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Original article

Rapid reconstruction of historical urban landscape: The surroundings of Czech chateaux and castles

Pavel Tobiáš*, Jiří Cajthaml, Jiří Krejčí

CTU in Prague, Faculty of Civil Engineering, Department of Geomatics, Thákurova 7, 166 29 Praha 6, Czech Republic

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ABSTRACT

Modern digital techniques of contemporary cartography allow us to study changes in the landscape character with the use of tools primarily designed for geomatics science. Old maps and plans can be scanned, georeferenced and vectorised and historical photographs can be geocoded in the GIS environment, and thus experienced users can get an idea about the landscape character throughout history from these data sources. However, a lot of users from the general public are not familiar with the language of maps, especially the old ones, and are not able to understand the landscape appearance from 2D datasets only. For that reason, 3D modelling can be very beneficial because 3D models can significantly improve users' experience gained from the portrayed landscape situations. This article presents a complete workflow of landscape model creation based on old maps, plans, drawings and photographs. The described approach employs a combination of GIS techniques, 3D CAD software and procedural modelling tools and aims to maximally exploit datasets which are processed for the purposes of a classical 2D web mapping application. The main goal of this research is not to create highly-precise models, but rather to provide simple though credible visualisations, from which even less-experienced users could identify the urban landscape character in history and its changes in time.

1. Research aims

The main goal of our research is to develop a comprehensive workflow suitable for the creation of information-rich 3D visualisations of Czech urban landscapes. As a basis, we use old maps, plans and drawings that have been previously pre-processed using geomatics skills, i.e. they have been digitised, georeferenced and vectorised. The 3D visualisations should mainly serve for presentation and dissemination purposes and they ought to be maximally simple and time-effective to produce. Therefore, we utilise the procedural modelling approach for the reconstruction of common urban areas, and only landmark buildings (in our case mainly chateaux or castles) are modelled using classical CAD software. The resulting 3D scenes are supplemented with metadata originating in 2D GIS layers. Thus, models of all historically significant buildings can be queried for attributes. As procedural modelling facilitates rapid 3D reconstruction of landscape, multiple models can be created for multiple time periods and users can also study the development of urban areas in time which is more intuitive in 3D. Finally, historical and up-to-date photographs are added as "billboards" to the 3D scenes enabling further investigation of the landscape appearance and its changes in time.

2. Introduction

2.1. Historical photographical material – the project

The workflow described in this article is at present deployed mainly for the purposes of the "Historical photographical material" project of the Czech Ministry of Culture. This project intends to collect, process and visualise various old maps, plans, pictorial, photographic and textual documents related to 60 chateaux and castles formerly in the property of noble families and at present owned by the Czech Republic and administrated by the National Heritage Institute (NPU). In this way, the general public will be acquainted with the history of selected domains and their development from the beginning of the 19th century to the mid-20th century.

The essential thing is that not only the chateaux or castles themselves, but also wider surroundings of the manor houses are considered, which enables us to depict the economic and cultural background of the whole domain. The result of our effort will be a web mapping application which consolidates all the heterogeneous data sources found and makes the outcomes of extensive archival

* Corresponding author.
E-mail address: pavel.tobias@fsv.cvut.cz (P. Tobiáš).

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and geomatics skills accessible to the general public in a comprehensive and understandable way. For the most interesting objects, classical 2D application will be supplemented by 3D web scenes portraying the state of landscape in the past. The creation of these three-dimensional scenes is the main topic of this article.

To facilitate the collection and processing of the vast amount of data sources, not only the academics but also selected undergraduate students are involved in our project. The results of this project can then serve as a basis for their theses and they can benefit from engaging in a real-world research project in general. Involving students in the project means that understandable workflows have to be developed to be adaptable and applicable for less experienced users without reducing the quality of outputs. This applies especially to the pre-processing of data for the purposes of 2D application (data collection, georeferencing, vectorisation, etc.).

2.2. *Background and related work*

In our research, we have worked with the premise that 3D scenes can be more legible than plain 2D visualisations, especially for users inexperienced in cartography. This assumption is based not only on subjective opinions of application testers, but it is also supported with serious research using modern scientific methods (e.g. eye-tracking [1]). Nevertheless, highly detailed 3D visualisations of urban landscape can be in the final consequence confusing due to high cognitive load on users who are focused on geometrical details and are not able to perceive the wider context of the landscape [2]. Moreover the creation of such splendid scenes is very time consuming and extensive knowledge of the appearance of all real world objects in all modelled time periods is necessary to develop credible visualisation. For this reason, we decided to model rather semi-photorealistic scenes where only the most important buildings, i.e. mainly chateaux and castles would be modelled in high detail.

Modellers who aim to reconstruct urban landscape can basically choose from two options. First, they can model all buildings point by point in a simple CAD software (such as Trimble SketchUp or Bentley MicroStation). This is a well-established approach in 3D cartography adopted e.g. by [3–7] and many others. However, this method is highly time consuming and therefore, it is advantageous to employ a more automated approach. Hence, the second option is constituted by procedural modelling, which can be used in various fields of study, e.g. in modelling of textures, plants, terrain, buildings, urban areas, road networks, rivers or in art creation. A comprehensive review of contemporary techniques used in procedural modelling can be found in the paper by Smelik et al. [8]. They consider *shape grammars* to be "the most developed, used and compact method for building representation" although these tools have in general several limitations such as the inability to control the results interactively and directly in 3D scenes [9].

The first appearance of the shape grammars term can be traced back to 1971 when it was first mentioned in the article by Stiny and Gips [10]. The basic principle of shape grammars lies in the progressive refinement of basic shapes according to specified rules and the creation of more complex geometries is analogous to the formation of strings from symbols, described in the field of formal languages. This principle is also used in the computer generated architecture (CGA) grammar, which was primarily developed to serve as a tool for rapid architectural modelling. The origins of this tool were described in the articles by Parish and Müller [11] (creation of *simple* 3D city models based on 2D polygons), Wonka et al. [12] (reconstruction of geometrical *details*) and finally Müller et al. [13] (combination of methods, implementation in a software called CityEngine). Recently, a new derivation of this grammar, called CGA++, was presented in [14].

Although CityEngine was originally designed for movie and gaming industry [13], it has also been employed for the tasks of virtual reconstruction of cultural heritage. Examples of this approach can be found in the articles by Haegler et al., Watson et al. or Calogero et al. [15–17] whereas the first two papers mainly deal with models of large ancient cities (Rome, Pompeii) on the basis of archaeological excavations and the last effort tries to reconstruct various unrealised designs of one particular building (Louvre). The usage of CityEngine is not necessarily limited to the exterior of buildings but can also be utilised to model indoor spaces [18]. Furthermore, another researchers experiment with the application of different approaches to procedural modelling. Examples can be found in Rodrigues et al. [19] (Roman houses in Conimbriga) or Quattrinni and Baleani [20] (Palladian architecture) although they modelled individual building complexes rather than whole conurbations. Laycock et al. [21] dealt with the reconstruction of urban areas based on historical map sources while they experimented with the automated extraction of footprints of old maps [22]. An effort to depict development in time is presented in the scale of one building complex. Moreover, Belloti et al. [23] work with the premise that for users' experience it is not necessary to model all buildings in a town or city individually but it is more important to portray the general appearance of conurbation based on "architectural likelihood" which expresses the probability of occurrence of various architectural styles in a particular settlement. Last but not least, Perrin et al. [24], already in the year 2000, experimented with the procedural reconstruction of landscapes primarily for the purposes of urban planning while they tried to predict the appearance of landscape in the future (vegetation growth, development of buildings).

In our work, we would like to combine knowledge from aforementioned approaches to 3D reconstruction of landscape. Therefore, we would like to extract the information contained in old maps, mix procedural and CAD modelling and depict the historical appearance of conurbations and their changes in time. The concept of our workflow was briefly proposed in [25]. Hereafter, we would like to provide a more in-depth explanation and present several types of our results.

3. Materials and methodology

3.1. *Data sources*

To collect as many old maps, plans and historical photographs as possible, an extensive archival survey was carried out. In order to assemble available maps and plans, various archives in the Czech Republic were searched, namely: Central Archive of Surveying and Cadastre, State Regional Archives, State District Archives, archives of the National Heritage Institute. Moreover, other highly valuable data sources can be found in the collections belonging to particular manor houses and also in private collections.

The most common data sources for our purposes are archival documents from the Central Archive of Surveying and Cadastre. From this archive, we have obtained former cadastral maps and maps which were acquired through their derivation. To the most appealing data sources that we process and utilise belong certainly the coloured Imperial Imprints of the Stable Cadastre. The corresponding land registry was built on the basis of the Francis I patent of 1817 and it was assumed to be "stable", i.e. definitive for the whole Habsburg monarchy. The mapping of the Stable Cadastre was executed between the years 1826 and 1843 in a scale of 1:2880. While this map series gives us an overview of the state of landscape in the first half of the 19th century, we also use a set of newer discarded (i.e. replaced by a new and updated map) cadastral maps that depicts the same situation at the end of the 19th century (or at the beginning of the 20th century if additional edits in maps are taken into consideration). In addition to this, the State Derived Map in a scale of 1:5000 published in the 1950s also contains contour lines providing information about the terrain relief. Last but not least, we utilise up-to-date vector data from the Registry of Territorial Identification, Addresses and Real Estate (RÚIAN) provided by the Czech Office for Surveying, Mapping and Cadastre. Thus, after the processing of the data sources, we are equipped with four temporary datasets for each chateau or castle with similar contents and precision, which enables us to carry out the research into the changes in time related to the manor house surroundings.

Whilst the data sources described in the previous paragraph are obtainable for most of the objects of interest, the availability of other maps and plans as well as photographs differs from manor to manor. Maps of domains give us an idea about the delimitation of whole domains in history and often also about the deployment of subsidiary facilities. On the other hand, maps or plans of chateau parks or gardens depict the closest surroundings of manor houses. Floorplans and other drawings of buildings in the chateau complex are the largest scale data sources that also portray the interiors of the most important buildings complementing the multi-scale range of our data sources. In this way, the closest and also the widest surroundings of chateaux or castles within domains and their changes in time can be examined. Finally, the map and plan content in the resulting 2D and 3D applications will be widely supplemented with historical and up-to-date photographs. Because of that, also historical photographs and postcards are searched and comparative images are taken in the field.

3.2. Processing of available maps, plans and photographs

All data sources described in Section 3.1 had to be carefully preprocessed before 2D or even 3D applications could be designed. Speaking in particular about maps and plans, the classical techniques from geomatics science were employed – digitisation, georeferencing and vectorisation. Because the majority of data sources found were obtained in the analogue paper form, high resolution scanning had to be employed to acquire digital copies of requested maps and plans.

All the scanned data had to be georeferenced into an appropriate coordinate system so that they could be further examined in the GIS environment. In the Czech Republic, Křovák's universal conformal conical projection and the S-JTSK (Datum of Uniform Trigonometric Cadastral Network) national grid are mostly used for this purpose. The methods of georeferencing can be separated into two groups. First, global transformation methods use a set of control points to compute a transformation key, usually by least squares method adjustment. Based on selected method (i.e. similarity, affine, polynomial), the image data can be moved, scaled, rotated, etc. while residuals on control points remain. Second, local transformation methods transform the map to be non-residual on control points. There is no global transformation key and the map can be distorted to fit onto these points (i.e. rubber-sheeting method). In our case, mainly the first approach was chosen. When using global transformation methods, the image of the map is distorted just globally within the geometric method, instead of local deformations occurring when using local methods. Specifically, the Imperial Imprints of the Stable Cadastre as well as the discarded cadastral maps and maps of domains were georeferenced using affine or second order polynomial transformations. Large scale maps and plans of parks and gardens were transformed with affine transformation. For the high-quality State Derived Map, affine or projective transformations on corner points were used.

To facilitate further usability of the resulting web mapping application, selected maps and plans were vectorised. The closest surroundings of chateaux and castles were vectorised completely allowing the comparison of the land use in different periods of time and thus the development of urban landscapes. Important subsidiary facilities within domains were vectorised as point layers based on maps of domains and on a thorough historical survey of textual data sources (Fig. 1) Historical and up-to-date photographs were geotagged and stored as point layers. All the important buildings, other objects and photograph locations are now stored in a geodatabase, including attributes such as name, type, description, etc.

3.3. 3D scene preparation

In our project, we aim to reconstruct the surroundings of chateaux and castles, i.e. historical parts of urban landscape which, in most cases, have not undergone many significant changes. Beside this, we try to limit our area of interest, which should be modelled, so that there are no signs of modern terrain changes (e.g. notches for highways or railroads). Therefore, we can mostly rely on up-to-date terrain models and we usually utilise the Digital Terrain Model of the Czech Republic of the 5th generation (DMR5G), which consists of points in TIN with total standard error of 0.18–0.3 m [26]. DMR5G is distributed by the Czech Office for Surveying, Mapping and Cadastre (ČÚZK) as a text file containing points with X, Y planar coordinates (in the S-JTSK) and an H height value in the Bpv (Baltic Vertical Datum – After Adjustment). To process the terrain model, we mostly utilise the ESRI ArcMap GIS tool. First, the text file is converted into a shapefile multipoint feature class. Then, a triangulated irregular network (TIN) is created and lastly, the resulting TIN is transformed into a raster in the TIFF file format, which is further usable for 3D scene generation. The average point spacing of DMR 5G is approximately 3 m so we use this value for the output cell size.

Even though we try to avoid the occurrence of localities with modern terrain changes in our area of interest, sometimes we have to deal with alterations directly in the closest surroundings of a castle or chateau. In that case, there are essentially three ways of solution. First, we can utilise the tools of procedural modelling software described in the next section and adjust the terrain manually. Furthermore, GIS filters can be deployed to align larger terrain changes. Lastly, we can decide not to use up-to-date terrain models and depend on the height information contained in old maps, e.g. in the State Derived Map (contour lines) whereby we must be aware of significantly lower accuracy of such data. In our case, the first solution have been sufficient so far due to minor nature of terrain alterations.

Pre-processed cadastral maps (3.2), are usable in two ways. First, they can be "glued" onto terrain models and serve as textures. Second, their vector form can be utilised as a basis for procedural modelling because it contains building footprints and information about the position of trees and other supplementary objects. Moreover, we also use a combination of these two options since not all of the maps are suitable for 3D visualisation purposes. Whereas, for example, the Imperial Imprints of the Stable Cadastre were painted very carefully and their true-like colours enable them to be used directly in a semi-photorealistic visualisation, the State Derived Map is, except for contour lines, "only" a precise binary representation of topography. Therefore, the latter mentioned map is first vectorised and these vector data are, after true-like associated colour symbolisation, converted back to the raster form.

3.4. Procedural and CAD modelling

Meanwhile, we use two different approaches to the creation of 3D scenes. The ESRI CityEngine procedural modelling tool and the Trimble SketchUp 3D CAD are employed to model 3D scenes of the closest surroundings of chateaux and castles. On the other hand,

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Fig. 1. Point layer of subsidiary facilities in a domain (left) and vectorised Imperial Imprints of the Stable Cadastre (right, only buildings displayed, differentiated by material).

the QGIS open source GIS software with the Qgis2threejs library are utilised to generate 2.5D visualisations of whole domains (Fig. 2)

In this chapter, we start with the first mentioned approach. To generate a 3D scene in CityEngine, four basic data sources are necessary – a digital terrain model, an old map for its texturing, footprints of buildings and, which is of utmost importance, a set of CGA procedural modelling rules, according to which a model of a conurbation will be generated. To design a CGA rule file, old photographs and postcards were used since the appearance of buildings in the past can be determined from this image data. Colour images, in particular, were most valuable because they could be used as a template for creating textures for facades and roofs of buildings, although, given their age, they had mostly been coloured additionally. As we deal with a large number of chateaux and castles in our project, several urban landscapes should be generated, which are located in different regions of the Czech Republic where different architectural styles were used in history. Therefore, it is clear that not only one but more rule files have to be generated to be applicable in various regions. Nevertheless, because we aim to model common conurbations in a rather lower level of detail, we tried to design one fundamental rule file from which slightly different sets of rules would be derived for each landscape modelled.

Procedural modelling with the use of the CGA shape grammar, implemented in CityEngine, works on the principle of progressive refinement/replacement of shapes. Speaking of buildings, building footprints are usually basic shapes. In this case, the first rule typically involves the extrusion of the basic shape to a certain building height. Then, the faces of the resulting body are separated into facades and roof. Furthermore, facades are split into walls and openings and a roof is created (flat, hip, shed, etc.). The last step of this process consists in placing texture images on appropriate faces. Speaking in general, one less precise shape is always replaced by several more precise shapes, which, in the result, creates a tree of shapes diagram.

In Fig. 3, there are two examples of rule files utilised within our research. The diagram above shows an original approach to procedural modelling while only an excerpt is depicted since the whole derivation tree is too much branched to fit into the picture. This rule file is most suitable for modelling based on the Imperial Imprints of the Stable Cadastre because it exploits the differentiation of building materials contained in this map series. Thus, building footprints can be separated into three categories. Buildings which are marked on maps as "flammable" were mostly agricultural buildings made of wood. "Non-flammable" buildings were better quality houses made of brick or stone and finally "significant" buildings were the most important landmarks (labelled as "heritage buildings" in our rule files). In the original rule file, all footprints are separated accordingly and then, for all three categories separately, buildings are created in the manner described in the previous paragraph. This approach might be more consistent with the principles of the CGA shape grammar because a clear structure of derivation is evident, but it involves extensive branching of the derivation tree. Since we do not require a high level of detail and the three categories of buildings are eventually distinguished mainly by different textures, this approach is too complex for our purposes.

The rule file in Fig. 3 below represents a simplified yet identical results giving approach currently used for our purposes. The differentiation of building footprint rules was deleted and thus the resulting appearance of buildings is only ensured by the corresponding attributes. This approach is simpler to understand for 3D modellers who have to adapt the rules for a particular chateau or castle area and who are also students involved in our project. All attributes which are used to distinguish the building appearance are shown on the left. These attributes are at first chosen randomly from the values which express the common appearance of buildings in a particular region (roofing, type of roofs, etc.). In addition, all attributes are designed to be changeable manually and thus after generating the buildings, users can adjust the final appearance of 3D scenes to match with archival photographs and postcards.

Using the CGA rule file explained afore, 3D models of buildings are generated and they are placed onto the terrain model covered with an old map as a texture. Furthermore, with the use of simpler rule files, also models of trees can be positioned, which appropriately completes the appearance of the urban landscape in history.

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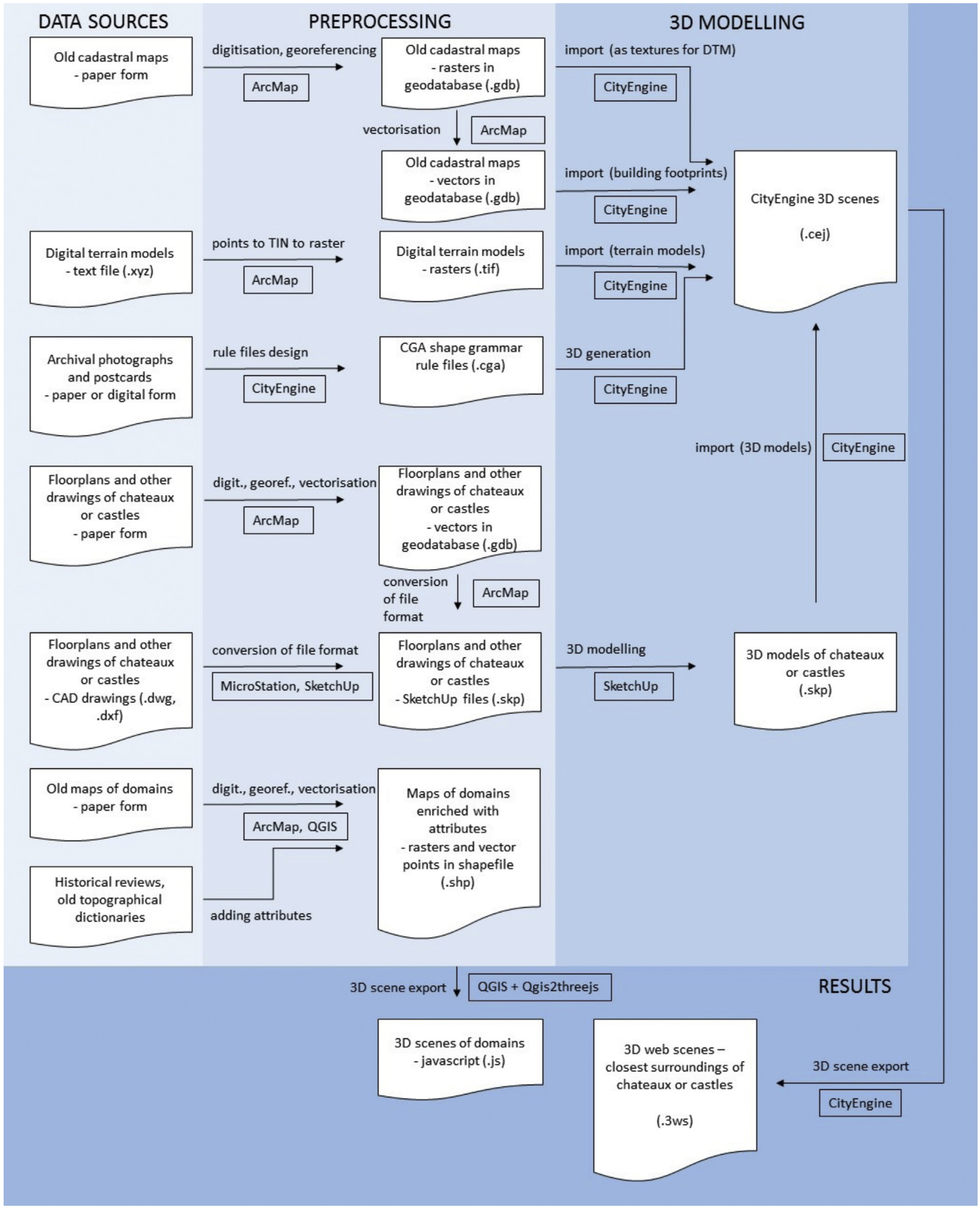

Fig. 2. The workflow of 3D landscape model's creation.

Nevertheless, the models of the most important landmark buildings – chateaux or castles still have to be added. As in the case of complex landmark buildings, whose appearance is unique, it would not be effective to use procedural modelling, we use classical CAD software for the purpose of their 3D reconstruction. Currently, we employ mainly the popular Trimble SketchUp application, but we also use Bentley MicroStation for processing drawings obtained in a digital form. The resulting 3D model is transferred into the CityEngine 3D scene with the use of the KMZ file format.

The main prerequisite for choosing particular castle or chateau area to be modelled is the sufficient presence of data sources, i.e. architectural drawings describing the building. These drawings can be up-to-date or historical and reconstructed time periods are chosen accordingly to ensure the credibility of results. This obviously means that the historical appearance of specific chateaux or castles cannot be modelled on the basis of modern drawings if significant changes have been made until today. Nevertheless, as most of the buildings of our interest completed their architectural

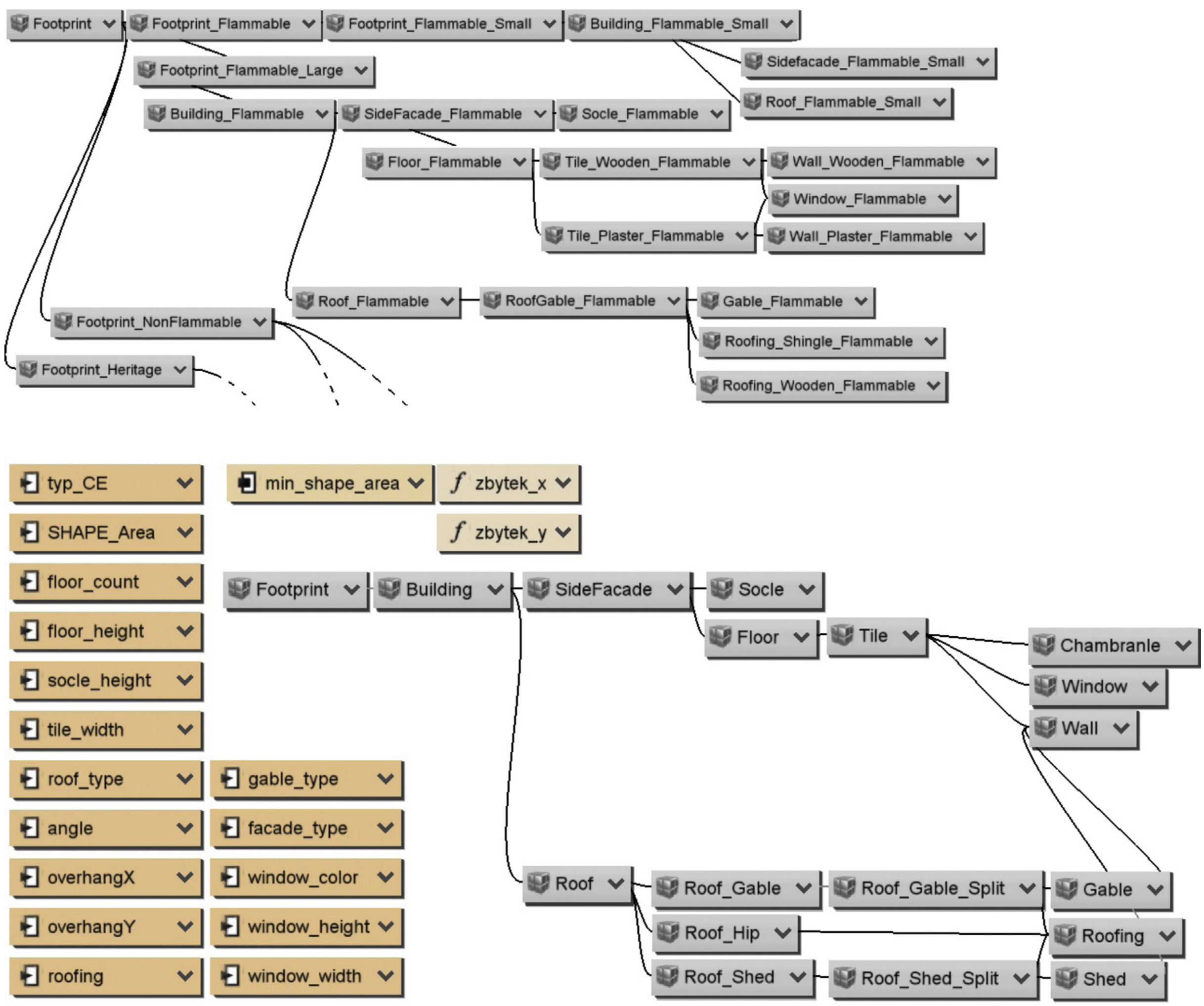

Fig. 3. Excerpt from the original rule file (above), the set of rules currently utilised (below).

development before the 19th century, we have to deal mainly with minor changes of structures and often rather with the change of facade colours. Therefore, we mostly do not use up-to-date photographic textures for whole facades but we rather colour particular building parts with textures prepared in CAD software in accordance with historical sources and archival photographs. Hence, we would be able to model even buildings which no longer exist in the same manner – the only limiting factor is the presence of drawings and eventually suitable photographs to estimate appropriate colours.

4. Results and discussion

4.1. Outputs

Currently, we have three types of outputs of our workflow. The most detailed results of our research are semi-photorealistic 3D scenes of the landscape character in the closest surroundings of chateaux and castles (see Fig. 4). The scenes were created with the aforementioned combination of the CityEngine procedural modelling tool and the SketchUp 3D CAD. All buildings in the scenes were placed according to the footprints contained in old maps. The placement of trees was also guided by old maps and, when possible, it was checked with historical orthophoto. 3D contents are supplemented with directly-in-scene embedded historical photographs. All photographs are accompanied with attributes, such as title, description of photographed objects, author, year of capturing, archival source, item number in inventories, URL of photo in full resolution or links to information systems of the National Heritage Institute.

As the second output we can consider scenes that present changes of conurbation in time. Within these scenes, users can compare three to four different 3D models – one for each time period for which we can obtain old maps. Models of buildings are created only schematically and no random values are used. For example, the heights of buildings were set to one approximate value and no textures were added. This assures that users will not identify changes where we cannot determine from historical photographs that a change really happened. Both of the two aforementioned types of results are currently published as 3WS web scenes via ArcGIS Online and thus they are available to the general public with HTML5 and WebGL compatible browsers (Fig. 5).

Lastly, we produce 2.5D scenes of whole domains based on maps of domains, historical reviews and on the maps of the 2nd Military Mapping Survey. As mentioned in Section 3.2, all important subsidiary facilities found within each domain were vectorised as point layers. Therefore, we can show these points on a digital terrain model with an old map as a texture. Thus, users can observe the topographic situation, including height conditions in a domain and the distribution of subsidiary facilities depending on the situation. All subsidiary facilities are divided into the following groups: farming estates, forestry, food industry, religious buildings,

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Fig. 4. 3D scene of closest surroundings of a chateau (see directly-in-scene embedded photographs).

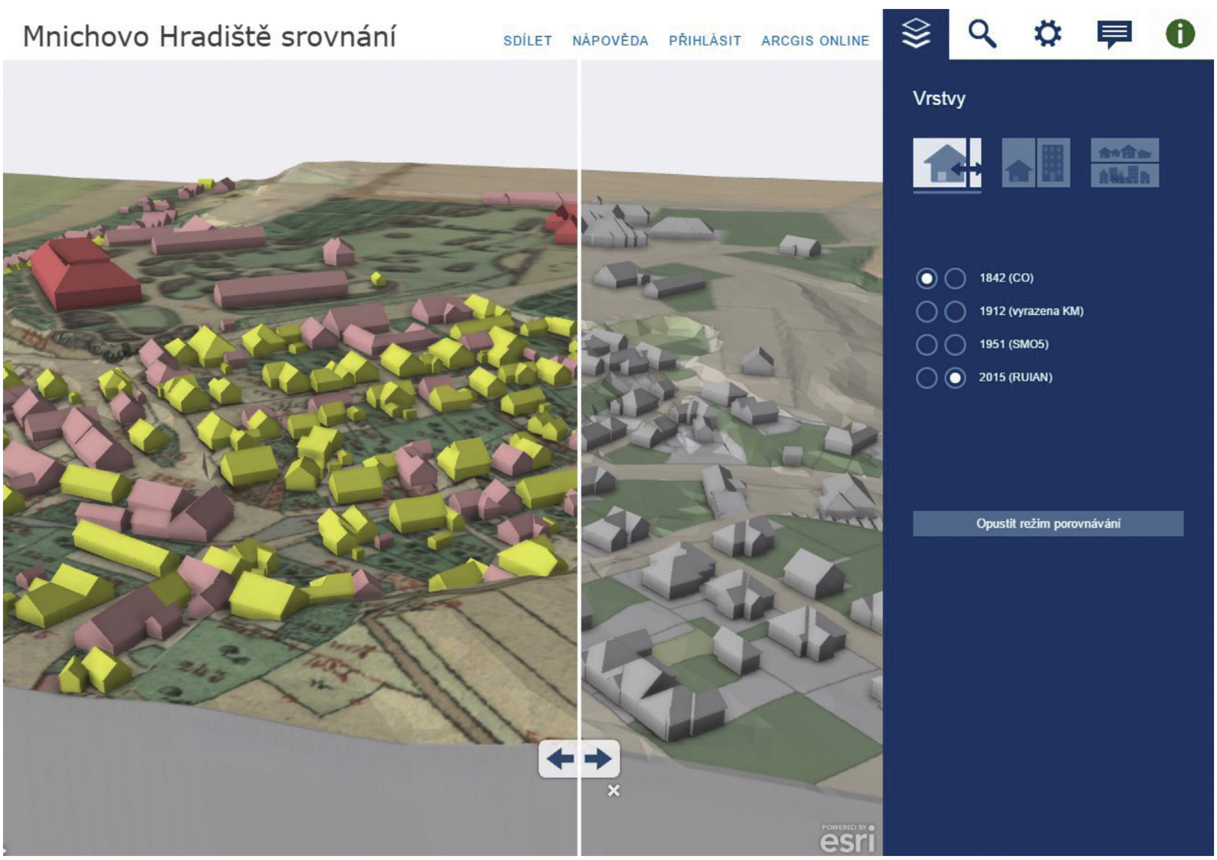

Fig. 5. A 3D comparison of conurbation in different time periods based on old maps.

residential and administrative buildings, settlements, socio-cultural facilities, mining, water management, and manufacturing and processing. Localisation of particular facilities is determined by 2D symbols always facing the camera (see Fig. 6) while these symbols are selected from the same map key which is used in the 2D web mapping application. The scenes showing whole domains are generated with the use of the open-source QGIS tool and with the Qgis2threejs library. After exporting, the resulting scene in JavaScript can be embedded into a web page and viewed by all compatible web browsers. All point representations of facilities retain their attributes which can be browsed within the resulting scene (name, type of facility, group, source, etc.).

The deployed technology of web scenes is different from the presentation of 2D contents in the aspect of data displaying. Whereas contemporary 2D map services allow us to download only data within our area of interest, 3D scenes have to be downloaded as a whole. This may take some time and is dependent on the extent of the scene and its level of detail and mainly on the complexity of landmark building models. In our case, with average or slower internet connection, we speak about tens of seconds. Not to bother

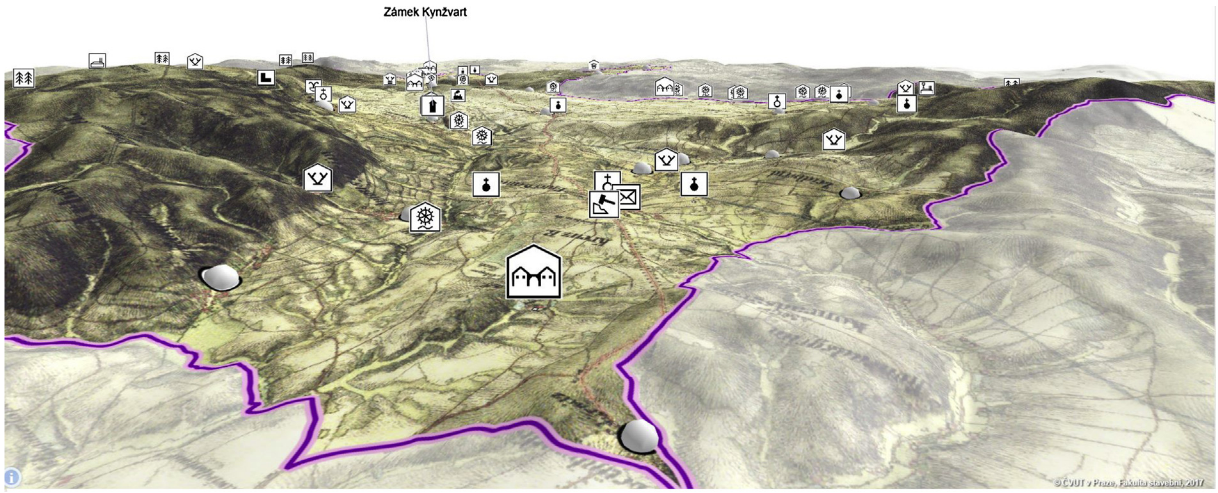

Fig. 6. 2.5D representation of a domain with subsidiary facilities and settlements. The purple line determines the boundary of the domain.

users with long waiting, we decided to publish each of the three results as a separate scene. Furthermore, this approach is necessary in the case of whole domains because they show completely different extent in a different scale/level of detail. However, users can access all three separate products from one menu which connects all 2D and 3D types of contents related to each castle or chateau.

5. Discussion

In general, it can be stated that the developed workflow have fulfilled our expectations and it has been an important tool for the purposes of rapid 3D modelling based on old maps. However, it must be clearly stated that we do not exploit all the possibilities of procedural modelling by far as our workflow is focused mainly on the transformation of 2D maps into the form of 3D landscape model and not as much on precise 3D geometry modelling. Thus, our models of common buildings are rather low detailed (approximately LOD2 in the language of the CityGML standard [27]) and we can write CGA rule files without extensive knowledge of architectural orders. In the case of modelling more complex architectures, it would be necessary to study relationships between particular building elements, e.g. by examining architecture books as recommended in literature [6]. This is in the case of complex landmark buildings created in external CAD software compensated by careful examination of data sources, i.e. drawings and structural-historical surveys.

The main advantage of procedural modelling reported in literature is time saving when creating complex models of large cities. This is paid back by the necessity of learning the language of utilised modelling tool and designing rule files in advance. Therefore, in our case of rather less detailed models, the profits may not seem so significant because an experienced modeller would create similar building models fairly quickly in a classical CAD tool. Nevertheless, we see the fundamental benefit in the possibility of fast adjustments of generated models. By a quick change of parameters we are able to make significant alterations of the resulting impression from the 3D virtual landscapes. This way, the average height of buildings or trees, prevailing type of roofing or the facade appearance can be quickly changed to match archival photographs. In a classical CAD software, this would be highly time consuming because modellers would have to change the look of each building or other modelled object manually.

Moreover, the inclusion of further details, additional refinement of geometry and change of textures are possible by changes made to the rule files and affect all buildings in a scene. Lastly, we have tried to design our rule files to be simple to understand and all important attributes (heights of buildings, trees, dimensions of windows, types and colours of roofing, etc.) are projected to be changeable for each building individually. Thus, we can also employ our students to generate the scenes and they can, with the use of historical sources, alternate the appearance of all objects (by changing the rule file) and also of each object separately (by changing the attributes).

On the other hand, even with careful editing, it is not possible to ensure that all modelled buildings will be similar to their real world counterparts. That is an understandable disadvantage of procedural modelling due to the fact that if we tried to reconstruct all buildings realistically, one by one, the advantage of time cost saving would disappear. Furthermore, the appearance of all buildings is not obtainable from 2D old maps and historical photographs only and random values are used to a large extent. Nevertheless, this does not constitute a problem for us as we try to reconstruct the appearance of landscape as a whole and are not so concerned with details. In addition, landmark buildings are modelled outside of procedural modelling, more detailed and in the consistence with historical reality.

The City Engine application and the CGA shape grammar seem to be the most mature tools for procedural modelling of architecture today. Other tools found in our review are rather individual solutions of research groups suitable for specific purposes. As we are familiar with the automatization of functions in Trimble SketchUp with the use of Ruby API, we considered the usability of this mechanism for our purposes. Although several tasks would probably be feasible, the creation of complex scenes on the basis of detailed terrain models looks to be far beyond the capabilities of this simple CAD software. Since CityEngine has been owned by the GIS software giant ESRI for several years, using the CGA grammar means to be less or more dependent on the rather expensive commercial solution. On the other hand, it also implies that CityEngine is designed well to be in compliance with data coming from GIS/digital cartography software. Moreover, it is not required to use ESRI software to process 2D data and prepare inputs into 3D modelling and free and open-source GIS systems, such as QGIS, can be utilised instead. Finally, to rely less on commercial solutions, we decided to create our 2.5D scenes of whole domains without the use of procedural modelling software and completely with the use of open-source

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Table 1
The summary of pros and cons of procedural modelling with the CGA shape grammar in the context of the 3D reconstruction of historical landscape appearance.

Advantages	Relatively rapid creation of extensive 3D scenes Possibilities of fast adjustment of generated models by change of parameters Re-usability of rule files for all our scenes Compatibility of used software with outputs of digital cartography tools
Disadvantages	Not all particular virtual buildings are similar to their real-world counterparts At least basic scripting skills are required to create CGA rule files The utilisation of CGA is dependent on commercial and relatively costly software

technologies. For the recap of advantages and disadvantages of the chosen approach see Table 1.

6. Conclusions and future work

In this article, we have presented a workflow of 2.5/3D modelling focused on interactive scenes showing the surroundings of Czech chateaux and castles. With this workflow, we do not aim to create an immersive photorealistic environment because this is rather a matter of computer science professionals. On the contrary, we try to rapidly generate simple 3D visualisations which are based on already pre-processed data sources intended for a classical 2D web mapping application. The presentation of these data sources (i.e. old maps and historical photographs), which belong to cultural heritage as well, should open the results of our research to the general public. Thus, even users who are not experienced in reading maps should visualise the urban landscape character in history.

The scenes presented in this article are the first 2.5/3D trial outputs of our workflow. In the coming days, we would like to use our workflow for other selected chateaux and castles. The more photorealistic 3D scenes (the first presented output in Section 4.1) are currently published without building attributes. However, our plan is to implement attributes for all significant buildings in a scene to achieve an even higher level of information value. Meanwhile, we have chosen a rather lower level of detail for the creation of 3D building models due to the fact that we have to model conurbations in various regions of the Czech Republic. To achieve higher detailed models it would be advisable to cooperate more closely with experts from the field of architecture to determine more precisely the actual appearance of buildings in particular regions throughout history.

3D scenes of selected castles and chateaux will be gradually added to the project websites: http://gis.fsv.cvut.cz/zamky/ where there are also available all types of 2D results.

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