input data of the first category. This creates the desired 3D representation of geographic data.

The extension installation contains a database of 3D objects in the Multipatch format, stored in a database (*. mdb) and used to represent and replace the 2D data. 3D objects were created so that the minimum time and system requirements would be needed for the maximally possible realistic look like of the resulting geographic data. Generally, the more complex geometry, the more realistic look of the landscape and the higher demands on processing time and storage size.

**3DISCWORLD TOOLS**

The main communication component of the 3Discworld extension is the toolbar of classic ArcGIS look, which divides the tools into four main sections according to the functionality (see the Figure 7).

The most important part is the 3D Transformation menu, which offers four tools to convert (or replace) 2D data to 3D format. These tools work with a polygon, line and point layers opened in the active window ArcMap.

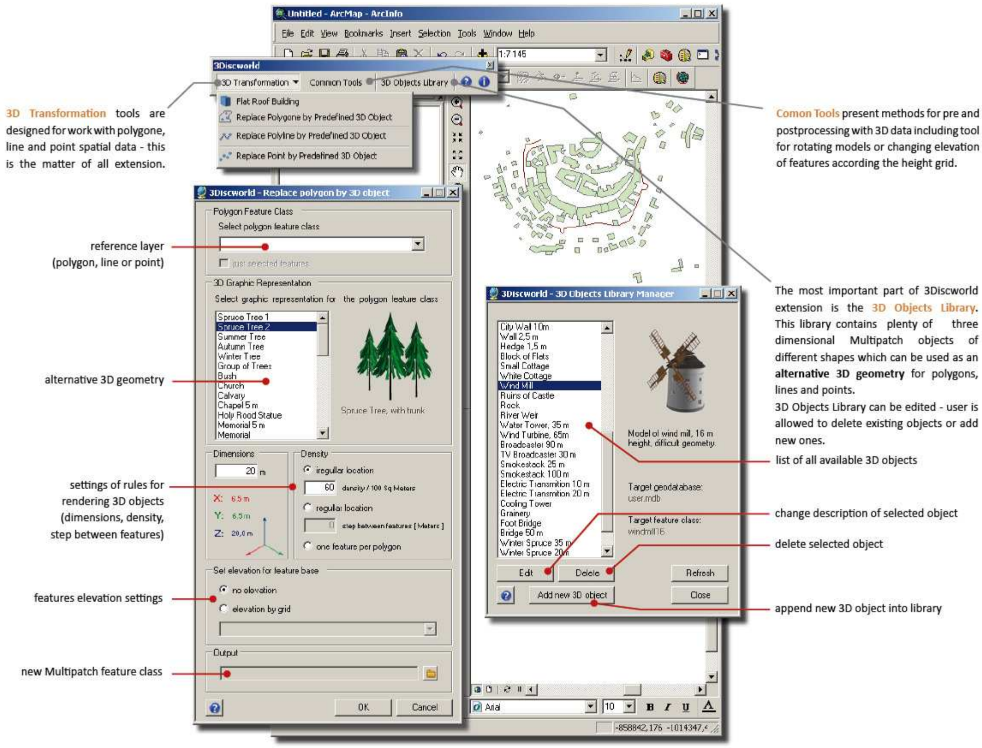


*Figure 10 User environment of 3Discworld tools.*

***Flat roof buildings*** -creates stylized buildings without roofs. In principle it is a simple increase of polygon layer base with user-specified height.

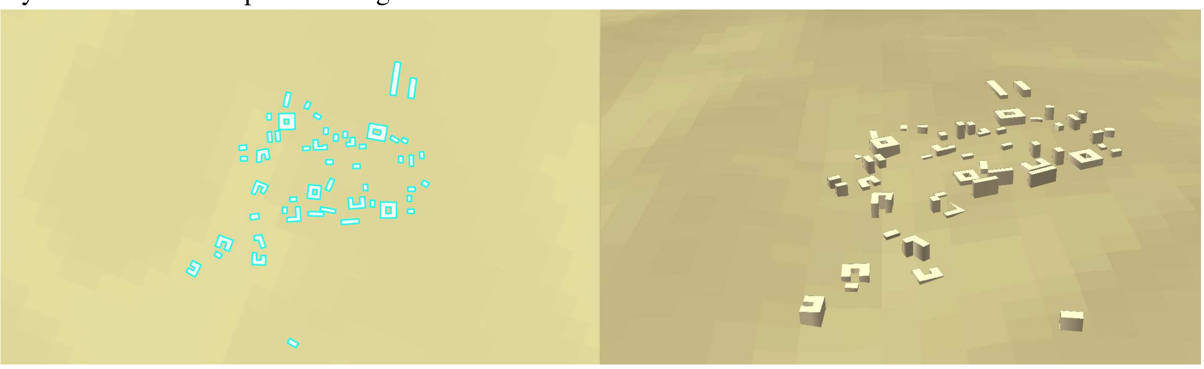

*Figure 11 Flat roof building tool – input planar data (left) and output 3D data (right) .*

***Replace polygon by predefined 3D object*** -creates 3D data in the base of polygon layer. User defines shape of 3D graphic representation, density of 3D features and way of localization within a polygon feature (irregular, regular or one 3D feature per one polygon).

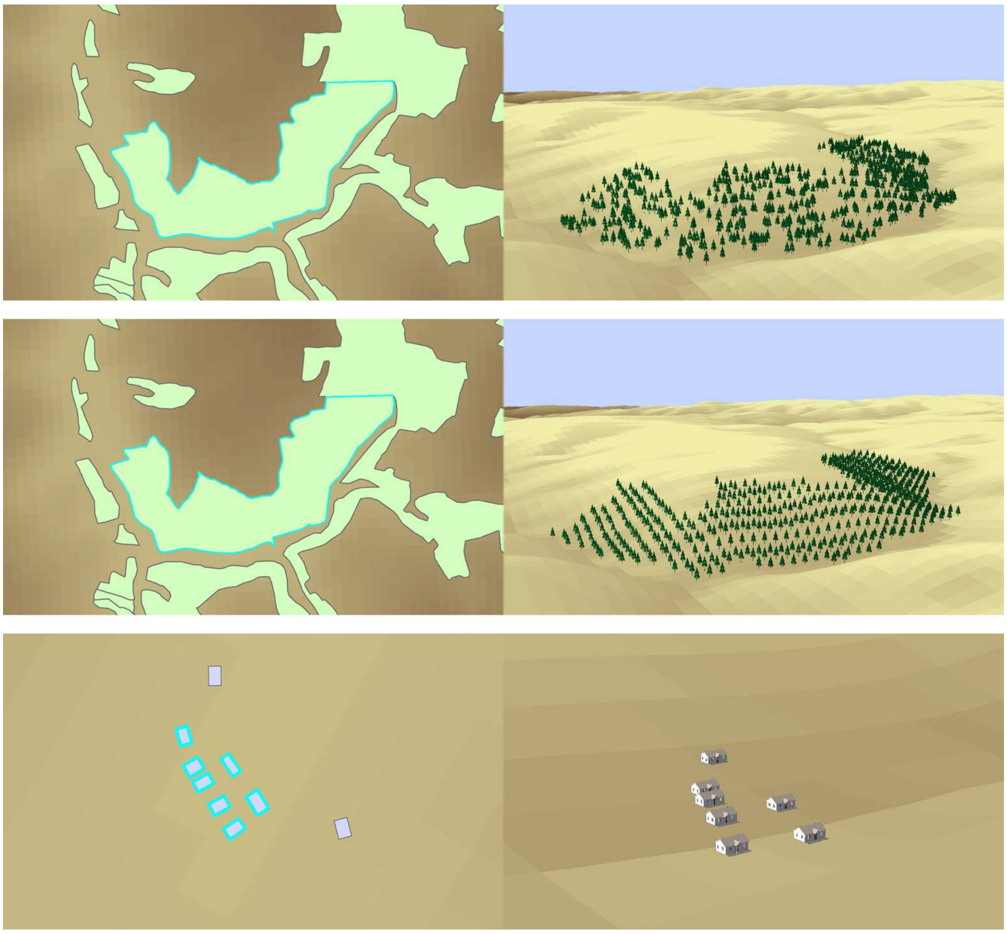

*Figure 12 Replace polygon by predefined 3D object tool – three possibilities of transferring input polygon data (left) into output 3D data (right).*

***Replace polyline by predefined 3D object*** -creates 3D data along the polyline features. User can define distance between two 3D features and decide whether features will be rotated according to line orientation.

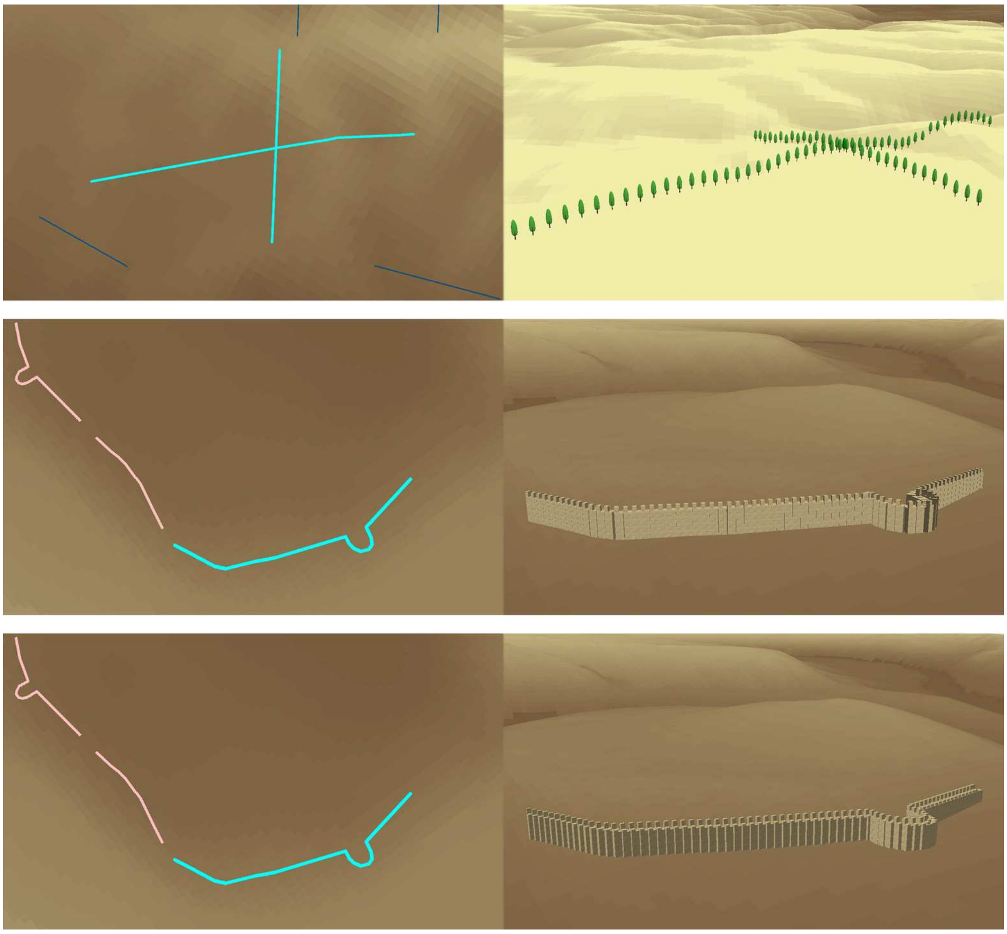

*Figure 13 Replace polyline by predefined 3D object tool - input polyline data (left) and output 3D data (right).*

***Replace point by predefined 3D object*** -creates 3D data within coordinates of point features.

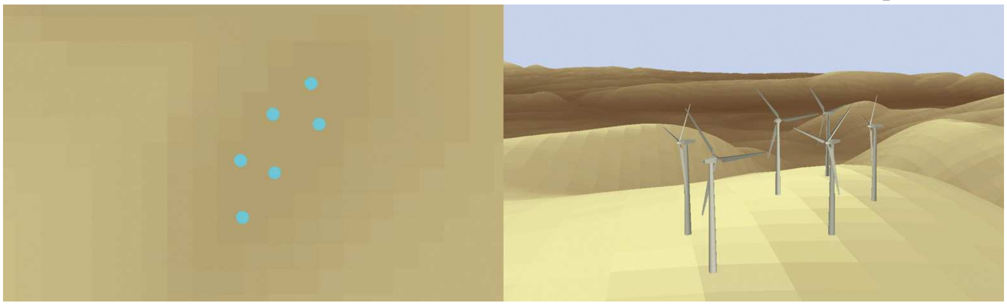

*Figure 14 Replace point by predefined 3D object tool - input point data (left) and output 3D data (right).*

**KEY POINTS IN PROCESS OF AUTOMATED TRANSFER OF 2D DATA IN 3D FORMAT**

- Due to limited information that could be deduced from data sources, it is not possible to add every detail to the virtual landscape. It is the designer's choice whether or not he or she models a particular detail or feature or not. However, we need well-defined visualization requirements to be able to achieve a realistic user experience [1]. The question is: "What is the required level-of-detail to let users perceive virtual landscapes as realistic and what is the required level-of-detail for purposes of spatial analyses?"

- The realistic face of three dimensional scenes decreases with increasing degree of automation of the transfer of 2D spatial data in 3D. This correlation stands in every case - regardless of the software solution. The World is infinitely complex and for its fully automated digital representation an infinitely complex algorithm is needed. There is no chance to obtain absolutely true model of the world through the automatic conversion of 2D spatial data

- Any more or less operator-dependent transformation is a kind of a cartographic representation; the three-dimensional model is assigned for the real three-dimensional phenomenon. The same process works in classic cartography when assigning cartographic symbol to the real object.

- The complexity and uniqueness of the 3D model, which represents a real phenomenon, depends on the desired accuracy of the resulting 3D scenes. The more 3D models are available for the purpose of automatic creation of 3D data on 2D data base, the more believable the resulting 3D scene is.

- 3D model, with its size and shape approximates the real object which represents. The higher requirements for the credibility of the final scene, the more 3D models of different parameters are needed in the automation process.

- Not all real-world objects are easy to create an automatic way. Some must be treated individually - i.e. shape its inimitable shape, and put it in a specific location.

- The quality of some objects can not be characterized by the third dimension (for example grassland, peat bogs, borders, road or rail communication) and the visualization depends on the user and their own invention.

**3DISCWORLD DATA RESULTS EVALUATION**

The principle of preparing 3D data by the extension 3Discworld lies in the automatic replacement of selected planar data (polygon, line or point) by Multipatch 3D objects with selected appearance.

The resulting data could be used for more complex spatial analysis. Unfortunately nowadays GIS software doesn't support well analyzing real 3D data. ArcGIS tools for analysis use information from the elevation grid. The advantage of this approach is simple computing, but on the other hand, a lot of details can be lost.

The extension 3Discworld was created for ArcGIS 9. Newer version of ArcGIS provides some new tools that can determine the spatial relationship between 3D features, such as checking if one feature is located inside another or combining two 3D features into one complex shape, calculate shadow volume, sky visibility or skyline silhouettes [18]. In comparison with use of elevation grid, the analyses with Multipatch data could prosper from higher level of the data detail.

To simply demonstrate differences in level of detail of output data we report the results of the calculation of shading landscape by linear vegetation.

*Figure 15 Visualization of linear vegetation – elevation grid representation (left) and Multipatch representation (right).*

*Figure 16 Differences of landscape shading with use of elevation grid (left) and Multipatch (right) data type representation.*

**CONCLUSION**

In this paper, we introduced a method of 3D data modelling, which is based on automatic transfer of two-dimensional spatial data. The main output of the research is an extension for ESRI ArcMap ArcGIS 9.3, which offers several tools to work with polygon, line and point data layers and convert them into realistic 3D appearance. Output 3D spatial data can be used either for visualization of virtual reality and for spatial analyses purposes.

There is much software that enables impressive three-dimensional visualization, however the possibility of computing analysis with real 3D data is low. We expect the wide practical use of the automatic transfer of 2D to 3D data, but prior to this, the analytic abilities of GIS must grow up - this can be the reference for the future work.

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