HUNGARIAN ARCHAEOLOGY
E-JOURNAL • 2024 WINTER
www.hungarianarchaeology.hu

DIGITAL SURVEYS AND RECONSTRUCTIONS OF THE FRANCISCAN FRIARY AT VISEGRÁD, HUNGARY.

Examples of the history of computer-aided reconstructions of medieval buildings in Hungary

Gergely Buzás[1] – András Fehér[2] – József Laszlovszky[3] – Balázs Szőke[4]
Hungarian Archaeology Vol. 13. (2024) Issue 4, pp. 27–38. https://doi.org/10.36338/ha.2024.4.2

The first computer-aided reconstructions of a Hungarian medieval building complex were created thirty years ago. The digital recreation of the cloister vault and the cloister walk of the Franciscan friary were part of the first Hungarian project aimed at creating a theoretical and visual reconstruction based on the preserved carved stones of a medieval building using computer-aided methods. This anniversary offers now an opportunity to summarise the development of the last thirty years and show the new possibilities of digital technologies and the methodological issues that emerged in the recent excavations of the friary.

Keywords: Visegrád, Franciscan friary, Gothic architecture, 3D reconstruction, *anastylosis*, CAD model

Digital technologies, 3D reconstruction, and the use of 3D scanners appeared relatively early in the archaeological investigations of medieval Visegrád, particularly of the Royal Palace. The most important phases and results of these projects and the related methodological issues were recently discussed in two studies (Fehér 2024a; 2024b). Therefore, this paper provides an overview of how these technologies have been used in the survey and the digital modelling of the Franciscan friary and its church, the Church of St. Mary, in Visegrád for the last three decades. This overview is also relevant because, while medieval building design and the related issues of theoretical reconstruction have been discussed in the scholarly literature, the history of digital solutions remained out of focus (Fehér & Halmos 2015, 251; Jobbik & Krähling 2023). The most recent results of such projects will be published soon.

THE FIRST DIGITAL RECONSTRUCTIONS

The first reconstruction of the Franciscan friary in Visegrád was created by Gergely Buzás and Mária Réti in 1989 as part of an image showing the palace complex as it likely looked at the time of the reign of King Matthias (*Fig. 1*). The drawing, made with black ink on tracing paper, was already published in 1990, and it was included in several studies in the early 1990s (Buzás 1991, 101; Buzás & Szőke 1992, 153, 13. kép). This drawing was made based on the results of archaeological excavations led by Miklós Héjj in 1983 and by Mátyás Szőke in 1989, which also served as a starting point for György Szekér in reconstructing the ground plan of the palace and the friary complex. This ground plan was presented in the first publication of the excavations of the friary in 1994, together with his reconstruction of the ground plan of the net vault of the chapel (chapter house) (Buzás *et al.*

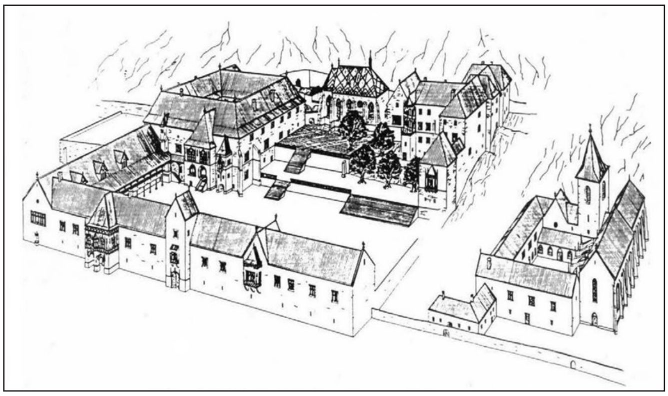

Fig. 1. Reconstruction drawing of the Franciscan friary in Visegrád (by Gergely Buzás and Mária Réti)

[1] King Matthias Museum, Hungarian National Museum, Visegrád; e-mail: buzasgergely@visegradmuzeum.hu, https://orcid.org/0009-0005-4378-5922
[2] 4iG/ Mensor 3D; e-,mail: ndrs.fhr@gmail.com
[3] Central European University, Vienna; e-mail: laszlovj@ceu.edu, https://orcid.org/0000-0003-2181-7610
[4] Gál Ferenc University, Szeged; e-mail: szokebalazs.boltozat@gmail.com, szoke.balazs@gfe.hu, https://orcid.org/0009-0004-3714-0696

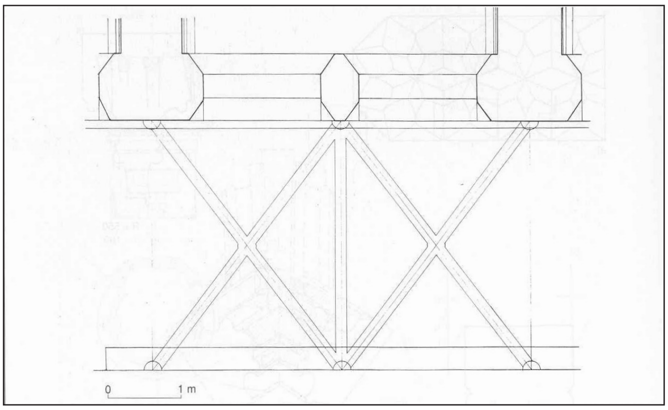

Fig. 2. Reconstructed ground plan of the cloister walk of the Franciscan friary (by Szilárd Papp)

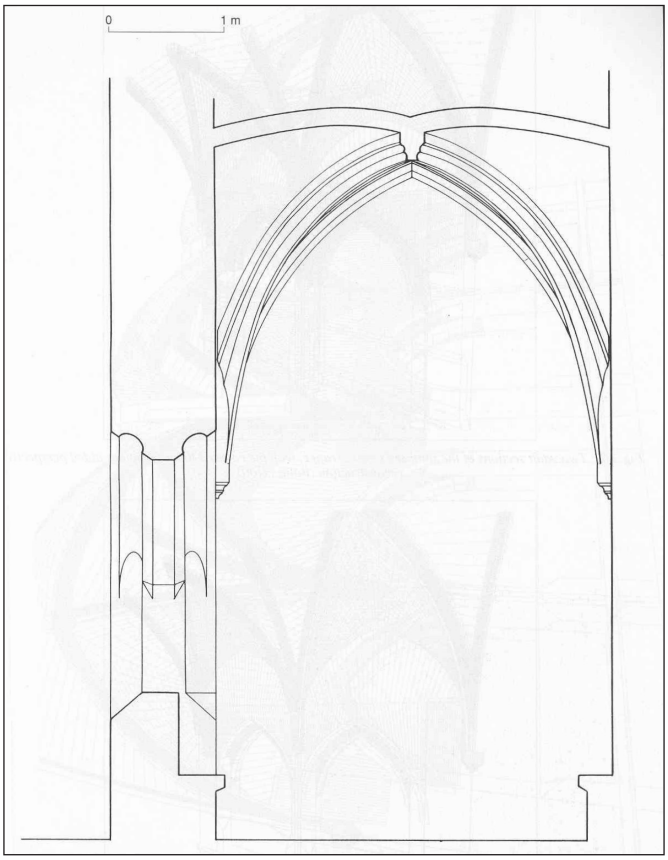

Fig. 3. Theoretical reconstruction of the vault of the cloister walk (by Szilárd Papp)

1994, 2/a–b. ábrák; 9. kép). The reconstruction drawings by Szilárd Papp of the structure of the cloister, with an orthographic projection of the openings and the vaulting of the cloister walk, were also published in that paper (Buzás *et al.* 1994, 18–20. képek). These features could be reconstructed because a significant part of the rising walls of the cloister had been preserved and was exposed by the excavations, and many of the Gothic carved stone elements of the collapsed vaulting (ribs, springers, and keystones) were also found on the floor of the cloister walk. The original positions of the springers in the surviving walls could also be determined, allowing the original height of the vault to be calculated (*Figs. 2–3*).

Computer programs offering digital tools for architectural design were already available in the early 1990s. However, these softwares were developed for designing modern architectural structures in the first place, while creating computer-aided 3D reconstructions of archaeological remains and surveying and presenting historical architectural structures using digital tools were less advanced and common. The pathbreaking volume edited by Colin Renfrew, considered the first forerunner of how digital technologies may be used to create archaeological reconstructions (Renfrew 1997), was not yet published back then. However, one of the first digital reconstructions of a medieval building has already been available, showing the potential of digital technologies by the example of the recreation of the monastic church of Cluny. This program was released in 1990, and its later versions presented the reconstruction of the enormous church of Cluny III. This project also had a significant impact on Hungarian research (Buzás 1995). Considering these examples, the excavated remains of the cloister of the Franciscan friary in Visegrád, with its carved stone material, seemed suitable for a 3D reconstruction, which was carried out by Balázs Holl (*Fig. 4*). This reconstruction was presented first in an article in 1995 (Holl & Laszlovszky 1995), and the results were also published in an English volume on the new investigations in Visegrád (Buzás *et al.* 1995, Fig. 201–204).

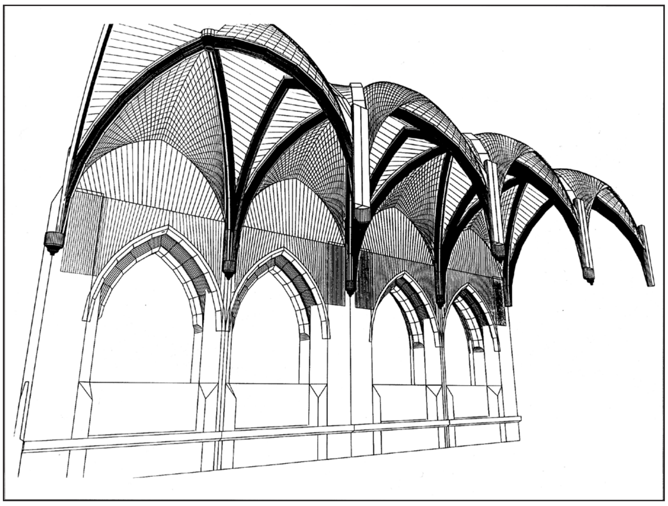

Fig. 4. Computer-aided reconstruction of the cloister walk of the Franciscan friary (by Balázs Holl)

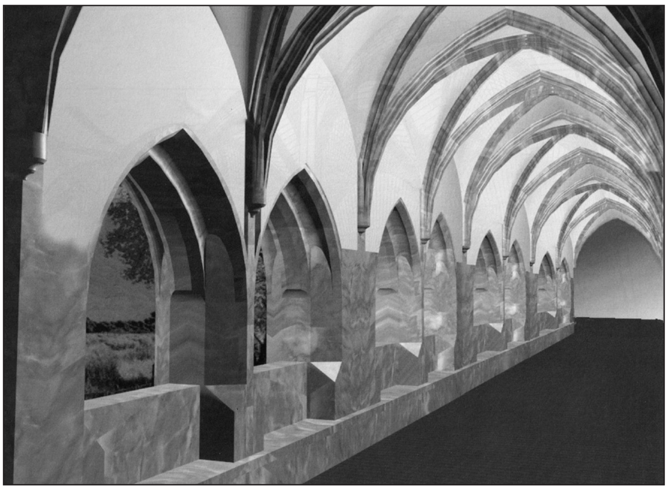

Fig. 5. Photo-like rendering of the computer-aided reconstruction (by Balázs Holl)

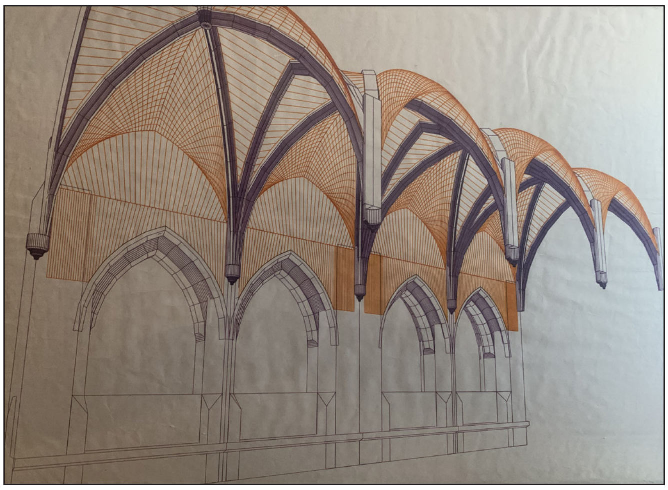

Fig. 6. Image of the computer-aided reconstruction produced with a plotter (Balázs Holl)

The 3D reconstruction model of the cloister was made from two-dimensional surveys with an HP 9000-735 workstation using AutoCAD R12. Its construction started with the rib profiles, the symmetry of which could be used in the following steps. The ribs were then moved and rotated to their original position in the ground-plan, thus creating a true spatial model of the vault's arcs. Relying on the symmetrical structure of the vault, first, a quarter of the cross vault was reconstructed, and the vaulting was built back from this 'building block' in the following step. The 3D reconstruction of the cloister walk was made by copypasting this single reconstructed vault unit, which reveals a lot about the technical possibilities offered by the digital tools of the time (as mentioned above, AutoCAD was not designed to present medieval architectural structures). While rendering, creating texture for surfaces and façades, and adding the natural environment to the cloister garth are all automated, built-in functions of a software today, back then, they had to be done manually 'from scratch' (*Fig. 5*). A drawing of a particular view of the 3D reconstruction of the vault, resembling more hand-made surveys than digital reconstructions, sheds another light on the very different digital support available in the era. This drawing was not printed but made using a plotter, a device creating vector graphics on paper using a pen by digitally moving the paper and the pen at the same time (to obtain multicolour drawings, one had to change the pens by hand). Many of these technologies are outdated today; accordingly, this image cannot be digitally recreated because the original file formats cannot be read, and programs cannot be run anymore. Therefore, the original drawing was scanned to be published here for the first time (*Fig.6*).

COMPLEX DIGITAL MODELS AND 3D RECONSTRUCTIONS

The building of a fully digital 3D reconstruction of the palace and the friary of Visegrád started in the second half of the 2000s in preparation for the exhibition entitled *Renaissance Visual Treasury* of the Hungarian National Museum, a programme of the *Renaissance Year* in 2008. As part of this work, Gergely Buzás created the first 3D model of the friary using Archline Xp CAD. The model only presented the main body of the building in the building phase, dated to the Jagiellonian Period (*Figs. 7–8*). A black-and-white version reworked by Narmer Ltd of this model was incorporated into the exhibition (*Fig. 9*) (Buzás, Orosz & Vasáros 2009, 177, 432, 437), and the first wooden models of the palace and the friary were also created based on it. The virtual

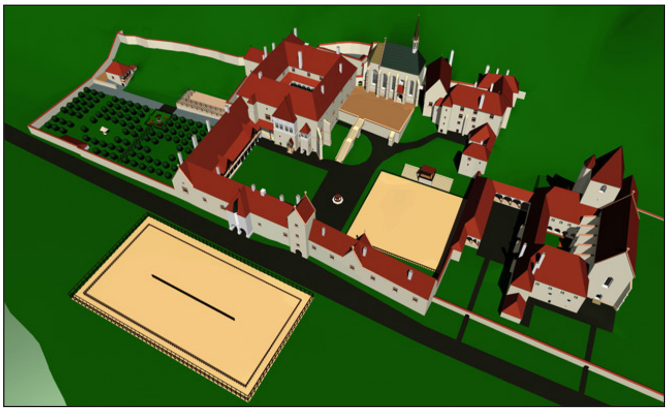

Fig. 7. The first digital reconstruction of the royal palace and the Franciscan friary (by Gergely Buzás)

Fig. 8. The first digital reconstruction of the cloister garth of the Franciscan friary (by Gergely Buzás)

Fig. 9. Computer-aided reconstruction of the Franciscan friary in the Renaissance Visual Treasury exhibition in 2008 (by Narmer Ltd)

Fig. 10. Digital reconstruction of the royal palace and the Franciscan friary in the animated film created by Narmer Ltd in 2010

model was developed in the following years, and in 2010, Gergely Buzás presented models of different building phases of the building complex, including the palace and the friary, with a 3D reconstruction of the friary's Sigismund Period building phase. These reconstructions were already textured and coloured (*Fig. 10*) in the animated video by Narmer Ltd on the royal palace of Visegrád. The same models were also published in the archaeological monograph on the palace (Buzás & Orosz 2010) and its English version published in 2013 (Buzás & Laszlovszky 2013).

SCANNERS AND DIGITAL PROCESSING

András Fehér and his team first started working on the site in 2013 as part of the SziMe3D AR research and development project. Later, the legal successor of the project, Mensor 3D Ltd, continued with the work, the primary aim of which was to explore the potential of state-of-the-art technologies in the preservation and presentation of cultural heritage. For this reason, several castles, palaces, and excavations were surveyed and digitised using terrestrial laser scanners, and the digital models of hundreds of valuable finds, artefacts in museum collections, and carved stones were created with structured-light 3D scanners. The work in the Franciscan friary in Visegrád was considered particularly important as the area had been regularly flooded before the con-

Fig. 11. Digital reconstruction of the royal palace and the Franciscan friary, 2017 (Pazirik Informatics Ltd)

struction of the dam protecting the town from the Danube. Although the floods were a destructive force, the sediment layers left behind by them covered and protected the ruins, thus contributing to their preservation.

Therefore, an application featuring this site was submitted to the Cyark 500 Foundation (USA), which supports projects aimed at surveying and digitising the world's most endangered heritage sites; the collected data is preserved for eternity in one of the world's most secure military bunkers. In October 2014, the project was informed that the Royal Palace of Visegrád, including the friary, have been added to the

Fig. 12. Digital reconstruction of the Franciscan friary, 2017 (Pazirik Informatics Ltd)

Fig. 13. Digital reconstruction of the church of the Franciscan friary, 2017 (Pazirik Informatics Ltd)

Fig. 14. Digital reconstruction of the cloister garth of the Franciscan friary, 2017 (Pazirik Informatics Ltd)

list of sites to be preserved. During the first surveys, the entire area of the friary was digitised using terrestrial laser scanners, and several elements of the vaulting (ribs, nodes, and keystones) were surveyed using object scanners.

The opportunity for developing more 3D models opened with the '*Visegrád of the Kings'* project, which included making a movie and an exhibition in 2017 and a book in 2018 (Buzás 2018). Within the frame of this project, Pazirik Informatics Ltd created more lifelike surface textures than ever before in the models of the Sigismund and Jagiellonian Period looks of the palace and the friary (*Figs. 11–14*). Another project starting in 2021, entitled *Renaissance of Visegrád*, enabled further improving the 3D model of the friary. In 2023, János Albert used the 3D scans of the friary by Mensor3D to enhance the digital model of the last building phase in ArchiCAD. His work brought novelties in the presentation of the inner spaces of the cloister walk in the first place (*Fig. 15*). The project also included new archaeological excavations in 2023–2024; the results of these call for further development of the 3D model in the near future.

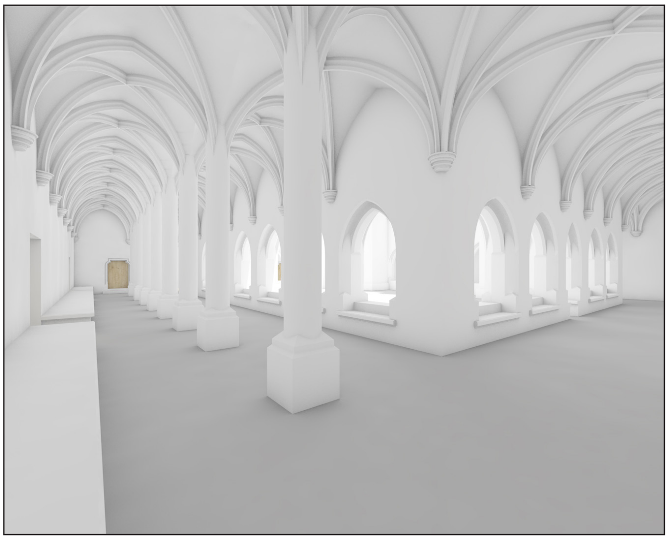

Fig. 15. Digital reconstruction of cloister walk of the Franciscan friary, 2024 (by János Albert)

POSSIBILITIES OF APPLICATION AND METHODOLOGICAL ISSUES

The previous research and development project has already yielded important, extensive, and comprehensive studies, including the '*Inventory and assessment of digitisation technologies in the protection for different objects and feature types*', '*Identification and selection of tools for the generation of pixel-based models calculated from perspective distortion and differences in viewpoint (photogrammetric methods)*', and '*A review of processing methods and software tools used in cultural heritage protection. Practical testing with documentation*'. The work carried out in the friary and the lapidary of the museum is often cited in these works as case studies. One of the outstanding advances of the project was the integration of the 'Eva' handheld scanner by Arctec, a Dutch company, with a rotary table (*Fig. 16*). This tool had been used extensively to digitise stone carvings during the archaeological excavation of the medieval cathedral of Kalocsa. Relying on the experience gleaned there, measuring could be semi-automated, thus speeded up considerably. When launched in 2012, 'Eva' with its software cost $21,200, and it was considered one of the best commercial devices (i.e. in the category below $50,000). According to the manufacturer, it can capture 18 million points per second at 16 FPS, with an accuracy of 0.2 mm. It is not an easy device to use (only a

Fig. 16. Scanning the carved stones of the friary using an 'Eva' scanner and a rotary table, 2013 (photo by András Fehér)

Fig. 17. Scanning the carved stones of the friary using a Breuckmann scanner, 2024 (photo by András Fehér)

skilled technician can operate it), as a fixed distance must be maintained from the surface of the object, and one must ensure that the device has enough time to process information from the scanned area, for which it must not be moved either too fast or too slow. Also, it is very sensitive to light conditions and the material of the object to be scanned. Optical scanners generally merge and stitch images from successive frames, continuously calculating the distance between the scanner and the object. In open spaces and strong sunlight, the device often 'loses' the object during scanning. In such cases, the operator is warned by light and sound signals. The software processing the measured data also has its knacks, which can only be learned by working with it for hours. This is why semi-automation, combined with a rotary table, has represented a major step forward. The Breuckmann scanner, a device that cannot be considered a manual scanner, although it also generates a model using the structured light technology, was also used in the surveys of the friary (*Fig. 17*). It was selected after a thorough market survey comparing and assessing forty different devices (SziMe3D AR). This scanner is mainly used in mechanical engineering, industrial quality assurance, and laboratories, but its 'creator' also recommended it for cultural heritage projects. It was applied in several major projects, including the scanning of Michelangelo's David, the Laocoön Group in the Vatican Museum, the Temple of Hadrian at Ephesus, and Angkor-style reliefs in Cambodia. A major Hungarian project should also be mentioned: the 3D reconstruction of the Temple of Zeus in Olympia, where the scanner proved useful (Patay-Horváth 2011).

The selected Breuckmann StereoScan-HE scanner uses 'Miniaturised Projection' for structured light scanning. With its two CCD cameras, each with a 3296 × 2472 pixel resolution (considered high at the time), the scanner could produce an eight-megapixel image within a few seconds. The lenses could be changed depending on the size of the target object. For example, an L-750-type lens with a 605 × 480 mm FOV (field of view), a 400 mm measuring depth, a 185 µm spatial resolution, and a 51 µm feature accuracy was chosen for the survey of the friary. These parameters were more than suitable for measuring stone carvings accurately. Measured data were processed using the OPTOCAT program developed by the manufacturer. This software can build models without guide points but needs human assistance to stitch the individual images. The generated models can be exported to all common 3D formats, allowing for a wide range of further uses.

An even more advanced scanner was purchased in a subsequent research and development project: a Hexagon Aicon StereoScan Neo R16, which features two 16-megapixel cameras (4864 × 2032 CCD) and multicolour LED projection technology. The parameters of its L-type lens are slightly better than of the previous device. Several optical systems were also purchased for this system to cover the widest possible range of tasks, from the high-precision scanning of small pieces of jewellery to digitising building parts.

Recently, solutions applying photogrammetry have also become important in such tasks. Although dozens of software packages facilitating the generating of 3D models from photos were available already a decade ago, the real breakthrough has come since. The potential of photogrammetry was also discussed in detail in the SziME3D AR research project: the physical principles behind the basics, the unwanted phenomena due to differences between cameras and lenses and their flaws, and the shortcomings of the processing software packages were analysed in numerous several-hundred-page studies. Only a few of the good software manufacturers of the time have survived to this day. Agisoft, a Russian company, is one of them; it has grown to be one of the most significant market players. Obviously, photogrammetry could not have become so widespread without major developments in the design and manufacture of cameras and lenses, the increase in the computing power of the processing hardware, the emergence of smartphones, which are excellent imaging tools by themselves, and the explosive development of processing software. Another factor that has contributed to the rise of photogrammetry is the willingness of younger generations to embrace technology and their ability to master the related skills. In addition to journals dedicated to photogrammetry, thousands of relevant studies can be accessed today in scientific databases on the Internet. We do not wish to take a position on whether handheld scanners or photogrammetry yield better results, as both technologies have their advantages and disadvantages. Solutions considered technically superior failed in the market several times in the past, and not only due to economic considerations.

CONNECTING DIGITAL SURVEYS AND 3D RECONSTRUCTIONS OF THE ARCHITECTURAL REMAINS OF THE FRANCISCAN FRIARY

The excavations of the chapel (chapter house) of the Franciscan friary in Visegrád took place in the early 1990s. Of the surviving parts of the former building, the ruins of the chapel in the eastern wing were probably the easiest to reconstruct. The rectangular space, with three walls corresponding to the sides of an octagon, once had a net-vaulted ceiling. The results were published in 1994 in a collection of papers on the architecture of mendicant orders. György Szekér made reconstruction drawings of the former vault (Buzás *et al.* 1994, fig. 2/b, 6–10). He reconstructed the top view and the one-time shape of the stellar vault, and published, in a study summarising the result of his reconstruction work, the survey drawings of the two most important rib nodes and a reconstruction of one of the keystones. The paper also contained a complete reconstructed floor plan with indications of the assumed positions of the nodes. A fragment found on the site proved that the vault's springers enclosed V-shaped spandrels (*Fig. 18*). As the remains of the vault were found in the excavation where they had fallen upon collapsing, it was possible to estimate the exact positions of the nodes. The vaulting's basic design was common at the time, but this stellar net vaulting was constructed with particular care. Interestingly, this vault type was part of the practical training of master builders as late as the 17th century (Maissen 2019, 71–72) (*Fig. 19*). In the SziMe3D AR project, Balázs Szőke created a 3D model and a digital reconstruction of this vault (*Figs. 20–23*), in which the digitised and modelled original architectural elements appear in their original places; his model is also suitable for *anastylosis* (Canciani *et al*. 2013).

He started with digital models of stone carvings made using structured light projection technology and a triangle mesh created from the survey point grids, which could then be used as an object in DWG files. Considering the possibilities of the available software environment, models with a resolution limited to 1% of

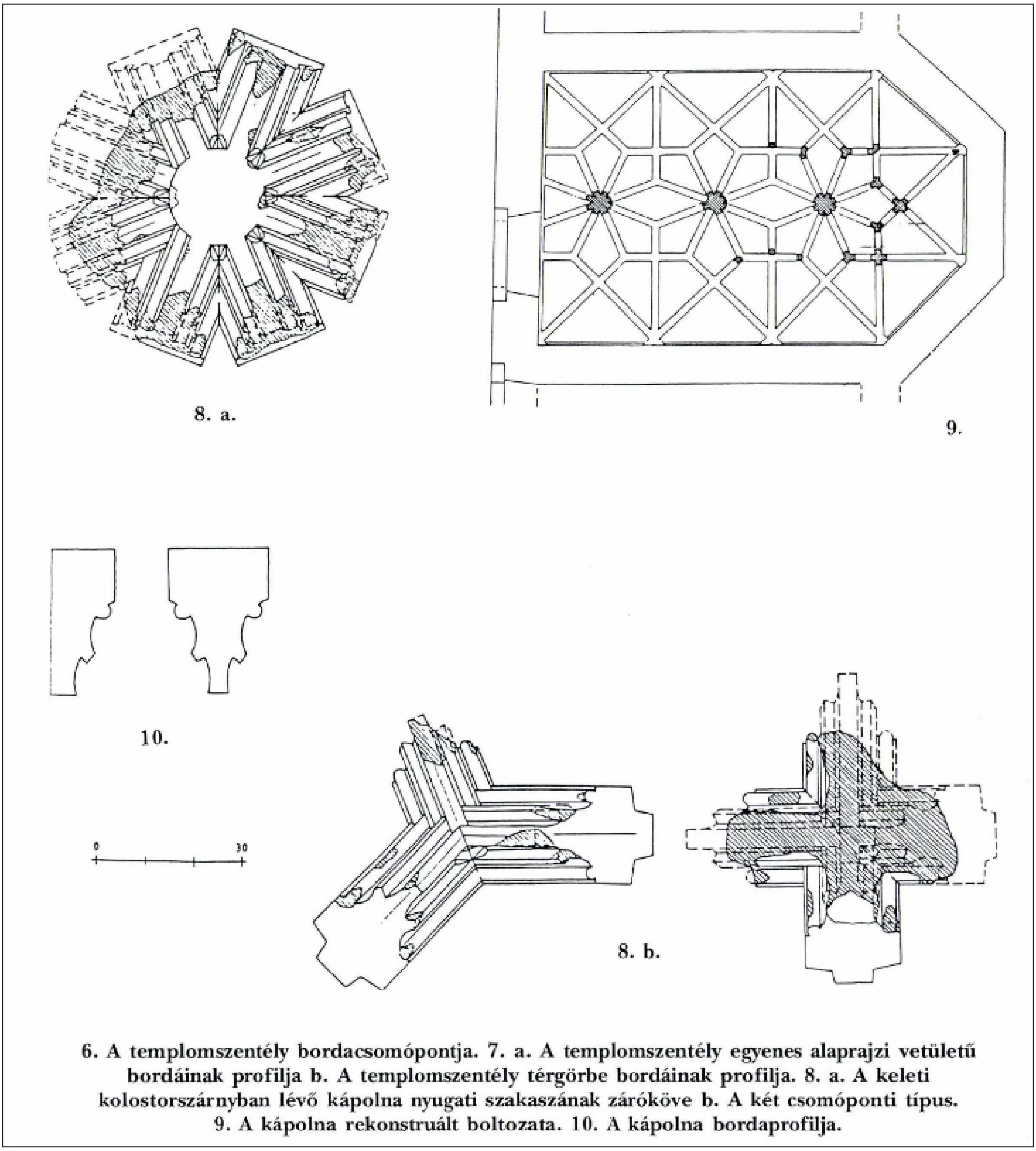

Fig. 18. Theoretical reconstruction of the chapel (chapter house) of the Franciscan friary (by György Szekér)

the survey accuracy were used for visualisation; this still provided significantly more accurate results than any previous one. The CAD model was based on digitally surveyed carved stone elements (e.g., rib profiles were calculated as the average of the measured ones to mitigate differences rising from them having been crafted by hand) and followed the technical principles of the structure, only correcting for the irregularities of the floor plan. The chapel's floor plan is almost regular, with only minor differences between the angles at some points. The digital models of the stone carvings (measured by structured light projection) were placed in the CAD model after deleting their places in the virtual structure. The idealised model and the

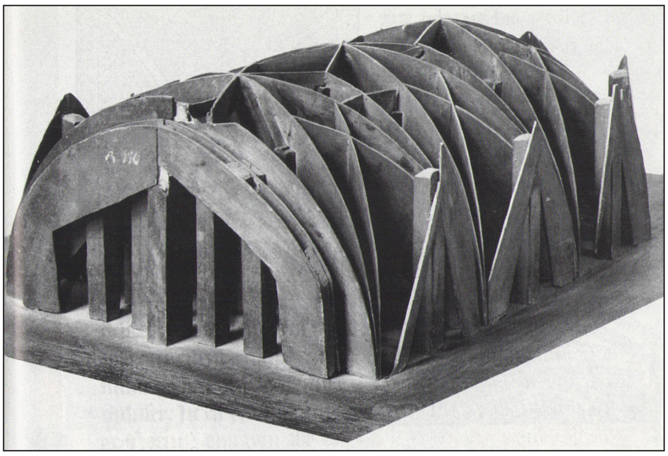

Fig. 19. Model of a vaulting. Masterwork from the 17th century in the collection of the Bamberg Historical Museum (after MAISSEN 2019)

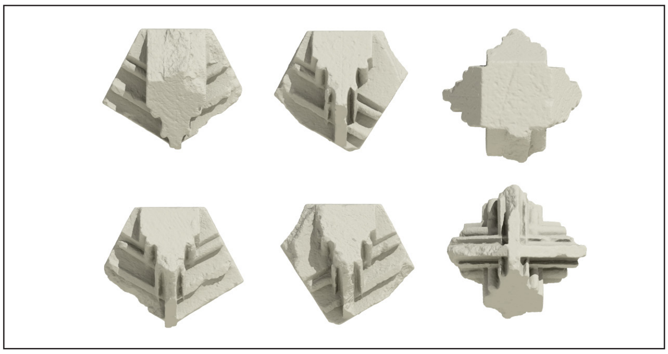

Fig. 20. Digital survey of a node from the chapel of the Franciscan friary, SziMe3D AR project

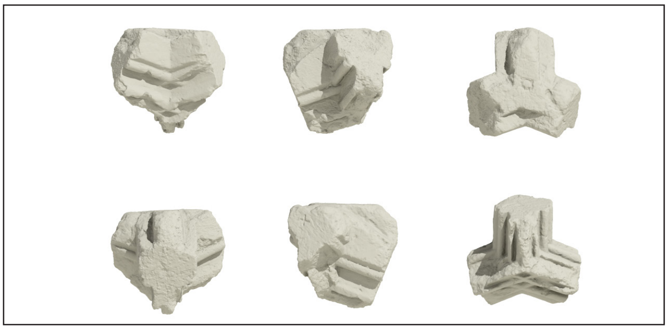

Fig. 21. Digital survey of a node from the chapel of the Franciscan friary, SziMe3D AR project

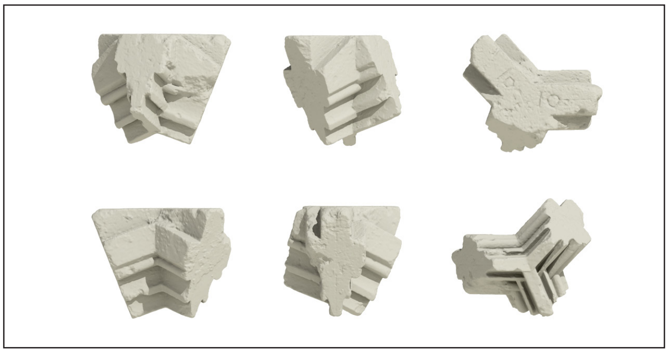

Fig. 22. Digital survey of a node from the chapel of the Franciscan friary, SziMe3D AR project

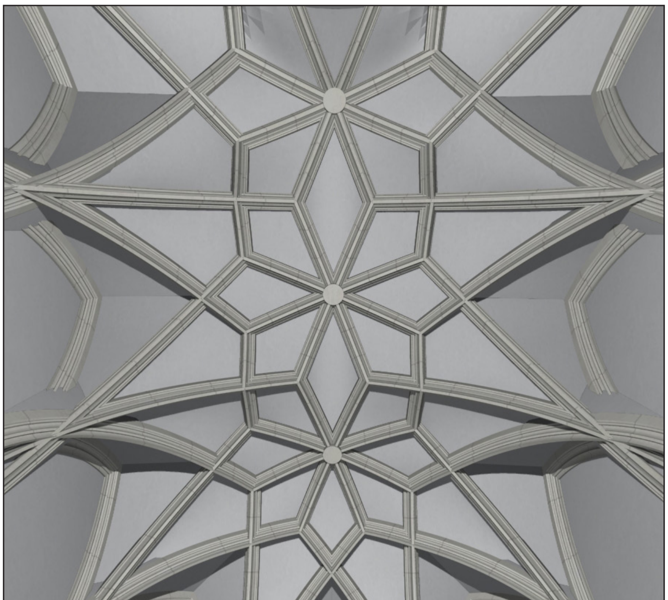

Fig. 23. Computer-aided theoretical reconstruction of the chapel of the Franciscan friary (by Balázs Szőke)

Fig. 24. Computer-aided theoretical reconstruction of the chapel of the Franciscan friary. The digitised carved stone elements of the vault are marked in red. SziMe3D AR project

digitised fragments matched fairly well, with only minor differences due to irregularities of the carved stone surfaces. As a result of modelling, the one-time built space could be presented in its former glory. Besides, it could be proven that *anastylosis* can be a suitable solution for reconstructing ancient monuments as well as modelling medieval vaulted structures (*Fig. 24*), as also illustrated by the partial 3D reconstruction by György Szekér of the identical net vault's rib structure of the sanctuary of the church in Nagyszekeres. 3D models containing digitised images of existing carved stone elements can help the general public see and understand the original structures and demonstrate the correctness of theoretical reconstruction drawings.

As the examples above illustrate, the excavated relics of the Franciscan friary in Visegrád and their surveys can be used as a guideline in summarising the digital surveys and 3D reconstructions made of cultural heritage elements in Hungary in the past three decades, as well as the evolution and spread of digital technologies in archaeology.

References

Buzás G. (1990). A visegrádi királyi palota. *Valóság* 33/1, 91-101.

Buzás G. (1995). Számítógép és építészettörténet, Cluny III. rekonstrukciója. *Építés és Felújítás* 2:1, (január–február), 64–65.

Buzás G. (2018). *A királyok Visegrádja*. Visegrád: Mátyás Király Múzeum.

Buzás G., Laszlovszky J., Papp Sz., Szekér Gy. & Szőke M. (1994). A visegrádi ferences kolostor. In Haris A. (szerk.), *Koldulórendi építészet a középkori Magyarországon. Tanulmányok* (pp. 281-304). Művészettörténet–Műemlékvédelem 7. Budapest: Országos Műemlékvédelmi Hivatal.

Buzás, G., Laszlovszky, J., Papp, Sz., Szekér G. & Szőke M. (1995). The Franciscan Friary of Visegrád. In Laszlovszky, J. (ed.), *Medieval Visegrád: Royal Castle, Palace, Town and Franciscan Friary,* (pp. 26-33). Dissertationes Pannonicae ex Instituto Archaeologico Universitatis de Rolando Eötvös Nominatae Budapestiensis provenientes III.4. Budapest: ELTE Régészettudományi Intézet.

Buzás, G. & Laszlovszky, J. (eds.) (2013). *The Medieval Royal Palace at Visegrád.* Medieval Visegrád: Archeology, Art History and History of a Medieval Royal Centre 1. Budapest: Archaeolingua.

Buzás G., Orosz K. & Vasáros Zs. (szerk.) (2009). *Reneszánsz látványtár – Virtuális utazás a múltba.* Budapest: Magyar Nemzeti Múzeum.

Buzás G. & Orosz K. (2010). *A visegrádi királyi palota.* Budapest: MNM Mátyás Király Múzeum.

Buzás G. & Szőke M. (1992). A visegrádi vár és királyi palota a 14–15. században. In Cabello, J. (ed.), *Várak a későközépkorban / Die Burgen im Spätmittelalter.* Castrum Bene 2. (pp.132–156). Budapest: Castrum Bene Egyesület.

Canciani, M., Falcolini, C., Buonfiglio, M., Pergola, S., Saccone, M., Mammì, B. & Romito, G. (2013). A Method for Virtual Anastylosis: the Case of the Arch of Titus at the Circus Maximus in Rome. In Grussenmeyer, P. (ed.), *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* II-5/W1 (pp. 61–66). XXIV International CIPA Symposium, 2–6 September 2013, Strasbourg, France. https://doi.org/10.5194/isprsannals-ii-5-w1-61-2013

Fehér A. (2024a). A visegrádi műemlékegyüttes 3D felmérése és dokumentálása. *Archaeologia – Altum Castrum Online,* A Magyar Nemzeti Múzeum visegrádi Mátyás Király Múzeumának középkori régészeti online magazinja. https://archeologia.hu/content/archeologia/943/feher-visegrad-3d-felmeres-2-1-.pdf

Fehér, A. (2024b). The application of 3D scanner technology in building archeology and heritage preservation. *Hungarian Archaeology* 13:1, 1–8.

Fehér K. & Halmos B. (2015). A középkori építészet szerkesztési módszerei a hazai szakirodalom tükrében. *Építés- Építészettudomány* 43:3–4, 237–284. https://doi.org/10.1556/096.2015.43.3-4.7

Holl B. & Laszlovszky J. (1995). A visegrádi kolostor középkori kerengőjének számítógépes rekonstrukciója (Módszertani és gyakorlati tapasztalatok). *Építés és Felújítás* 2;2, 60–61.

Jobbik, K. & Krähling, J. (2023). Real Net Vault or Pseudo-Ribbed Net Vault? Geometry, Construction and Building Technique of the Vault of the Reformed Church of Nyírbátor and the Nave Vault of the Franciscan Church of Szeged-Alsóváros. *Építés- Építészettudomány* 51:3–4, 229–256.

Maissen, M. (2019). Von Haspelsternen und Prinzipalbögen: Spätgotischer Gewölbebau österreichischer Baumeister im Bistum Chur. *IN SITU* 11:1, 67–82. https://doi.org/10.3929/ethz-b-000333534

Patay-Horváth, A. (2011). *The Virtual 3D Reconstruction of the East Pediment of the Temple of Zeus at Olympia – Presentation of an Interactive CD-ROM*. Geoinformatics FCE CTU. https://doi.org/10.14311/gi.6.30

Renfrew, C. (1997). *Virtual Archaeology: Great Discoveries Brought to Life Through Virtual Reality*. London: Thames and Hudson.

SziMe3D AR eredménytermékek. Eszközök meghatározása, kiválasztása fehér fényű szkennerekre. Digital manuscript.