Experience with Methods of 3D Cartography Gained During Visualisation of Detailed Geographic Data for Purposes of Documenting Cultural Heritage (Case Study of the Castle Kozel)

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ABSTRACT

Apart from the two classical dimensional maps, there always were projects focused on creating material based three dimensional maps or landscape models. Rapid development of computer graphics has allowed also the production of maps in 3D virtual environments.

This contribution presents experiences with creating both virtual and material 3D model of the castle Kozel during long term research cooperation between University of West Bohemia and National Heritage Institute (since 2005). It is focused on presentation of the work on turning geo-related datainto interpretable information using cartographic tools.

First, the article describes the aim of the research: development of a system for management of Cultural Heritage, which is now in the stage of Proof-of-concept. From a technical point of view, the management system is built-up upon a comprehensive spatial database which consists of three main data substructures. First substructure is designated for real estate at the level of detail of floors and rooms. The second part describes mobiliary (furniture, paintings, books, pottery, etc.) of a castle, chateau or other type of cultural heritage object or area. The third part covers exteriors (all objects outside of building footprints of both natural and anthropomorphic origin, including complete topography of the area of interest).

The core cartographic part of the article focuses on gained experience, how the mentioned spatial database can serve as a basis for both two and three dimensional cartographic outputs. Particular stress is placed on description of these aspects: scale dependent 3D visualization, completion of map from geographic data with different spatial accuracy, the way to visualize many diverse characteristics of heterogeneous objects in the large scale map, transitions between exteriors and interiors of buildings in interactive model, and last but not least, also the way of transformation virtual 3D model into a materialized map using 3D printing.

The conclusion of the article summaries strengths and weaknesses of used methods and provides possible guidelines for similar projects.

Keywords

3D Cartography, 3D Printing, Large Scale Map, Spatial Database, Geographic Database, Cultural Heritage

INTRODUCTION – COMMON APPROACHES TO 3D CARTOGRAPHY

The third dimension represents one of the opportunities of contemporary cartography. The importance of an interconnection of traditional cartographic methods and modern visualization in 3D is emphasized also in the part Geovisualization and visual analytics of document ICA Research Agenda (Virrantaus et al., 2009) that declares the directions and trends of research activities in cartography. But this topic is a little bit exotic in cartographic literature. The lack of information about 3D cartography is partially substituted by the book Multimedia Cartography (Cartwright et al., 2007) that contains several chapters dealing with 3D cartography and its products.

There are several methods of vizualization the third dimension in cartographic products. The most traditional and the oldest approaches are represented by block diagrams (used mainly in geology and geomorphology) and volume choropleth maps. The volume choropleth maps are related to similar thematic maps constructed on the basis of isolines or profiles. The third dimension is in such maps represented by very schematic symbols (these methods are described in Dent et al. (2010) as well as in Pravda and Kusendova (2007) – Quantitative 3D Methods in 2D Space. The three-dimensional geometric symbols and graphs as tools for making maps more attractive are mentioned in overview of techniques of quantitative thematic mapping published in Dent et al. (2010). On the other hand there are 3D products which use very realistic symbology. The publication (Cartwright et al., 2007) distinguishes photorealistic and non-photorealistic approaches of 3D cartographic visualization.

Also other methods of visualization used in cartography such as augmented reality or digital globes work with third dimension. Looking to physical 3D models, new approaches based on 3D printing are also used, besides classical plastic or relief maps, see e.g. ZCorp (2012). Also globes and similar models could be incorporated, talking about the group of 3D products. According to the scope of the paper, both virtual and physical 3D photorealistic models are presented as examples of 3D cartography used in the case study at the Castle Kozel.

MAP AS AN OUTPUT OF A SPATIAL DATABASE

From the technical point of view, almost all modern maps are created by using some kind of cartographic software or geographic information system. Consequently these maps come from digitally stored spatial data – data stored in spatial database. As a general fact, spatial database is a database that is optimized to store and query data that are related to objects in space. Principles related to the objects of space such as spatial measurements, functions, predicates, indexing etc., are implemented in all current Spatial Database Management Systems (SDBMS). It means that there are two general objectives for SDBMS which should be fulfilled (according to Rigaux et al., 2002):

• SDBMS should integrate the representation and manipulation of geometric information (spatial data) with traditional data at the logical level.

• SDBMS should provide an efficient support at the physical level to store and process this information.

This list of requirements for extension of general DBMS which could fulfill the objectives listed above is summarized into five points:

1 – The logical data representation must be extended to geometric data while satisfying the data independence principle and keeping as much as possible its simplicity and its closeness to the user's vision of reality.

2 – The query language must integrate new functions in order to capture the rich set of possible operations applicable to geometric objects.

3 – There should be an efficient physical representation of the spatial data.

4 – Efficient data access is essential for spatial databases as well as for classical ones. Unfortunately, B-Trees are no longer appropriate for spatial data access. Therefor new data structures for indexing need to be implemented.

5 – Some operation in query processing such as join algorithm cannot be used in spatial databases, so that new algorithms are needed.

As mentioned above, all these five requirements are fulfilled in classical SDBMSs nowadays (more information can be found in any SDBMS dealing literature). On the other hand, these requirements are applicable predominantly for up to 2-dimensional data stored in mainstream SDBMSs. Furthermore, there is a support of 2D objects for 3D coordinates within them (that means this approach is 2,5D, when $z = f(x,y)$). However the full approach of 3D volume objects and their support is not implemented in the main SDBMSs yet (according to Breunig and Zlatanova, 2011). Nevertheless, there are possibilities of working with representation of 3D objects in spatial databases (e.g. boundary representation via Multipatch in Esri geodatabase).

Spatial Objects

Generally speaking, there are two fundamental approaches of modeling a geographic space and geographic objects: entity-based model (or object-based model or feature-based model) and field-based model (or space-based model):

Entity-based model (Rigaux et al., 2002; OGC, 2011; Esri, 2008; Esri, 2012a):

This view of geographical information gathers within spatial object points of the embedding space (limited Euclidean space) sharing common properties (i.e., having the same description. In order to distinguish an object from another, an explicit identity is assigned to it. The entire set (identity, spatial object, common description) constitutes a geographic object, also called a feature or entity.

• Although the definition of a spatial object as a set of points (if the generalization of objects is considered) is quite general, in practice one of the following types of spatial objects are used: Point objects (0- dimensional objects) – geometric type Point:

Are used for representing the location of entities whose whole shape is not considered as useful or when the area of an entity is small with the respect of the embedding space.

• Linear objects (1- dimensional objects) – geometric type Polyline:

These objects are usually used for representing linearly-formed objects. Polyline is defined as a finite set of line segments or edges, such that each segment endpoint (vertex) is sheared by two segments.

• Surface/Area objects (2- dimensional objects) – geometric type Polygon, TIN:

These objects are usually used for representing superficial objects defined by their area. A polygon is a region of the plane bounded by a closed polyline, which defines its boundary.

• 3D objects (3- dimensional objects) – geometric type Multipatch:

A 3D geometry used to represent the outer surface, or shell, of features that occupy a discrete area or volume in three-dimensional space. Multipatches comprise 3D rings and triangles that are used in combination to model a three-dimensional shell. Multipatches can be used to represent simple objects such as spheres and cubes or complex objects such as isosurfaces, buildings, and trees.

There are two remarks for choosing an appropriate geometric type. First, the choice of geometric types for representation of features depends on the future use of the collection of entities. Many factors may influence that selection, scale of visualization is the most important one. For example a house can be described by its outer surface as multipatch, by its building footprint as polygon, or by its boundary of the footprint as polyline, or as a point at small scales of visualization. This decision corresponds to the dimension of visualization, or the purpose of visualization (plane map, 3D visualization, combination of these two, etc.).

Second, description of objects is based on how to describe the shape of an object (how many segments of geometry features need to be used for its representation). With more precision of representation of an object, more memory space is required for store the object.

As a conclusion of the information listed above the entity based model leads to the vector mode of data representation.

Field-based model (Shekhar and Chawla, 2003; Rigaux et al., 2002):

Field-based model requires to determinate three components – a spatial framework, field functions and field operations.

• Spatial framework:

Is finite grid imposed on the underlying (embedding) space. All measurements are then based on this framework. An example of this framework is a system of latitude and longitude.

• Field function:

Value of a function is mapped on the framework. This function can be discrete or continuous. An example is a set of points of altitude above sea level.

• Field operation:

Operations define different relationships and interactions between different fields. There are three categories of operations: local (the value of a new field depends only on a value of the field at a given location), focal (the value of a new field depends on a value of the field at a given location and its neighborhood), zonal (are associated with aggregate operations or the integration functions).

This approach of modeling is defined as a space, where a set of values is mapped on an embedding space (plane), on fields of this plane respectively. There is no description of objects as a set of points.

As a conclusion of the information listed above this field-based model leads to the raster (tesselation) mode of data representation.

Spatial Query Language

A query language as a principal means of interaction with the database is a core requirement of a DBMS. A query language for relational DBMS is Structured Query Language (SQL). It is partly based on the relational algebra and it is easy to use and it is versatile. Because spatial DBMSs are examples of an extensible DBMS and deal with both spatial and non-spatial data, it is natural to seek for an extension of SQL to incorporate spatial data into the structure.

The widespread use of the relational model and SQL for applications involving simple data types combined with the functionality of the object-oriented model has led to the birth of a new hybrid paradigm for database management systems, the OR-DBMS. In OR-DBMS, the desire is to extend SQL with object functionality. This effort materialized into a new OR-DBMS standard for Structured Query Language, SQL:1999 also called SQL 3, (Shekhar and Chawla, 2003).

The whole standard will not be discussed here, only the overview. The latest version of SQL and information about implemented specifications can be found in SQL:2011 (2012).

Looking particularly to 3D data, Zlatanova (2006) states that to manage 3D features (as volumetric objects) in the database, the user can choose between:

1) using DBMS data types polygon and multipolygon, or

2) creating a used-defined data type. The three candidates for a simple volumetric object are polyhedron, triangulated polyhedron and tetrahedron and all three can be easily realized with provided data types.

According to 1): objects are defined such as a set of polygons (table consists of records of each feature - featureID and polygon data type) or as a multipolygon (all the polygons are listed inside the data type, which is practically one record in the relational database).

Indeed, both representations are not recognized by DBMS as a volumetric object, i.e. they are still polygons and thus a kind of boundary representation. The objects can be indexed as 3D polygons but not as 3D volumetric objects. Spatial operations can be performed as well but on the 'flattered' polygons, i.e. the z-coordinate will not be considered. Moreover, both representations are highly inefficient in terms of storage space. The coordinates of the points in such a volumetric object are repeated at least three times (a point is a part of at least three adjacent polygons) either in 3D multipolygon record or in the list of polygons.

According to 2): user defined spatial data types can be implemented using different approaches simple SQL create data type statement or complex implementations (using a Procedural Language (PL), Java, C++, etc.). The common drawback of such implementation is impossibility to apply the native spatial functionality (operations and indexing) of DBMS.

From the text above it can be seen that the standardized querying of spatial objects in databases is limited by the dimension of two and there is a need for whole 3D volumetric querying.

For creating particularly 3D maps from spatial databases, some issues must be taken into consideration. It is the integration of 2D and 3D view of data that means that there must be a careful consideration of which features from 2D maps should be taken into the 3D model by their 3D shape (using e.g. some kind of boundary representation) and which 3D features represent just with an anchor point and predefined 3D cartographic symbol.

DESCRIPTION OF THE SYSTEM FOR MANAGEMENT OF CULTURAL HERITAGE AT THE CASTLE KOZEL

Classicist castle Kozel was built in the late 18th century and it os situated near Pilsen in the Czech Republic, Europe. More information about the castle itself can be seen at its official website http://www.zamek-kozel.eu.

Before the case study, there existed heterogeneous both analog and digital data. Therefore, one of the first tasks to do during the case study, was to scan (and vectorize) the analog data and to convert existing digital data in one data format. According to the technology platform used by the National Heritage Institute, the data were gradually converted to Esri geodatabase format.

Consequently, there were realized geodetic surveying, architectonic measurements and even photogrammetric and laser-scan campaigns, to complete the information sources about the Castle. Experiences gained during these campaigns were further used during assembling the Methodology for the electronic passport of publicly accessed site, (Bezděk et al., 2011). As there was created a large amount of heterogeneous data, it was crucial to develop a well-structured data model for a spatial database for purposes of storing and further querying, analyzing and visualizing of the data.

During the data model development, both approaches mentioned in the section "Spatial Objects", were used. Although the entity-based model was the major one (see section "Structure of the logical Model"). The field-based model was used for digital terrain model represented as triangular irregular network (TIN) and for orthophoto and image data, such as textures of buildings.

The data model has been designed according to commonly used methodology of data modeling (see the theory e.g. in Arctur and Zeiler (2004), Longley et al. (2010) or an application in Jedlička (2010)):

• Human oriented conceptual model based on analysis of user requirements.

• More abstract and formalized logical model which groups particular objects into classes and creates and describes relationships among them.

• Computer oriented physical model is represented as the structure of the database and keeps the data. Please note that there are two different meanings of the physical model: cartographic – see introduction; and database – depicted here. Therefore the database-related term physical model is further replaced with synonymous term database structure.

User Requirements and Conceptual Data Model

Before data model development it was crucial to gather user, analyse and write down all user requirements. Those requirements were originally defined in internal document Jedlička and Bobek (2004) and first time publicly described in detail in Bobek and Jedlička (2011). According to these documents, the fundamental concept of a castle data model is built on following key principles:

1. Interoperability to national systems – the data in the model is related to existing databases using unique identifiers of these national level databases as foreign keys (e.g., register of immovables is related to national system called paGIS and the register of movables is related to national system called CASTIS). See more information about this connectivity in section "Structure of the Logical Model", where the logical model is described in figure 1.

2. Smooth transition – the model allows consecutive import of data and hybrid maintaining of data in both old (analogous) model and the designed model - for a transitional period.

3. Openness and future expandability – the model allows storing both 2D and 3D data gathered in various ways (e.g., geodetic survey, photogrammetry, laser scanning – see e.g. in Fiala (2011) for more information). While 2D registers prevails at present (for financial reasons) a massive uptake of 3D technologies can be expected even in cultural custody in the future.

4. Completeness and sufficient detail – the model allows registering both exteriors and interiors of a castle, which are separated by outer walls of buildings. While the structure of exteriors is relatively simple (even if both natural and manmade objects have to be registered in exteriors and thus both types of data have to have appropriate classes in the model), castle interiors are more complex (even or because they keep just manmade features). Interiors have to be encapsulated into outer walls of buildings and basically divided into storeys and rooms (and other spaces in the building) and structural elements. But unlike ordinary buildings, interiors of castles are much more irregular.

5. Awareness of a spatial threshold – not all the registered data about movables has to have full-valued spatial representation. To keep the database manageable, there had to be set a spatial threshold among different types of movables:

a. Full-valued (3D) representation of the object shape (and a 2D footprint for purposes of 2D management – see principle 6 bellow) – used for big or culturally valuable subjects, such as for example altar (fulfills both size and value criterion); case, book case, table or chair (fulfills size and may fulfill value criterion) or even a small piece of pottery, if it has extremely big cultural value.

b. Point representation of object's position – used for small items with usual cultural value or even for bigger objects if there is no possibility or need to create a 3D representation (see principle 2).

c. Indirect spatial representation – used for small, culturally not valuable objects (e.g., pottery again) or even for culturally valuable objects of similar type stored in a closed space (e.g. books in bookcase or paintings in repository or safe deposit).

As can be seen from above, a pottery as an example of a movable item can potentially fit in any of the three mentioned categories. The key for decision lies in the cultural value of such item.

6. Hybrid 2D / 3D access – all contemporary software clients use tabular or 2D access to database records and such an access is sufficient enough for purposes of registration. But the custody of cultural heritage is not only about its registration but also about its protection and presentation. And there can be useful to have a 3D visualization of an object, e.g.:

a. For a time-critical situation such a fire, flood or natural disaster endangering the object (protection issue).

b. For remote on-line propagation or even in site virtual presentation of a castle or some of its parts (whose can be e.g., inaccessible to public for various reasons).

Therefore the model allows the hybrid access and also storage of the data (it is possible to store just 2D footprint to fulfill principle 2, which is realized by observing the principle 5.a).

Structure of the Logical Model

The logical model structure is based on above mentioned key conceptual principles and is depicted in figure 1.

As can be seen in the figure 1 that there is class area which geographically bounds all other classes and also interconnect developed database structure to a national system for management of immovables used by the National Heritage Institute. Other classes are divided into following groups (note that just classes written in bold are real classes, others are abstract classes; features mentioned in parentheses are subtypes of classes):

Exterior group:

- Relief group: surface, contour line, elevation spot and terrain skeleton lines (thalweg, ridgeline, slope line, break line).
- Hydrology group: water area and line.
- Vegetation feature: tree, wood, grass, garden, etc.
- Communication (line, area).

Names of classes in the exterior groups are common in spatial databases. They are self-explanatory; hence they are not described in detail. For the better notion of the exterior group classes, the figure 2 shows 3D visualization of castle exteriors from resultant spatial database.

Interior group:

- Building – composed of outer walls and footprint of a building. Separates interiors from exteriors.
- Storey – abstract class composed of rooms.
- Room – abstract class composed of its floor, walls, ceiling and belonging building openings.
- Floor (of the room) – represents the simplest expression of a room. Each room is primarily represented by its floor because most of the movables belonging to the room can be spatially identified as lying on its floor or lying in between its floor and its ceiling or higher floor.
- The class wall represents all inner walls of a room.
- Ceiling holds the information of ceiling of a room.
- Building opening stores all wall openings (such as doors, windows or even empty spaces - passages).
- The class movable holds the information about geometric shape or position (see principle 5) of movable subjects and also their unique identifier which interconnect them to the CASTIS (management system for movables used by the National Heritage Institute).

The example of transition in between exteriors and interiors, there are portrayed exterior classes combined with border class Building (composed of footprints and exterior walls) and also a subset of interior classes (floor and movable), see figure 3. Depiction of interiors (complete visualization of first storey covered with second floor) can be seen in figure 4.

Storage of the Spatial Database

When the logical model was created, a spatial database format Esri geodatabase was selected for implementation of a physical model (in a meaning of database structure), because the Esri geodatabase fulfills all five requirements for extension of general DBMS mentioned in chapter 2.

Esri geodatabase can also handle both field and entity based data and allows user to use GIS based query language to query the data. Esri geodatabase is planar, generally stores 2D or 2,5D data in raster format, triangulated irregular network (digital terrain model) or in point, polyline or polygon classes (all other exterior classes). The multipatch classes are used for boundary representation of 3D objects (buildings and interior features in this project). While the support of 2D and 2,5D classes is on a high level in the geodatabase, the 3D class multipatch has some limitation, therefore it is useful to present and describe mention them a bit.

A multipatch feature is a GIS object that stores a collection of patches to represent the boundary of a 3D object as a single row in a database. Patches store texture, color, transparency, and geometric information representing parts of a feature. The geometric information stored in a patch may be triangles, triangle fans, triangle strips, or rings. Some multipatch features are considered closed, meaning they properly define a volume. Closed multipatches may be used in additional analysis tools, such as Union 3D, Difference 3D, Inside 3D and Intersect 3D. For a multipatch, considered as closed, it must be constructed in the correct fashion. The feature must represent one distinct volume. The patches from whose the feature is compo-

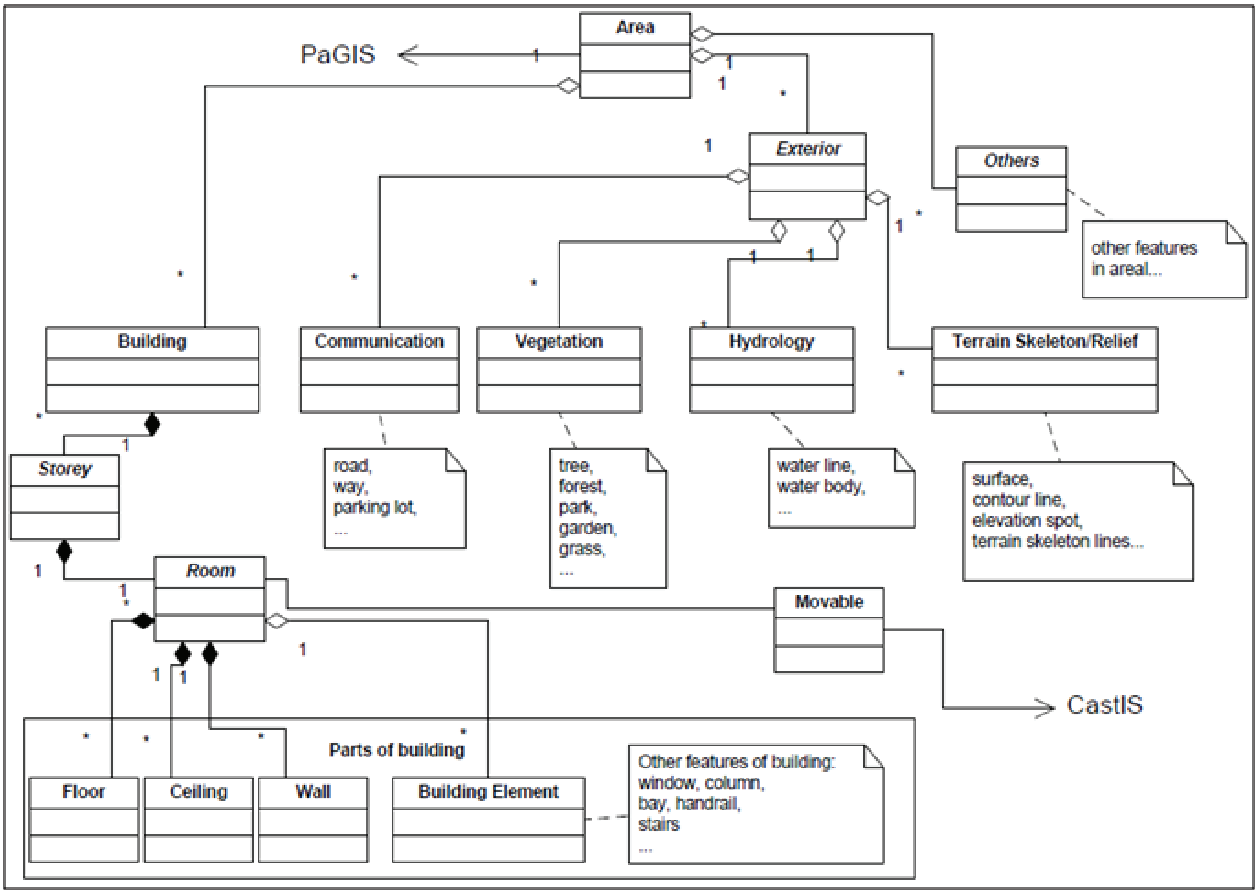

Figure 1. Logical structure of the model of a castle using Unified Modeling Language (in UML).

Figure 2. 3D visualization of castle exteriors from resultant spatial database.

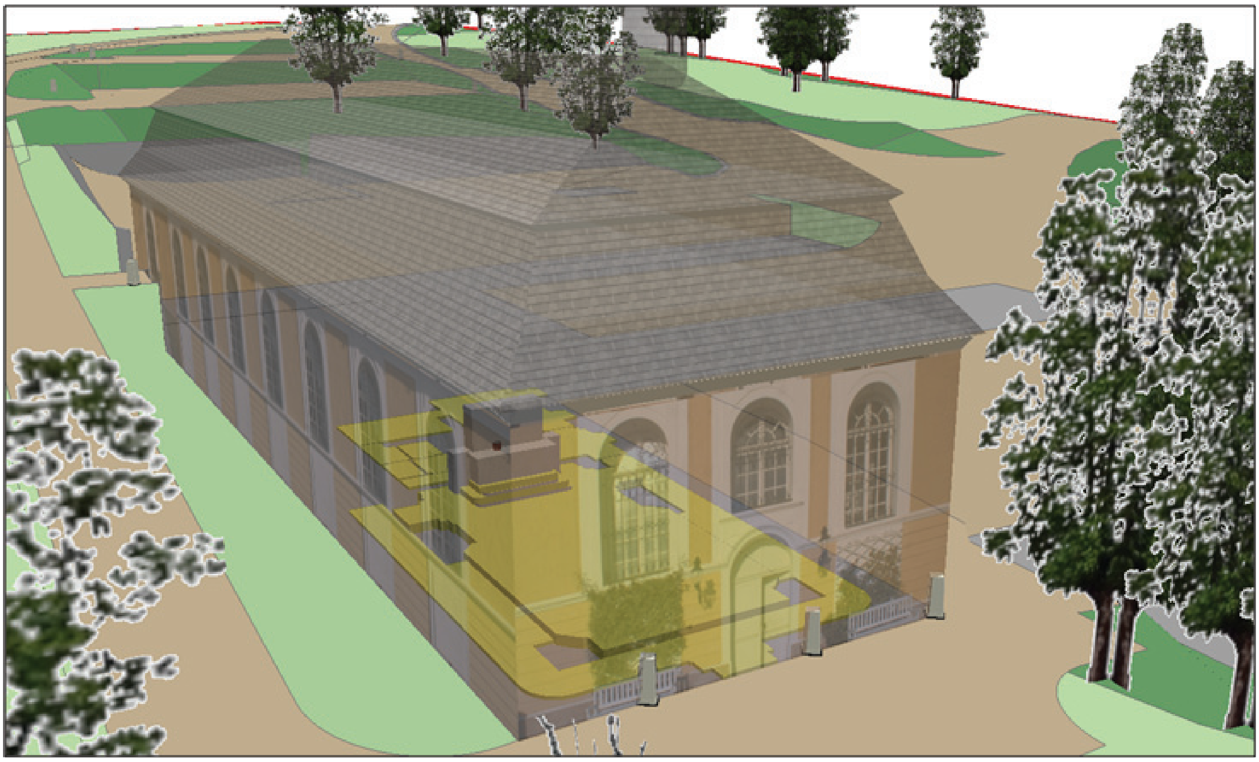

Figure 3. 3D visualization of transition in between exteriors and interiors.

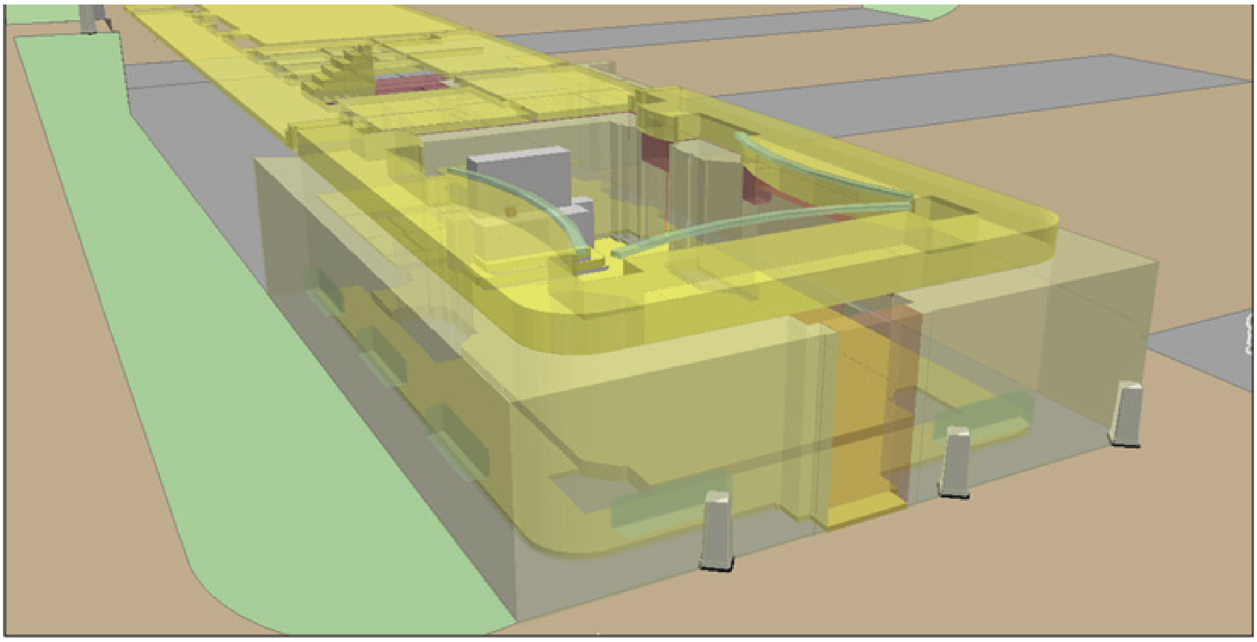

Figure 4. 3D visualization of chapel interiors (complete visualization of first storey covered with second floor).

sed of must all have the same counterclockwise orientation of their coordinates and participate in defining the shell of the volume. The patches mustn't intersect each other, and there must be no gaps or empty spaces in the shell, Esri (2012a).

But the usability of editing of multipatches features is limited to the basic functions such as: copy, paste, move, rotate, rescaling, snapping, attribute editing, see Esri (2012b). Extended editing features, such as split tools, various edit tasks, sketch and topology edits are not yet included. Therefore the approach of creating 3D objects is recommended by Esri throughout the SketchUp software and then the importing of created objects via Sketch Up to the geodatabase of Esri, which creates a multipatch object there, see e.g. Esri (2012c).

MAPS CREATED FROM THE DATABASE

The described spatial database was created for purposes of documenting and preserving of Cultural Heritage, whose have been deeply described in Bobek and Jedlička (2011). One of the activities in heritage custody is also a presentation of the managed property. And this is an excellent opportunity for cartography and hence even for making maps. Following types of maps were created as outputs of developed and populated spatial database.

Classic two Dimensional Maps

Alongside to classic map (created using ArcMap, see a cutout on the left in figure 5), also web map was created (right side in the same figure). The printed map will be used as guide map in situated on a board in the castle area. The web map is available at the address http://www.arcgis.com/explorer/?open=09c134dd23ef492b9ad2ca9dbbe3c069 and after a validation process it will be used for presentation purposes at the pages of the castle Kozel (http://www.zamek-kozel.cz/).

Comparing these two maps, it is obvious that the cartographic language of the web map had to be changed (using web safe colors), simplified so as the map was readable on a screen which has lower resolution than a paper and last but not least the web map is limited to more use of simple symbols.

Three dimensional Maps

Creation of a three dimensional map is based upon a detailed, well-shaped digital terrain model (DTM). The 2.5D DTM represented in TIN is used as a height source for all two dimensional layers. Finally, three dimensional layer of buildings is also placed on the terrain.

The virtual 3D model was created and it is possible to visualize it in perspective or even full 3D view using software ArcScene (see examples of perspective visualization of the 3D model can be seen in figures 2, 3 and 4) and there are ongoing works on visualize the model also in the Google 3D buildings layer. See also the comparison of the created 3D model to a reality in figure 6.

Also a sample 3D print of the model was realized in a scale of 1:400 (see the figure 7). The whole model has not be realized yet because of its financial costs, but even from this test print it is possible to state that creating a physical 3D model requires more precise work on a model. There follows main difficulties which authors had to deal with during the proposing the process of printing a physical model:

- Printer has to be set to minimum thickness of printed layers. The thickness 0.1 mm used on a sample print has created visible "contour lines" in the model.
- Printer effective area limits the size of the printed model to 200 x 250 mm, therefore larger models have to be composed of tiles.
- As it is not possible to lay out the tiles in the way they do not cross buildings, it is necessary to print buildings models separately.
- The dpi of textures used in print must be ideally at least 300 dpi. Even if this can be achieved for building textures the buildings, it is a problem for orthophoto. For example a very detailed ortophoto map with pixel size of 10 cm has resolution of 100 dpi in the scale of 1:400.
- Therefore there is planned a further model-making using real models of trees and smooth sand for coverage of paths.
- Nowadays, many virtual models are created but it should be stated that not every virtual model is feasible to print and even if you have well created virtual model, it is still necessary to deal with specifics of physical model described above.

Figure 5. Comparable cutouts of map created by desktop software (ArcMap) and internet map created in web client (ArcGIS Explorer).

Figure 6. Comparison of the created 3D model to a reality.

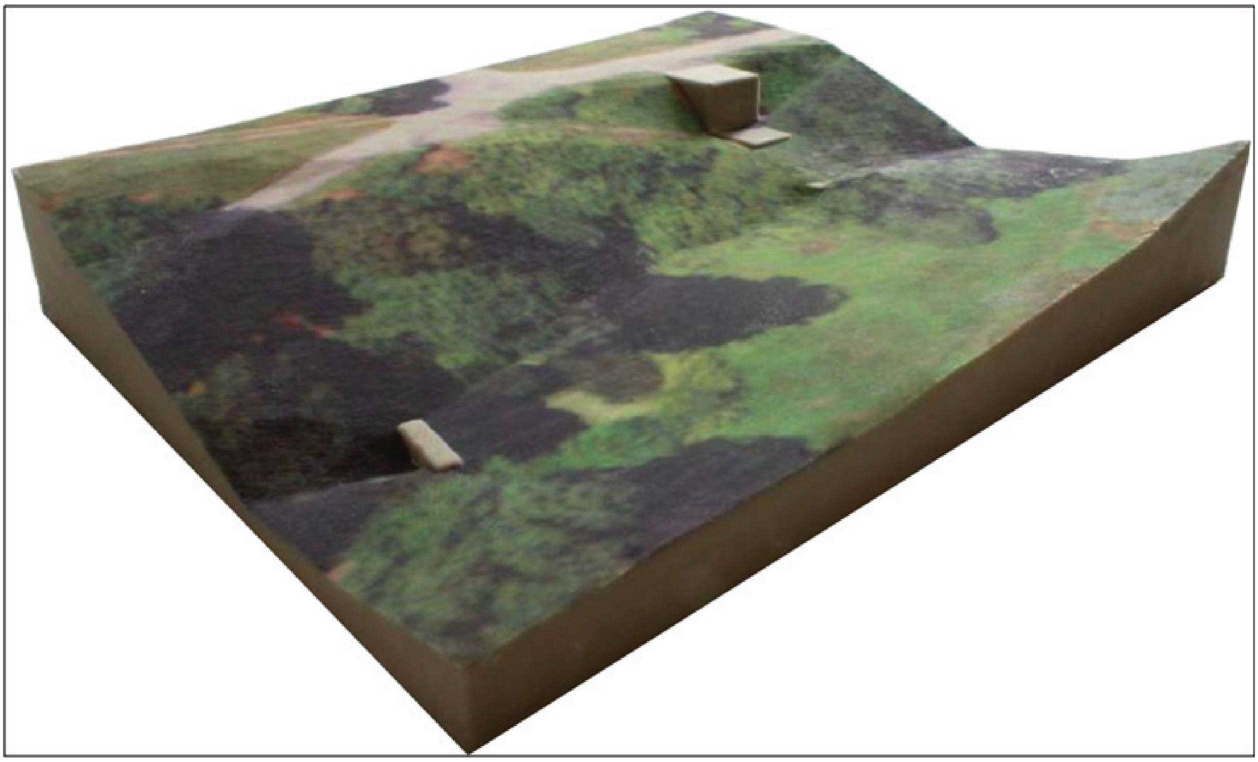

Figure 7. Sample 3D print of part of created model in a scale 1:400.

DISCUSSION

The presented case study shows interconnection of spatial databases and map production in 3D. Namely figures 3 and 4 clearly shows how important is well designed data model for visualizing detailed 3D data – castle exteriors and selected parts of buildings interiors in this case. Currently, authors study similarities between designed data model and the structure of CityGML data format.

Disregard the cartography, the designed data model is compliant to national data model used by the National Heritage institute for its registers.

The designed data model is close to common models used in building information management (BIM), but compared to them it adds the information of culturally valuable mobiliary and non-mobiliary funds. Therefore the model could serve as good practice example for extension of classic BIM models for historically valuable areas.

During the work on the case study, authors have added heritage preservation knowledge and skills to their professional geomatic curriculums.

SUMMARY

This article describes experiences with methods of 3D cartography gained during visualization of detailed geographic data for purposes of documenting Cultural Heritage (Case Study at the castle Kozel).

First of all, introduction to common approaches to 3D cartography is depicted, few methods of visualization of third dimension in cartographic products are mentioned and examples of 3D cartography used for the Case Study are stressed.

Second, the article deals with spatial databases as a background for making maps. The requirements for extension of classical databases to be capable to hold spatial data are assembled, approaches of modeling reality and cartographic objects are put together and the use of Structured Query Language for querying the spatial 3D objects is outlined.

Next, the case study itself is described user requirements of the documenting Cultural Heritage are listed. Consequently the conceptual model is and detailed structure of the logical model is depicted. Furthermore 'pros and cons' of the technology used for implementation of storage of the collected spatial data are shortly presented.

The last chapter describes each type of cartographic visualization created from the spatial database during the project (2D maps for print and for web; 3D virtual and physical model) Consequently the chapter summaries strengths and weaknesses of used each visualization type and provides possible guidelines for similar projects.

REFERENCES

Breunig M and S Zlatanova, 2011, 3D geo-database research: Retrospective and future directions, Computers & Geosciences 37, p. 791–803

Bezděk L, K Bobek, D Buršík and K Jedlička, 2011, Metodika pro elektronický pasport zpřístupněné památky. [Methodology for electronic passport of publicly accessed site] National Heritage Institute, Praha, available online at http://www.npu.cz/download/1328798071/41-meto-elektronický-pasport-zpřístupněné-památky.pdf , [5-17-2012].

Bobek K, and K Jedlička, 2004, Koncept GIS Kozel. Internal report for purposes of National Heritage Institute.

Bobek K, and K Jedlička, 2011, 3D data model for purposes of cultural heritage custody. Case study in the state Castle Kozel. Proceedings of XXIIIth CIPA Sympozium. Praha. ISBN 978-80-01-04885-6.

Cartwright W, M P Peterson, and G Gartner (Eds.), 2007, Multimedia Cartography. 2nd ed., Springer, 546 p.

Dent B D, J S Torguson, and T W Hodler, 2010, Cartography. Thematic Map Design. 6th edition. McGraw-Hill. ISBN 978-0-07294382-5.

Esri, 2008, The Multipatch Geometry Type, An ESRI White Paper, December 2008, available online at <http://www.esri.com/library/whitepapers/pdfs/multipatch-geometry-type.pdf>, [4-24-2012]

Esri, 2012a, Feature class basics, ArcGIS Resource Center, Esri, available online at <http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//003n00000005000000>, [4-24-2012]

Esri, 2012b, Editing 3D multipatch features, ArcGIS Resource Center, Esri, available online at <http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/Editing_3D_multipatch_features/00q80000007v000000/>, [5-3-2012]

Esri, 2012c, Making a large-scale 3D Map: Part 2, ArcGIS Resource Center, Esri, available online at <http://blogs.esri.com/esri/arcgis/2012/01/10/making-a-large-scale-3d-map-part-2/> [5-10-2012]

Fiala R, 2011, Using a database as a data source for creating a 3D model. Proceedings of XXIIIth CIPA Sympozium. Praha. ISBN 978-80-01-04885-6.

OGC, 2011, OpenGIS® Implementation Standard for Geographic information - Simple feature access - Part 1: Common architecture, OpenGIS Implementation Standard, version 1.2.1, available online at <http://www.opengeospatial.org/standards/sfa>. [5-3-2012]

Pravda J, and D Kusendová, 2007, Aplikovaná kartografia. Geografika, Bratislava. ISBN 978-80-89317-00-4.

Rigaux P, M Scholl, and A Voisard, 2002, Spatial Databases with Application to GIS. Morgan Kaufmann Publishers, San Francisco, California, USA, ISBN 1-55860-588-6

Shekhar S, and S Chawla, 2003, Spatial Databases: A Tour, Prentice Hall, ISBN 0-13-017480-7

SQL:2011, 2012, ISO/IEC FDIS 9075-1 Information technology - Database languages - SQL - Part 1: Framework (SQL/Framework), 2011-07-18, available at <http://www.jtc1sc32.org/doc/N2151-2200/32N2153T-text_for_ballot-FDIS_9075-1.pdf>, [5-6-2012]

Virrantaus K, D Fairbairn, and M-J Kraak, 2009, ICA Research Agenda. In: The Cartographic Journal, Volume 46, Number 2, pp. 63-75(13), Publisher: Maney Pub.

ZCorp, 2012, Solutions/Geospatial, available at <http://www.zcorp.com/en/Solutions/Geospatial/spage.aspx>, [5-15-2012]

Zlatanova S, 2006, 3D geometries in spatial DBMS, In A Abdul-Rahman, S Zlatanova and V Coors (Eds.), Lecture notes in geoinformation and cartography: innovations in 3D geo information systems (pp. 1-14). Berlin-Heidelberg-New York: Springer.