

3D DIGITAL RECONSTRUCTION OF DEFUNCT RURAL BUILDINGS BASED ON ARCHIVAL SOURCES

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ABSTRACT

This paper deals with the specifics and working procedures for 3D digital reconstructions of defunct and altered buildings of vernacular architecture. Primarily, the resulting 3D models are intended to serve for general lay public in order to present and popularize vernacular architecture and for educational activities. Secondly, they can be used by professional public for the same purposes. The models are based on archival sources - archival 2D metric survey documentation (drawings and photographs), written sources. Another requirement is the possibility of presentation on the internet within a parallel developing web platform. SketchUp 2021 Pro software, extended by plug-ins, is used for the 3D modelling process.

KEYWORDS

3D modelling, Cultural heritage, Ethnology, SketchUp, Vernacular architecture, Virtual Open-air Museum

INTRODUCTION

Immovable cultural heritage monuments are important evidence of the development of human society in history. Just like in the past, these monuments around the world are threatened by devastation by human activity - war, terrorism, vandalism, changes in the social and cultural environment; as well as the forces of nature - weather conditions, fires, etc. For many immovable cultural monuments, it is too late, i.e. they were destroyed or defunct in the past. In some cases, it is possible to virtually reconstruct and visualize the destroyed monument using digital technologies. Various examples of destroyed cultural monuments and their subsequent 3D digital reconstruction are described in the professional literature.

A monument has been destroyed completely (1), but archival sources are available, see e.g. the Great Buddha of Bamiyan in Afghanistan[1] or the Great Bel Temple in the archaeological site of Palmyra in Syria[2]. A monument has been destroyed completely (2), but archival sources are available, and its immediate surroundings can be measurably documented, see e.g. the minaret of the Umayyad Mosque in the ancient city of Aleppo[3] or the civic tower of Sant' Alberto in Italy[4]. A monument has defuncted partially (3), while the existing torso can be measurably documented, see e.g. the Siegesburg Castle in Bad Segeberg in Northern Germany[5] or the ruins of Zvířetice Castle in Bakov nad Jizerou in the Czech Republic [6].

In addition to representative historical buildings of national importance, such as sacral buildings (churches, synagogues, mosques), mansions (castles and chateaux) or town buildings (town halls), the development of human society is also well captured in vernacular architecture. Vernacular architecture usually served immediate local needs and was limited by materials available in a particular area, thus reflecting local traditions and cultural practices. Traditional vernacular

architecture was mostly self-built, i.e. without the contribution of formally educated architects. Furthermore, it was usually based on the design skills and tradition of local builders[7]. In the environment of the Czech Republic, vernacular architecture has been a classic subject of interest for ethnology and other humanities, such as the history of art and architecture, for many decades[8–16].

Research on vernacular architecture is often based on surveys of existing rural buildings that are typical of a particular region. These surveys may be of different nature depending on their purpose and the erudition of researchers[17–19]. If time and money are available, it may be advantageous to use 3D laser scanning in combination with Close-range photogrammetry[20]. In the case of area research of vernacular architecture, it may be advantageous to use Geographic Information Systems (GIS)[16,21]. In the worst-case scenarios, this may be the last form of metric survey documentation of a building before its demise. In better case scenarios, the acquisition of metric survey documentation of the building is the first step towards its revitalization, e.g., in Open-air Museums[22,23], which have a long tradition in the cultural environment of the Czech Republic (since the end of the 19th century).

This paper deals with the specifics and working procedures for 3D digital reconstructions of defunct and altered buildings of vernacular architecture. Primarily, the resulting 3D models are intended to serve for general lay public in order to present and popularize vernacular architecture and for educational activities. Secondly, they can be used by professional public for the same purposes. Due to the fact that the application of modern computational methods to historical metric survey documentation allows its critical evaluation and reinterpretation in the context of current knowledge[24], it is possible to base the creation of 3D models on archival sources – archival 2D metric survey documentation (drawings and photographs), written sources. Another requirement is the possibility of presentation on the internet within a web platform developing in parallel.

VISKALIA – Virtual Open-air Museum of Vernacular Architecture

The project aims to (1) rescue the source of plans, drawings, and photographs of vernacular architecture in the Czech Republic which contain original ethnological data about the form, function and identity importance of vernacular architecture before its transformation into museum buildings, and (2) enable innovative access to this source by the public within a single platform. The implementation of the stated general objectives of the project will achieve the following[25,26]:

- a) Creation of the Virtual Open-air Museum of Vernacular Architecture (VISKALIA) which will cover basic thematic, typological and geographic variability of this architecture in the Czech Republic. The VISKALIA will become a basic tool for studies and popularization of vernacular architecture in the online environment and electronic media and will be useable in education and training focused on issues related to cultural heritage.
- b) Creation of a specialized public database and map outputs including plans and photographs and other documentation of vernacular architecture at the level of the Czech Republic, complemented by a maximum amount of ethnographic, historical and spatial metadata.
- c) Access to the information on vernacular architecture by the public through an exhibition and publications.
- d) Preservation and digitization of specific collection and archive sources of The Institute of Ethnology of the CAS and National Museum.

In the Viskalia project, 3D digital reconstructions of up to fifteen models of selected village architecture buildings are planned. To achieve this, complete background data will be collected, i.e. maps, plans, photographs, drawings, which are preserved in digitized collections, and which also represent (regionally, functionally, architecturally) the basic regional house types from the territory

of the Czech Republic. Models will be created with CAD tools, or BIM. In appropriate cases¹, the models will be supplemented with photographic surface textures. For the creation of 3D models, the basic criterion of the Level of Detail was determined, i.e. the resulting model must have visibly important and regionally specific structural elements of the building. The building models will be placed on a local digital terrain model in their immediate vicinity, to get a better idea of their relationship to neighbouring buildings, or to the given village settlement.

MATERIALS AND METHODS

In this section, the types of base materials are introduced. Their use is shown in 3D digital reconstructions of several models of completely or partially defunct or altered buildings of vernacular architecture. The used working procedures are also presented.

Archival sources

In our case, the archival sources consist mainly of metric survey documentation, which originated in the first half of the 1940s during the Protectorate of Bohemia and Moravia within its then borders. The so-called "Surveying event" was organized by the Czech Academy of Sciences and Arts and was attended by architects (a group of the Association of Architects) and students of closed universities, as well as students of the Vocational School of Applied Arts in Prague. Fieldworks yielded more than 2,000 sheets of plans, sketches and drawings of vernacular architecture, especially timbered buildings. Thanks to this event, research work in connection with the scientific interest in vernacular architecture and its values for the national cultural heritage could continue in the Protectorate period[8,27]. Another important source of information is the professional literature, that deals with vernacular architecture and reflects the scientific background in this field for the cultural environment of the Czech Republic[9–16,23].

The available archival metric survey documentation usually contains, considering the time of its creation, a relatively complex set of drawings, but its quality and completeness is variable. In general, complex 2D and 3D metric survey documentation should ideally operate on the principle of connected vessels. It should be possible to create a 3D model from the complex 2D metric survey documentation with the same Level of Detail as the underlying drawings. It should be possible to create a set of drawings from the 3D model, i.e. complex 2D metric survey documentation, in the same Level of Detail as the underlying 3D model. A comprehensive set of drawings should include at least:

¹ E.g. to improve the visual presentation of surface finishes of used building materials.

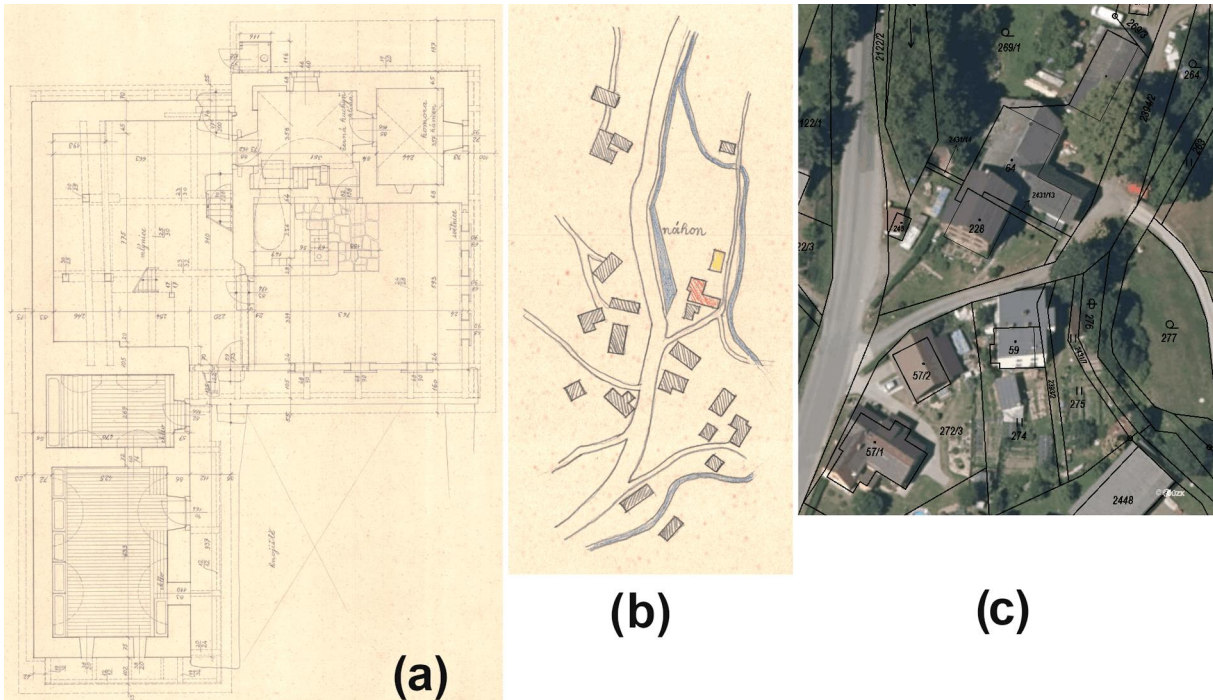


Fig. 1 – Example of archival floor plan (a) and comparison of archival situational sketch (b) with current cadastral map and aerial orthophoto (c), Kundračice, Semily District, Czech Republic

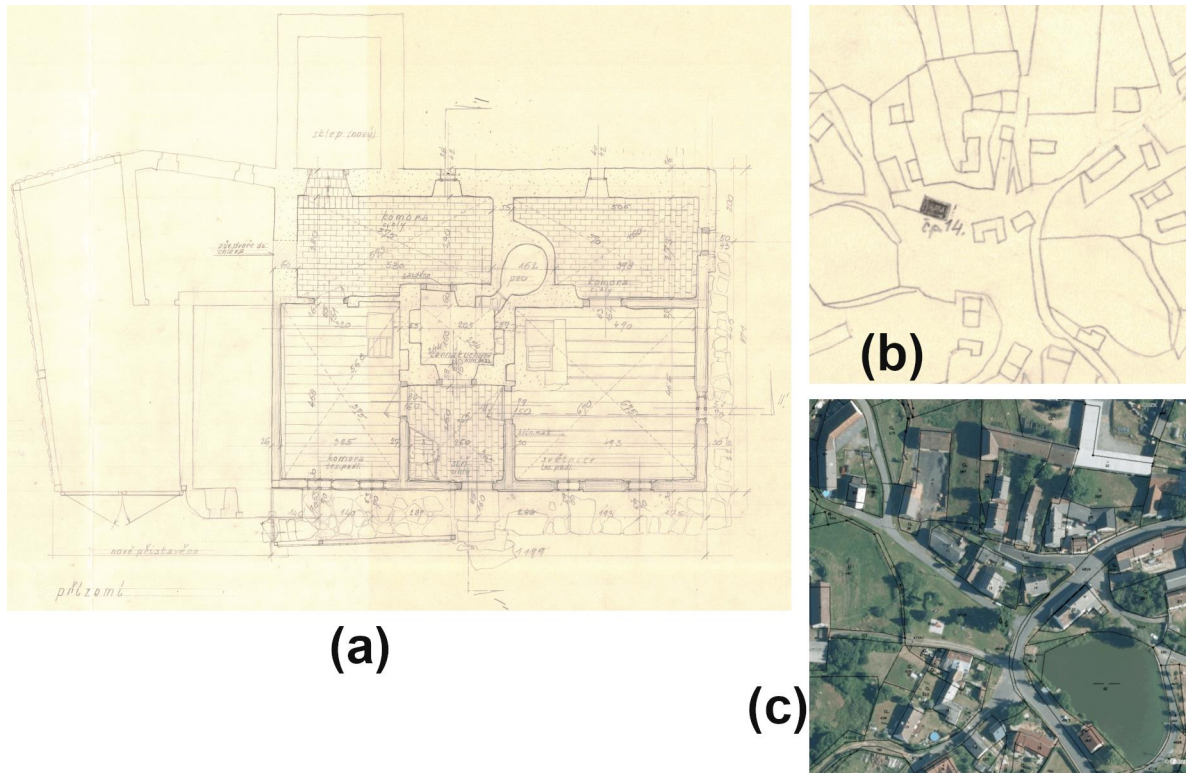


Fig. 2 – Example of archival floor plan (a) and comparison of archival situational sketch (b) with current cadastral map and aerial orthophoto (c), Petrovice, Domažlice District, Czech Republic

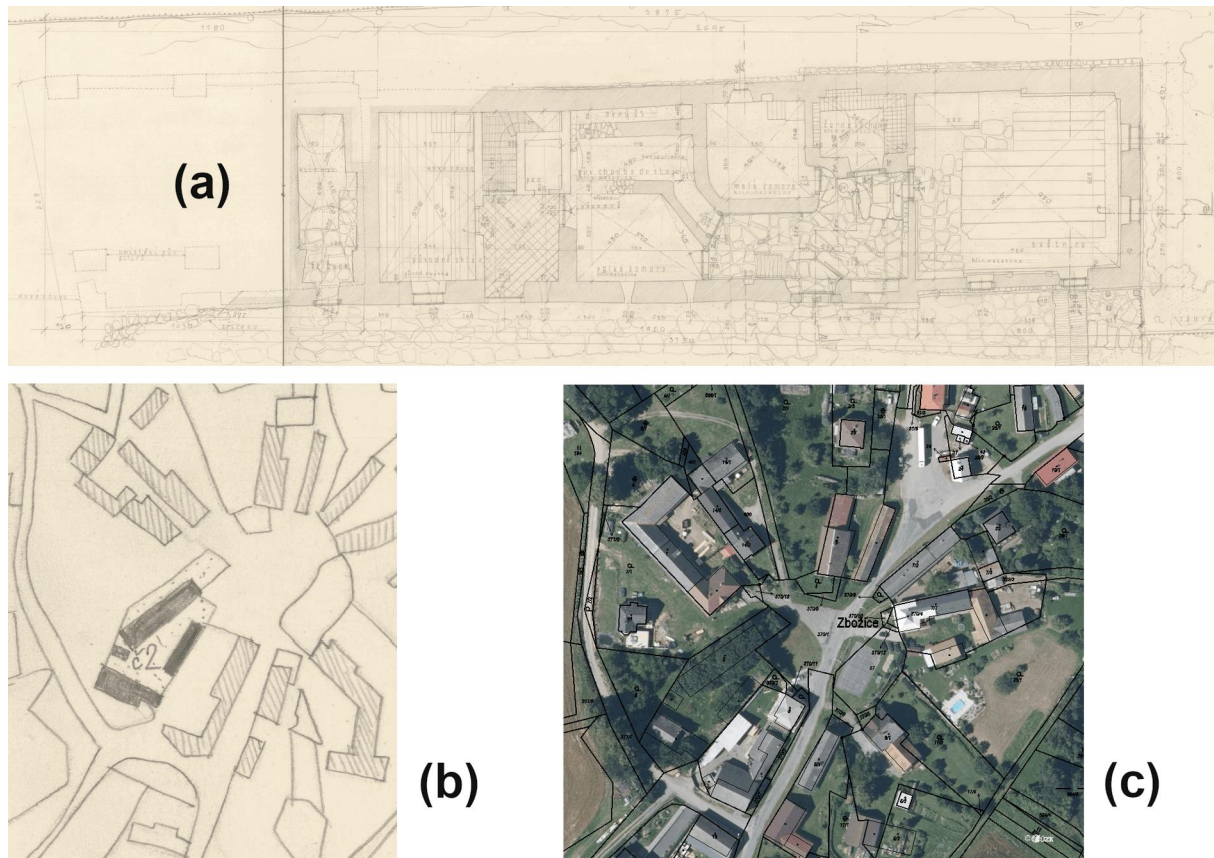


Fig. 3 – Example of archival floor plan (a) and comparison of archival situational sketch (b) with current cadastral map and aerial orthophoto (c), Zbožice, Havlíčkův Brod District, Czech Republic

1. Floor plans – should depict each floor of the building, including the attic with a depiction of the truss structure.
2. Vertical cuts – should depict the structure at least in a longitudinal and a transverse cut
3. Views – should depict views of individual facades, they can be effectively replaced by photographs.
4. Additional documentation – may contain exterior and interior photographs, situation plans, etc.

However, the archival metric survey documentation, which in this case serves as a starting point for 3D modelling, was not created for the purpose of spatial reconstruction of surveyed buildings. Logically, this leads to situations where the data lack spatial relationships, which is important to know during the process of 3D modelling. Then, these imperfections of archival plans must be supplemented from other information sources, usually based on analogies from other case studies.

For the exact geographical location of reconstructed buildings, archive situation plans or cadastral maps and current cadastral maps in combination with aerial orthophotos can be successfully used. In the current cadastral maps, the original boundaries of the plots are often still drawn, i.e. also perimeters of defunct buildings. These "echoes of the past" make it possible to locate the reconstructed buildings and determine their orientation towards the cardinal directions. Examples are shown in Figures 1–3.

The first building in Kundratice² (Figure 1) exists and is a protected monument. However, before the surveying in the 1940s, part of its construction disappeared, i.e. the so-called refrigerator for the mill wheel. The second building in Petrovice³ (Figure 2) also exists. The basic mass is preserved, but it is assumed that there have probably been partial modifications to its construction. The third building in Zbozice⁴ (Figure 3) has been destroyed. It was an enclosed village homestead with several buildings, see Figure 3, (b). I.e., a residential building in the north (Figure 3, (a)), cowshed in the east, a separate cellar, and a barn in the south. Examples of 3D models of reconstructed buildings are presented in Figures 6-8.

The process of 3D reconstruction

SketchUp 2021 Pro software^[28] was chosen and used for the creation of 3D models. It can be used in many fields, especially in construction, and allows intuitive work directly in 3D space, where it allows quick creation of models and their presentation. Plug-ins available for this software can be a useful aid in 3D modelling in SketchUp. Following our pilot study^[29], we mostly use the following plug-ins:

- CleanUp³ – used to clean the model, e.g. from unnecessary edges or duplicate areas^[30]. It contains a relatively wide range of elements that can be cleaned in the 3D model.
- RoundCorner – used to modify the edges of 3D objects, i.e. allows their bevelling or rounding^[31]. It can be used, for example, to round the corners of the wall or to model the oval mass of the furnace, see Figure 4.
- TopoShaper – allows you to generate terrain from contours or from a point cloud. In our work, the possibility of creating terrain from a point cloud was used^[32]. The plug-in generates terrain using Delaunay triangulation, with the network point density changing with altitude. The algorithm smoothes triangulation until the terrain is smooth enough. The smoothing angle can be set.

Historical constructions in the layers of the 3D model

For the 3D modelling process, a general system of 3D model layers based on the typology of historical building structures^[13] was designed. The proposed system consists of twelve layers into which the individual building structures are divided. The system was designed so that when the visibility of individual layers is turned off and on, it is possible to comfortably view the entire model (especially the interior). It was also necessary to consider the fact that vernacular architecture can be very diverse in the number of used building structures. The structure of the proposed system can therefore be easily extended, e.g. according to used building material, floor-levels, etc., or simplified, e.g. for the purpose of presentation on the internet. The proposed system is described in detail in Table 1.

² Due to capacity reasons, the complete archive documentation could not be attached to the article, which is available from: http://zamerovaciakce.eu.cas.cz/tlokalita_popis.php?jmeno=&kr=Libereck%C3%BD&ok=Semily&lo=Kundratice&cp=60&trej=MIS

³ Due to capacity reasons, the complete archive documentation could not be attached to the article, which is available from: http://zamerovaciakce.eu.cas.cz/tlokalita_popis.php?jmeno=&kr=Plze%C5%8sk%C3%BD&ok=Doma%C5%BElice&lo=Petrovice&cp=14&trej=MIS

⁴ Due to capacity reasons, the complete archive documentation could not be attached to the article.



Fig. 4 – Example of using RoundCorner plug-in – existing object (left) and its 3D model (right)

Tab. 1: Comparison of historical structures and layer system for 3D model of a reconstructed building

ID	Historical construction	Layer name	Examples of layer naming
1	Walls - stone or brick	Walls	Walls_perimetric_material_floor-level
	Wooden walls		Walls_interior_material_floor-level
	Clay and Layered clay		
	Surface finishes		
2	Floors and tiles	Floors	Floors_material_floor-level
3	Ceilings	Ceilings	Ceilings_material_floor-level
	Vaulting		Ceilings_vaulting_material_floor-level
4	Staircases	Staircases	Staircases_material_floor-level
5	Railings and bars	Railings	Railings_material_floor-level
6	Roof trusses	Roofs	Roofs_trusses_material_floor-level
7	Roof covering		Roofs_covering_material_floor-level
8	Doors and gates	Doors	Doors_material_floor-level
9	Windows	Windows	Windows_material_floor-level
10	Terrain surface etc.	Terrain	Terrain_floor-level
11	Heating	Chimneys	Chimneys_material_floor-level
12		Furnaces	Furnaces_material_floor-level
-----	Ventilation, water and waste regime	-----	-----

Phases of 3D modelling

The creation of each 3D model consists of several phases. In all phases of 3D modelling in the SketchUp environment, it is advantageous to pay attention to the correct orientation of the surfaces⁵.

In the first phase, a 2D floorplan of the building is vectorized in the initial working plane of the 3D model. Then, the floorplan is pulled into the space according to the height dimensions. In this way, the perimeter and interior walls are created. This is followed by the creation of floorings on the ground-floor. When creating floorings, it is important to find out whether the individual rooms on the ground-floor are height-shifted relative to each other. If so, it is necessary to take this into account when modelling the walls and floors on the ground-floor. This work process is also repeated when modelling other floor-levels of the building up to the attic-floor.

In the second phase, beams and a truss system are modelled. When modelling these parts, it is worth using clustering of surfaces into groups or components. This allows elements to be easily copied and prevents unwanted editing of already finished parts. The trusses are followed by the modelling of the roof and gables. The roof is usually created by a simply pulled-out surface, which is complemented by a texture according to the actual roofing of the building. Shields (squares) are often made of individual planks. The individual planks can be modelled separately or, to maintain the spatial impression, selected areas that represent the individual planks can be slightly pulled out or recessed. Another way to give the impression of a shield formed by individual boards is to use colours to create narrow spaces between imaginary boards and assign a different shade to them. This approach can also be used for the creation of timbered walls.

In the third phase, some elements of interior equipment and other types of structures are modelled, such as stairs, black kitchen equipment, furnaces, vaults, etc. These elements are usually only indicated in the archival plans, and for their modelling it is necessary to use other sources, such as existing period photographs of objects or professional literature dealing with vernacular architecture.

Due to the fact that in our case modellers⁶ are not at the same time erudite architects or historians, the process of 3D modelling is based on cooperation of modellers with the staff of the Institute of Ethnology CAS. In this phase, the appearance of the reconstructed building is continuously revised and compared with analogous studies to capture the period appearance of the building as best as possible. Thanks to the consultations, it is also possible to resolve ambiguities arising from the imperfection of archival plans. This may be associated with additional modifications to previously modelled constructions.

In the fourth phase, digital terrain in the immediate vicinity of the building is modelled. For this purpose, Digital Terrain Model of the Czech Republic of the 5th generation (DMR 5G)^[33] is used. ArcGIS Pro software^[34] is used for editing and formatting DMR 5G data containing the given territory. Data editing consists of (1) import into ArcGIS Pro, (2) cropping of data to the required area, i.e. the nearest neighbouring building, and (3) export to DXF format. Then, data in DXF format are (4) imported into SketchUp software, where the TopoShaper plug-in is used.

In the fifth phase, a presentation of the 3D model on the internet is performed, which is to be implemented within a parallel-developed web platform. This process usually requires tailoring the 3D model to the used environment for the web presentation. In this case, it was a topological

⁵ In SketchUp itself, the opposite orientation of the surfaces does not cause problems, but oppositely oriented surfaces can cause problems when exporting to other data formats, which are used for subsequent presentations of models on the internet. In SketchUp, it is possible to assign textures to both sides of any surface.

⁶ I.e. creators of specific 3D models.

cleaning⁷ of elements in the 3D model, or their geometric generalization, and the selection of suitable textures.

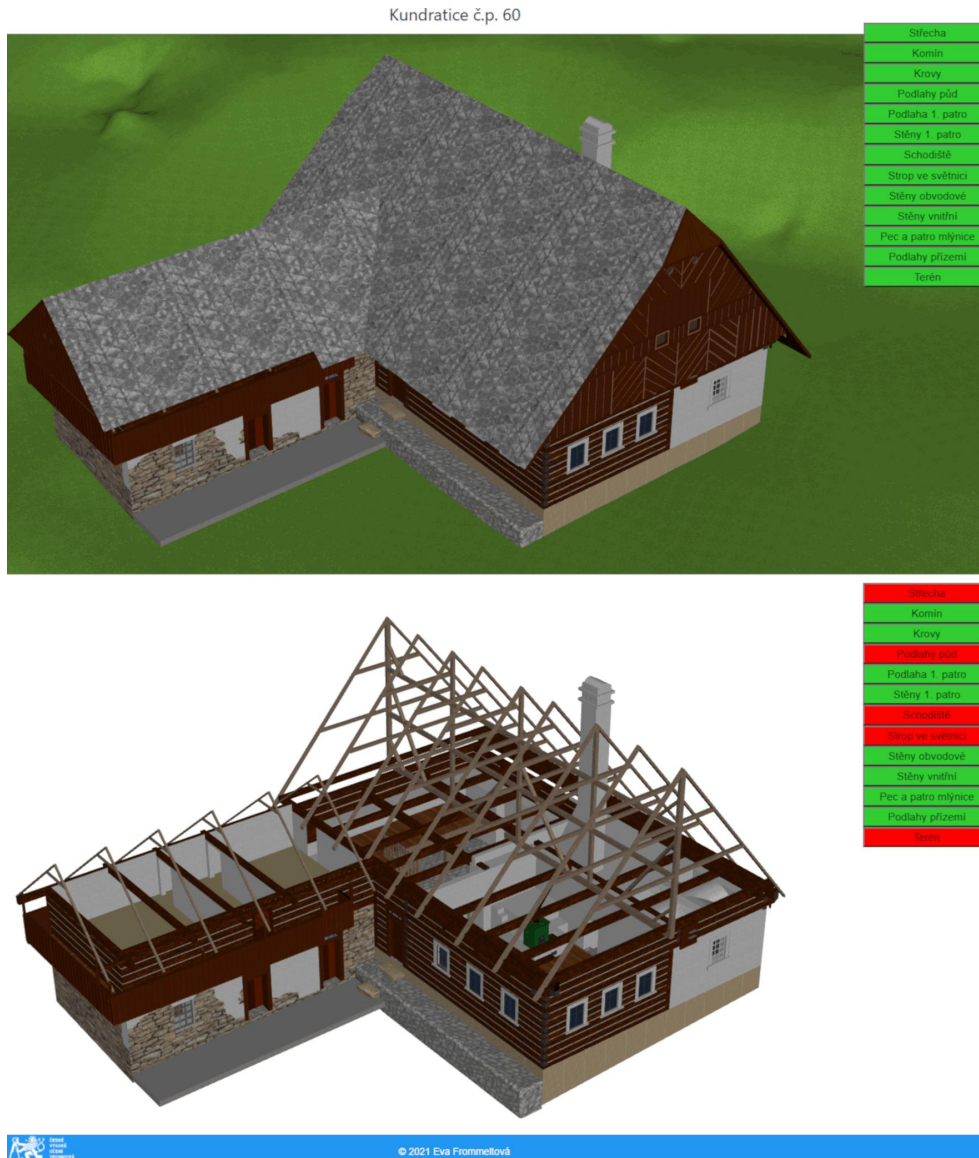


Fig. 5 - Example of visualization of 3D model in DAE format in Three.js interface including panel for displaying layers (in Czech language) – with all layers (top) and with selected layers activated (bottom)

Various technologies have been tested for visualization and presentation of the 3D model^[29]. It is assumed that WebGL technology^[36] will be used for 3D presentation on the internet, using the freely available JavaScript libraries Three.js^[37] or Babylon.js^[38], or using Coper Cube software^[39]. Using one of these tools, interactive scenes should be created that allow the user to view the digital 3D model directly in a web browser. To view the exterior and interior of the building, the scenes must

⁷ Within the 3D modelling process, the topology is understood in the same way as in the creation of maps, i.e. as “defining the structure elements of geosystems based on their relationships connectivity (interconnection) and continuity (relative positions); map elements create topological structures consisting of nodes, edges, and walls”.^[35]

include a panel that allows individual layers of the 3D model to be turned on and off. An example of this solution is shown in Figure 5.

Another software used for visualization and presentation could be Lumion software^[40], in which panoramic images of the object can be created. From the created images, it is possible to create a virtual tour complemented with text. The freely available Marzipano^[41] JavaScript library can be used to create a tour.

RESULTS AND CONCLUSION

As part of the Viskalia project, several defunct buildings of vernacular architecture have already been reconstructed. Examples of three specific digital 3D models are shown in Figures 6 - 8 in the Appendices section. These figures present ongoing work results, their final form will be adapted for web presentation. In particular, the colour and textures of 3D models are currently illustrative, their final form is still under development.

The resulting 3D models digitally reconstruct the appearance of selected rural buildings based on preserved archival sources. The Level of Graphic Detail of 3D models corresponds to the Level of Detail of archive drawings. Details and finishes of building structures were usually modelled on the basis of views-plans or period photographs. In situations where archival metric survey documentation did not provide enough spatial information for 3D modelling, building structures and elements were modelled on the basis of analogous studies and customs of vernacular architecture. The resulting 3D models meet the specified criterion of level of detail in the introduction, i.e., the resulting model must have visibly important and regionally specific structural elements of the building. The models also represent (regionally, functionally, architecturally) selected regional house types from the territory of the Czech Republic.

This paper describes the specifics and working procedures for digital 3D reconstructions of defunct and altered buildings of vernacular architecture, which were realized within the project Viskalia. Primarily, the resulting 3D models are intended to serve for general lay public in order to present and popularize vernacular architecture and for educational activities. Secondly, they can be used by professional public for the same purposes. That is why they are based on archival sources - archival 2D metric survey documentation (drawings and photographs), written sources. The process of digital 3D reconstruction of each building is based on cooperation of modellers with the staff of the Institute of Ethnology CAS. The appearance of the reconstructed building is continuously revised and compared with analogous studies to capture the period appearance of the building as best as possible. Thanks to the consultations, it is also possible to resolve ambiguities during 3D modelling, which are the consequences of imperfections of archival plans. The resulting 3D models are made so that they can be presented on the internet within a parallel-developed web platform.

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REFERENCES

- [1] Gruen, A., Remondino, F., & Zhang, L. (2002). *Reconstruction of the great Buddha of Bamiyan, Afghanistan*. <https://doi.org/10.3929/ETHZ-A-004655538>
- [2] Wahbeh, W., Nebiker, S., & Fangi, G. (2016). COMBINING PUBLIC DOMAIN AND PROFESSIONAL PANORAMIC IMAGERY FOR THE ACCURATE AND DENSE 3D RECONSTRUCTION OF THE DESTROYED BEL TEMPLE IN PALMYRA. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, III-5, 81–88. <https://doi.org/10.5194/isprs-annals-III-5-81-2016>

- [3] Pavelka, K., Šedina, J., Raeva, P., & Hůlková, M. (2017). MODERN PROCESSING CAPABILITIES OF ANALOG DATA FROM DOCUMENTATION OF THE GREAT OMAYYAD MOSQUE IN ALEPPO, SYRIA, DAMAGED IN CIVIL WAR. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W5*, 561–565. <https://doi.org/10.5194/isprs-archives-XLII-2-W5-561-2017>
- [4] Bitelli, G., Dellapasqua, M., Girelli, V. A., Sbaraglia, S., & Tinia, M. A. (2017). HISTORICAL PHOTOGRAMMETRY AND TERRESTRIAL LASER SCANNING FOR THE 3D VIRTUAL RECONSTRUCTION OF DESTROYED STRUCTURES: A CASE STUDY IN ITALY. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-5/W1*, 113–119. <https://doi.org/10.5194/isprs-archives-XLII-5-W1-113-2017>
- [5] Deggim, S., Kersten, T. P., Lindstaedt, M., & Hinrichsen, N. (2017). THE RETURN OF THE SIEGESBURG –3D-RECONSTRUCTION OF A DISAPPEARED AND FORGOTTEN MONUMENT. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W3*, 209–215. <https://doi.org/10.5194/isprs-archives-XLII-2-W3-209-2017>
- [6] Dvořák, V., Novák, V., & Šanda, M. (2017). *Zvířetice 3D intro*. <https://www.youtube.com/watch?v=7faRMvVWRhk>
- [7] Wikipedia. (2021). Vernacular architecture. In *Wikipedia, the free encyclopedia*. https://en.wikipedia.org/w/index.php?title=Vernacular_architecture&oldid=1051057511
- [8] Motyčková, D., & Sedlická, K. (2006). Činnost Národopisné komise při České akademii věd a umění v období protektorátu a její přínos k rozvoji oboru. In J. Pospíšilová & J. Nosková (Eds.), *Od lidové písni k evropské etnologii: 100 let Etnologického ústavu Akademie věd České republiky* (pp. 124–132). Etnologický ústav AV ČR Praha, pracoviště Brno ve spolupráci s Jiřím Plockem.
- [9] Langer, J. (1997). *Co mohou prozradit lidové stavby: Lidové stavební tradice v severozápadních Karpatech a jejich kulturní funkce* (Vyd. 1). Ready.
- [10] Mencl, V. (1980). *Lidová architektura v Československu*. Academia.
- [11] Vařeka, J., & Frolec, V. (2007). *Lidová architektura: Encyklopedie* (2., přeprac. vyd.). Grada.
- [12] Škabrada, J. (1999). *Lidové stavby: Architektura českého venkova*. Argo.
- [13] Škabrada, J. (2003). *Konstrukce historických staveb*. Argo.
- [14] Škabrada, J., & Ebel, M. (2014). *Chalupy v Čechách na historických stavebních plánech*. Argo.
- [15] Pešta, J. (2003). *Encyklopedie českých vesnic: Vesnické památkové rezervace, zóny a ostatní památkově hodnotná vesnická sídla v Čechách*. Libri.
- [16] Pešta, J. (2014). *Area research into vernacular architecture and rural settlements* (Professional and methodical publications). National Heritage Institute.
- [17] Kmošek, J., Křenková, Z., & Bryol, R. (Eds.). (2016). *The Survey and Documentation of Vernacular Architecture Monuments* (1st ed.). Valašské muzeum v přírodě v Rožnově pod Radhoštěm, Spolek archaických nadšenců.
- [18] Mira, J. A., Bevià, M., & Giner, J. (2020). CASTALLA (ALICANTE, SPAIN) VERNACULAR ARCHITECTURE: USE, LOSS, OBLIVION AND MEMORY. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIV-M-1-2020*, 73–80. <https://doi.org/10.5194/isprs-archives-XLIV-M-1-2020-73-2020>
- [19] Poloprutský, Z. (2018). METRIC SURVEY DOCUMENTATION AS A BASIS FOR UNDERSTANDING THE DEVELOPMENT OF RURAL ARCHITECTURE. *Stavební Obzor - The Civil Engineering Journal*, 27(1), 48–59. <https://doi.org/10.14311/CEJ.2018.01.0005>
- [20] Castilla, F. J., Ramón, A., Adán, A., Trenado, A., & Fuentes, D. (2021). 3D Sensor-Fusion for the Documentation of Rural Heritage Buildings. *Remote Sensing*, 13(7), 1337. <https://doi.org/10.3390/rs13071337>
- [21] Domínguez-Ruíz, V., Rey-Pérez, J., & Rivero-Lamela, G. (2020). Contribution to the Knowledge of Cultural Heritage via a Heritage Information System (HIS). The Case of “La Cultura del Agua” in Valverde de Burguillos, Badajoz (Spain). *Sustainability*, 12(3), 1141. <https://doi.org/10.3390/su12031141>

- [22] Wikipedia. (2021). Skansen. In *Wikipedia, the free encyclopedia*. <https://en.wikipedia.org/w/index.php?title=Skansen&oldid=1042162712>
- [23] Langer, J. (2005). *Evropská muzea v přírodě: Atlas památek*. Baset.
- [24] Balletti, C., & Guerra, F. (2015). The survey of cultural heritage: A long story. *Rendiconti Lincei*, 26(S1), 115–125. <https://doi.org/10.1007/s12210-015-0411-8>
- [25] Technology Agency of the Czech Republic. (2021). *VISKALIA – Virtual open air museum of the vernacular architecture*. TA ČR Starfos. <https://starfos.tacr.cz/en/project/DG20P02OVV003>
- [26] Herman, D. (2017). *Rozhodnutí Ministerstva kultury o přijetí projektů ve 2. Veřejné soutěži ve výzkumu, experimentálním vývoji a inovacích na rok 2018*. Ministerstvo kultury ČR. https://www.mkcr.cz/doc/cms_library/1-rozhodnuti-mk-o-prijeti-a-vyrazeni-z-vs-2018-7635.doc
- [27] Etnologický ústav AV ČR. (2021). *Databáze Zaměřovací akce ČAVU*. <http://zamerovaciakce.eu.cas.cz/>
- [28] Trimble. (2020). *SketchUp Pro Software: Create 3D Model Online*. SketchUp. <https://www.sketchup.com/products/sketchup-pro>
- [29] Frommeltová, E. (2021). *Virtual open-air museum—Presentation of models of rural buildings* [Master thesis, CTU in Prague, FCE, Department of Geomatics]. <http://hdl.handle.net/10467/96107>
- [30] ThomThom. (2021). *CleanUp³*. SketchUp Extension Warehouse. <https://extensions.sketchup.com/extension/046175e5-a87a-4254-9329-1acc37a5e21/clean-up>
- [31] Fredo6. (2021). *RoundCorner v3.3a*. SketchUcation. <https://sketchucation.com/plugin/1173-roundcorner>
- [32] Fredo6. (2021). *TopoShaper v2.6a*. SketchUcation. <https://sketchucation.com/plugin/716-toposhaper>
- [33] Czech Office for Surveying, Mapping and Cadastre. (2010). *Geoportal ČÚZK: Access to map products and services*. <http://geoportal.cuzk.cz/>
- [34] ESRI. (2021). *ArcGIS Pro. 2D, 3D & 4D GIS Mapping Software*. <http://www.esri.com/software/arcgis-pro>
- [35] Terminological Commission of the Czech office for Surveying, Mapping a Cadastre. (2020). *Terminological Dictionary of Geodesy, Cartography and Cadastre*. Terminological Dictionary of Geodesy, Cartography and Cadastre. <http://www.slovníkcuzk.eu/>
- [36] Wikipedia. (2021). WebGL. In *Wikipedia, the free encyclopedia*. <https://en.wikipedia.org/w/index.php?title=WebGL&oldid=1045854911>
- [37] *Three.js: JavaScript 3D Library*. (2021). <https://threejs.org/>
- [38] *Babylon.js*. (2021). <https://doc.babylonjs.com/>
- [39] Ambiera. (2020). *CopperCube: Free easy to use 3D engine*. <https://www.ambiera.com/coppercube/>
- [40] Act-3D. (2021). *Lumion 3D Rendering Software: Architectural Visualization*. <https://lumion.com/>
- [41] *Marzipano: A 360° viewer for the modern web*. (2021). <https://www.marzipano.net/index.html>

APPENDICES

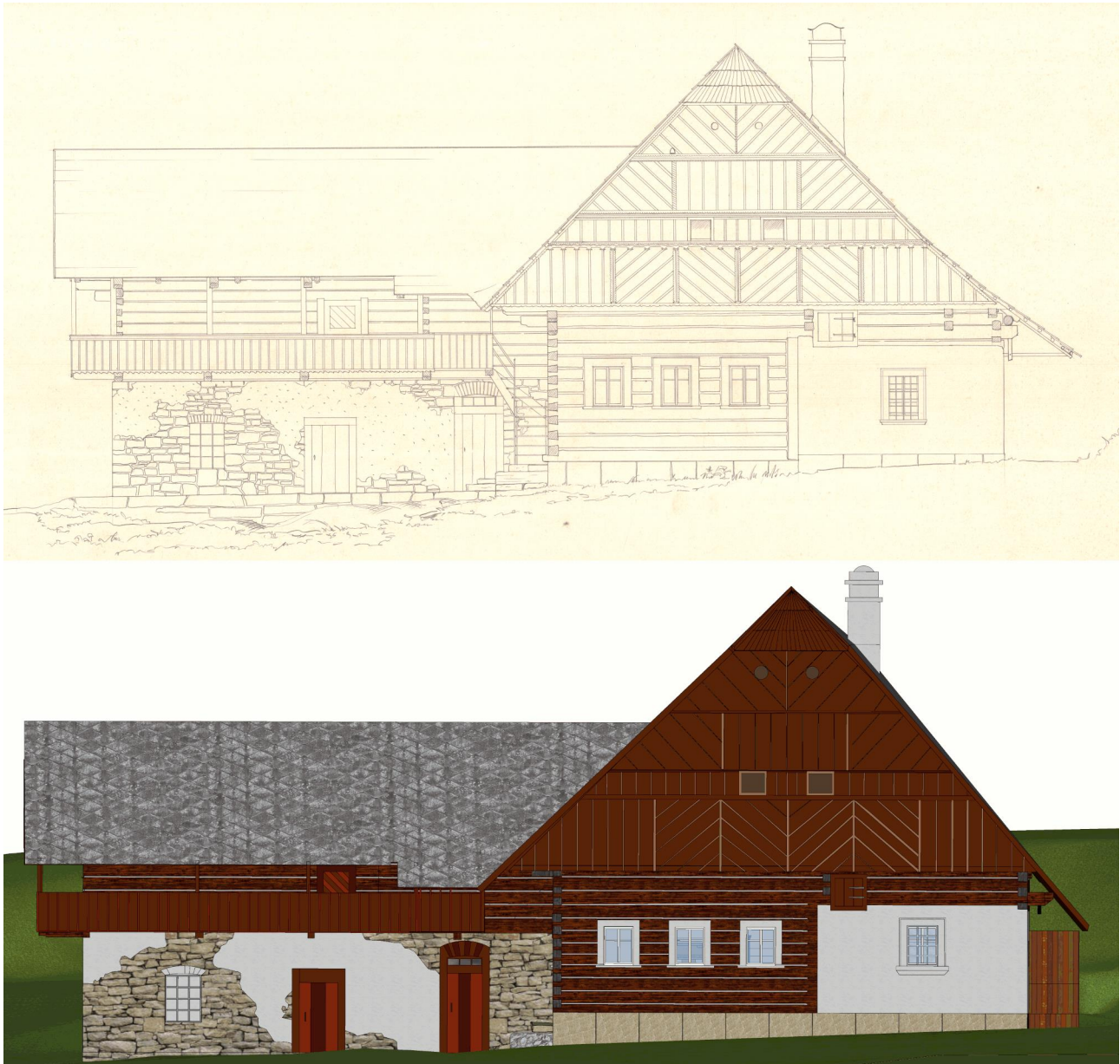


Fig. 6 - Comparison of the archival plan (above) with the corresponding view in the 3D model (below), Kundratice, Semily District, Czech Republic

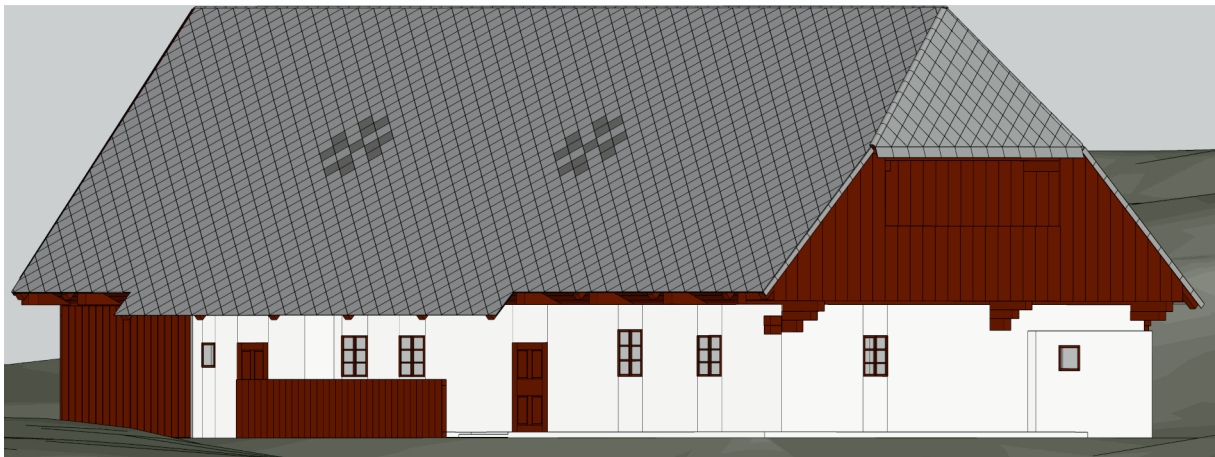


Fig. 7 - Comparison of archive photography (above) with the corresponding view in the 3D model (below), Petrovice, Domažlice District, Czech Republic

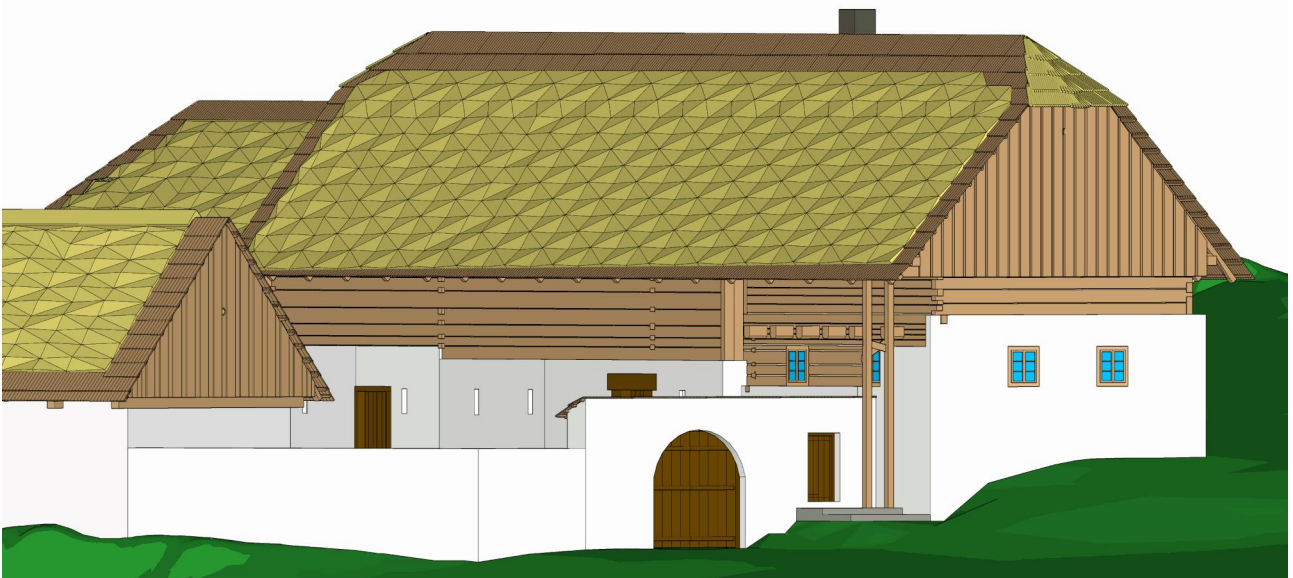


Fig. 8 - Comparison of archive photography (above) with the corresponding view in the 3D model (below), Zbožice, Havlíčkův Brod District, Czech Republic