Journal of Mediterranean Cities

2023, Volume 3, Number 1, pages 01–19

Use of Photogrammetry and Terrestrial Laser Scanning to Measure Superficial Weathering Damage on the Façade of Hanfelden Castle, Austria

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A B S T R A C T

Hanfelden Castle is one of the few Renaissance castles in Austria, which were subsequently hardly redesigned and changed since the tower building from the 14th century, and the extension in the 16th century to the today's appearance. This includes the façade with plaster layers from the 16th to the 18th century on the south and west side. Under these conditions, the concept for future scientific research of the object should essentially cover two needs: On the one hand, a collection of 3D basic data as complete as possible should be created for further work with the help of geospatial-technological methods, and on the other hand, methodological-technical expertise should also be built up (no substantial investigations have been undertaken in this direction). Additionally, and with regard to the determination of mostly conservation measures- the façade should be preserved - it has been important to check the façade made of plaster, natural stone or brick for the extent of superficial damage - such as weathering, flaking, bulging or bending. Therefore, non-contact 3D measuring systems are compared and applied as an alternative to visual inspection using standard cherry pickers or scaffolding. These so-called geospatial technologies applied in this study include methodological aspects of terrestrial photogrammetry, UAV assisted photogrammetry, and terrestrial laser scanning (TLS). This study used historical data/recordings and photogrammetric results from 1986 as well as newer techniques from the structure from motion (SfM) method (2019, 2022) and terrestrial laser scanning (2019, 2022). The different data recording methods and different result data in a multi-temporal and multi-sensoral approach, comparable for the changes to the facade, were a challenge for the study. Despite the different methodological approaches of the technologies used, the overarching goals of the study were, on the one hand, to detect and map the damage to the facade that has become increasingly apparent over the years. On the other hand, it has been shown that the applied 3D methods used (individually or in combination) represent a time-saving and cost-effective alternative to visual examinations using lifting platforms. The data sets obtained in the campaigns described should be homogenized and summarized in the sense of a historical BIM and serve as a basis for further work on the object. The focus was on multi- and interdisciplinarity as well as on taking into account the needs of science to science and science to public dissemination.

A R T I C L E I N F O:

Article History

Received: July 05 2023

Revised: September 18 2023

Accepted: September 27 2023

Available online: Oct. 08 2023

Keywords:

Digital Cultural Heritage; Façade Inspection; Photogrammetry; Terrestrial Laser Scanning

JOURNAL OF MEDITERRANEAN CITIES (2023), 3(1), 01-19
https://doi.org/10.38027/mediterranean-cities_vol3no1_1

www.mediterranean-cities.com

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How to cite this article:
Sulzer, W., Gspurning, J., Kaufmann, V., Fuerhacker, R., Catau, J., Wack, F., & Held, D. (2023). Use of Photogrammetry and Terrestrial Laser Scanning to Measure Superficial Weathering Damage on the Façade of Hanfelden Castle, Austria. Journal of Mediterranean Cities, 3(1), 01 - 19. https://doi.org/10.38027/mediterranean-cities_vol3no1_1

1. Introduction

In the last years, Geospatial Technologies became a usual tool for heritage managers, conservators, restorers, architects, archaeologists, painters, and all other categories of experts involved in cultural heritage activities, which can be found in numerous national and international case studies (e.g. El-Hakim et al. 2004, Kersten 2006, Kersten et al., 2012; Fassi et al., 2013; Micoli et al. 2013, Dostal 2014, Erenoglu et al. 2017, Maietti, F. et al., 2018, Doumit 2019, Galantucci & Fatiguso 2019, Sulzer et al. 2021).

The aim of this paper is to present a specific application of Photogrammetry, Structure from Motion (SfM), Terrestrial Laser Scanning, and Object-Based Classification tools to obtain detailed information about the historical and current status of façade from a last middle-aged castle. Would it be possible to obtain new information about the structure and development of façade with the applied methodologies of Geospatial Technologies? This paper goes beyond the pure geovisualization of the investigated cultural heritage, but additionally attempts the automatic classification of different façade structures and layers as well as the changes from 1986 until 2022, which are caused mainly by weathering. Additional information about the construction history, by visualizing building structures (construction joint) by means of different high resolution digital surface models will be achieved with this methodology. The final achieved information will help to assist conservation and reconstruction activities.

Photogrammetry enables the creation of accurate 3D models from two-dimensional images. It's a 3D scanning technique that uses multiple images taken from different angles to create a 3D model of an object or scene. It is a versatile tool that can be used in many fields, such as surveying, engineering, architecture, 3D printing, and video game development. Photogrammetry is also a method used in the preservation of cultural heritage sites, museum objects, or architectural monuments. Photogrammetry offers many advantages over traditional 3D modeling methods, including accuracy, precision, cost savings, and speed. If you are looking for an efficient and cost-effective way to create accurate 3D models, then photogrammetry is the perfect solution (Aicardia et al., 2018).

"Structure from Motion" (SfM) is a technique combining photogrammetry and computer vision that reconstructs orthophotos and 3D surface models based on overlapping images from drones or conventional cameras (Sulzer et al., 2021). Orthophotos are true-to-scale and distortion-free parallel projections onto a reference plane (Donath, 2008). The creation of such orthophotos of historical façades enables the documentation and analysis of façades for numerous applications such as restoration, historical preservation, visualization, analysis of the structural condition and damage (Kersten et al., 2012). These therefore represent a significant contribution to the preservation of cultural heritage or culturally valuable objects (Sulzer et al., 2021).

The question of the significance of (terrestrial) laser scanning in the cultural heritage context and how it should be evaluated in comparison with other modern technologies can be seen as the subject of many fundamental discussions. Representative of this is the work of Eppich and Hadzic (2013), in which the authors, based on a review of the relevant cultural heritage literature between 1975 and 2009, attempt to show the interactions between technology and cultural heritage application. This paper clearly demonstrates how and to what extent certain technologies have found their way into the field of cultural heritage. On the one hand, the relatively long tradition of conventional surveying tools such as the theodolite or - with some delay - digital cameras and GNSS is remarkable. On the other hand, this also documents the rapidly increasing penetration of the research field by thermal photography and laser scanning.

2. Hanfelden

Hanfelden Castle is located in the Murtal district (Styria, Austria) at an altitude of around 900m (fig.1). It is located at a key topographical position in the Pölstal south of the Triebener Tauern, an important Alpine crossing (1270m) between the Mur Valley and the Enns Valley, which was already the shortest connection between the Adriatic and the Danube region in Roman times. The location of the castle is characterized by a particularly favorable climatic terrain, as it is located in the lower area of a mighty alluvial fan of a western side valley that pushes the Pöls River to the eastern side of the Pöls valley. A few kilometers away is the Oberzeiring silver mine, which was important in the High and Late Middle Ages. Hanfelden Castle is based on a late medieval, three-storey, tower-like stone building, built around 1350, and was expanded from 1494 by Hans Han (ca. 1450 – 1516; Hollegger, 2018) and his son Peter Han in several construction phases into an early Renaissance castle (Theune and Winkelbauer, 2019; Theune et al., 2020). It can be assumed that the building as early as 1520/30 largely corresponded to its current appearance and after that only conversions and redesigns of the façades were made, which can be associated with several changes of ownership. After the male line of the Han family died out, the castle was owned by the mostly aristocratic families Rauchenberger, Stübich, Pichl, Herberstein, Prandau, Pfefferhofen and Schwarzenberg. In 1856 the tradesman Franz Xaver Neuper acquired the building for storage purposes or to accommodate workers or servants and it is still owned by the family today (Fuerhacker & Theune, 2016).

What particularly distinguishes Hanfelden castle is its unadulterated, authentic appearance (fig. 2). This is due to the fact that no major changes have been made to the building for around 250 years and that it largely corresponds optically to the oldest known depiction by G. M. Vischer from 1681 (fig. 3). Fig. 4 represents the castle from the year 1830, where baroque ornaments are visible, which are partially still now on the façade. The castle was placed under monument protection in 1965 and is conscientiously looked after by the Federal Monuments Office (Bundesdenkmalamt).

Figure 1. Location of Hanfelden Castle.

Figure 2. Perspective view from West (Photo Sulzer 2019)

The aim of the conservation and restoration measures that have been taking place since 2015 is primarily to preserve the original substance. A modern use of the castle, for example for residential or other purposes, which would require massive interventions in the original substance, is not planned. Damaged or missing parts of the wall are stabilized or supplemented, and missing roofs are reconstructed in order to prevent further deterioration. Particular attention is paid to the integrity of the roof of the main building.

Figure 3. Hanfelden Castle (1681), G. M. Vischer: Topographia Ducatus Stiriae, 1681

Figure 4. Hanfelden Castle (1830), J. F. Kaiser - lithographirte Ansichten der Steyermärkischen Städte, Märkte und Schlösser, Graz 1824-1833

The façade of the south and west side of the castle has several layers of plaster, which can be assigned to several chronological phases:

(1) The oldest phase (before 1510), which as far as can be seen is limited to the ground floor, shows a quarry stone masonry made of medium to large, worked stones (0), the spandrels of which were subsequently filled with small stones or pieces of slag pressed into the mortar and were not further plastered.

(2) The second phase (around 1510/30), which extends over the entire south and west façade, consists of a simple, white-colored plaster. At the south-east corner, ocher-colored cuboids with a border of red iron oxide were painted on. The gate frame in the middle is included in this phase.

(3) The third phase, which can also be seen in the Vischer engraving (1681, fig. 4), also shows a white coloring. Although no corner ashlars were painted on, there are remains of flat painting, especially in the southern area of the west façade. Since the plaster has partially fallen off in these areas or there is a newer layer of plaster, it is unclear which depiction it is.

(4) The youngest and last layer of plaster consists of a baroque brownish-grey structured plaster (around 1730) on which white structures have been applied. On the ground floor there was a large plinth zone depicting cuboids, horizontal cornice bands ran between the floors and on the first and second floor rectangular and profiled decorative fields were applied between the windows framed in white. The southeast corner was again painted with ashlars.

Since large areas of the façade have fallen victim to the weather in recent decades, the primary goal of the conservation measures is to secure the areas that are still preserved. Not just one of the cleaning phases should be preserved, but all of them. This represents a kind of artificial condition of the façade, since areas from different periods can be viewed at the same time, which is a great benefit, especially for building research. The broken edges are stabilized by applying a plaster of similar composition and lifted areas are secured by backfilling with a preservative mortar.

3. Methodology of the multitemporal and multisensorial analyses of the western façade

In Hanfelden Castle, the Graz Universities (Institute for Geography at University Graz and Institute for Geodesy at Graz Technical University) were able to use different methods of remote sensing, such as photogrammetry and laser scanning, as well as geovisualization, as part of the NAWI Graz cooperation (fig. 5). Aim was to document their potential in the recording and presentation of a unique cultural heritage. Classical recordings of the castle were done by Aigner (2002). Basic photogrammetric measurements were done by Graz University of Technology in 1986. Repeating photogrammetric measurements and recordings of the façade of the castle were done in 2019. Additionally, UAV flight campaigns have been used to generate highly accurate orthophotos (aerial maps), surface models and three-dimensional visualizations of the roof, façades etc. in 2019 and 2022. These initiatives were supported by terrestrial laser scanning of the circle wall, façades, and inner courtyard.

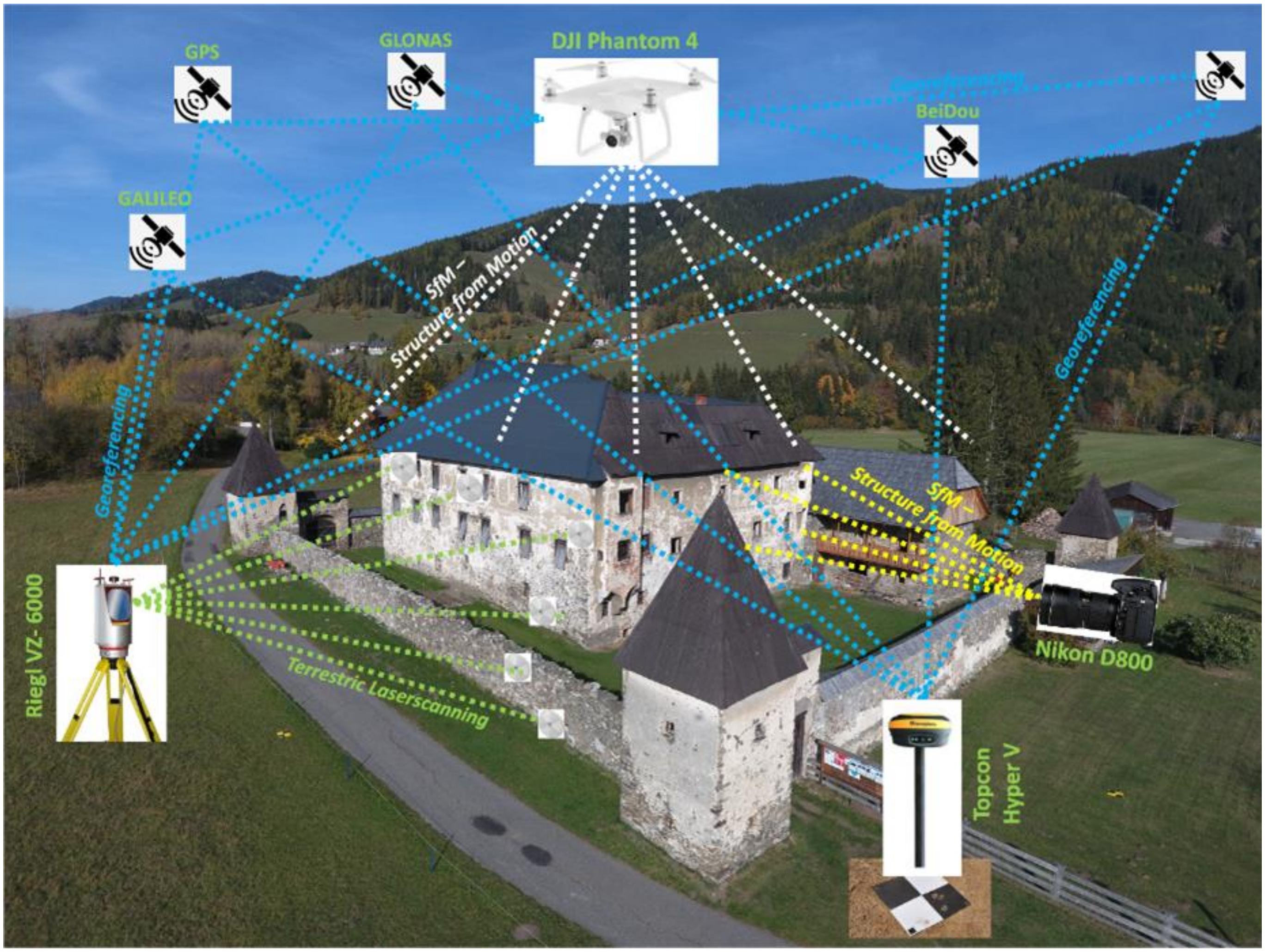

Figure 5. Methodology of data acquisition

The terrestrial photogrammetric recordings of the façades were carried out in 1986 and 2019. The aim was to create site and elevation plans on a scale of 1:100. Three large-scale plans were prepared as part of the project. The color negatives and positives, which were taken with the Hasselblad medium format camera, are also located at the Institute for Geodesy at Graz University of Technology.

After 33 years, the views of Hanfelden Castle were recorded again in 2019, with the primary aim of producing high-resolution orthophotos of the building façades for damage assessment and façade restoration purposes. Fig. 6 and fig. 7 document the weathering of the façade over a period of 33 years.

To register and control the terrestrial photogrammetric recording, control point signals were attached to the façade s of the two buildings at the level of the ground floor, the 1st and 2nd floor. A closed traverse (4 main station points and 3 intermediate points) was measured using the Total Station TPS1201R from Leica Geosystem GmbH. The signaled control points, but also supplementary natural control points and other points were measured polarly from the viewpoints. The terrestrial photogrammetric recording of the façades of Hanfelden Castle was taken with the digital single-lens reflex camera Nikon D800 (lens: Nikon AF Nikkor 20 mm 1:2.8 D). A total of 244 photographs in RAW format were acquired. The terrestrial photogrammetric evaluation with the primary goal of creating orthophotos for the individual façades was largely carried out in the Agisoft Metashape software and then post-processed with the Global Mapper software.

Figure 6. View from southwest 1986 (Photo Kaufmann)

Figure 7. View from southwest 2019 (Photo Sulzer)

In order to visually capture the castle and its surrounding wall in its entirety, an aerial survey was carried out using a small, unmanned aerial vehicle, commonly referred to as a UAV, as part of the surveying campaign in 2019. The aircraft (DJI Phantom 4) was operated at two different altitudes, about 33 m and 63 m above ground. This made it possible to generate a spatially very high-resolution (ground resolution 2 cm) database, namely an image mosaic of aerial photographs that can be directly compared with maps). In addition to these orthogonal overview flights, the individual sides (façades), the neighboring building and the ring wall were recorded with high precision (resolution in the cm range). These UAV flights were repeated in 2022.

Structure from Motion (SfM) is a topographic survey technique which can produce three-dimensional (3D) point clouds and therewith orthophotographs and digital elevation models (DEM) based on two-dimensional (2D) imagery. Algorithms are used to register matching points from a selection of overlapping images – e.g., different positions and angles - of an examined object. This allows the camera positions and orientations to be calculated, with the point clouds or models being output in an arbitrary reference system. Thereby the need of reference data and Ground Control Points (GCP) is inevitable for georeferencing and scaling (Carravick et al., 2016). Basically, SfM is a flexible and inexpensive alternative to TLS and allows to generate high-resolution orthophotographs and DEMs based on UAV images. Using recordings from 2019 and 2022, changes in the condition of the façade can be determined, which helps to improve the information required for restoration.

The application possibilities of laser scanners in the scenario discussed here are - apart from the purpose of the investigation - essentially determined by two further influencing factors, the technical specifications of the Riegl VZ 6000 with a maximum range of 6000 m used in the campaign and the associated recording parameters. The former include:

- Accuracy (the degree of conformity of a measured quantity to its actual (true) value (one sigma @ 150 m range under RIEGL test conditions): 15 mm,
- Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result 10 mm,
- Minimum Range: 5 m
- Laser Beam Divergence 0.12 mrad per 100 m distance (measured at the 1/e 2 points. 0.12 mrad corresponds to an increase of 12 mm of beam diameter),
- Laser Beam Footprint (Gaussian Beam Definition) 15 mm @ exit
- Field of View maximum 60° (from +30° to -30°) vertically and 360° horizontally,
- Minimum angular step width 0.002 rad in both directions (Riegl, 2015).

As already indicated, these parameters influence the configuration of the second group of factors. In the case of the given problem, the scanning density at the object (i.e., the façade) naturally had to be kept as high as possible (or the step size as small as possible); in order to achieve this, a balanced relationship between the scan step size to be set and the distance to the object had to be selected. Unlike in the case of long-range scans where the resulting amount of data also plays a certain role, in the present case the so-called minimum range distance is more important, the minimum distance that has to be kept in order not to destroy the receiving unit of the device. With these specifications (as little as possible more than 5 m from the façade and (for geometric reasons) as central a position as possible in front of the object), the problem arose that the surrounding wall of Hanfelden threatened to prevent the optimal positioning of the scanner or would have covered the lower parts of the building. For this reason, a telescopic tripod was used instead of the usual tripod, with the help of which the scanning platform could be raised to a height of 2.6 m, thus ensuring an unobstructed view of the entire west façade (fig. 8 and fig. 15).

Figure 8. Scanning position "west façade"; the (remote-controlled) scanner is located about 10 m in front of the object at a height of 2.6 m; this does not obstruct the view

The 2D drawings were produced using the rectified images from 2019 and 2022 of the building's façade resulting out of the SfM procedure. Additional to current digital images referential archive documents from 1986 allow to characterize and quantify the state of façade deterioration over the course of time. Further on, different layers/categories were used for the mapping and digitization of the façade's features. For the differentiation of the features, the façade materials and condition were considered (Patias et al., 2011).

The elements of the façade were categorized for the investigation according to the phases of development (see section 2 and legend in fig. 16). In addition, line signatures were used for the year 2022 to highlight cracks and exfoliation processes on the façade.

4. Results

The Surfer software was used to create 10 orthophotos and 7 plans on a scale of 1:100 in PDF format (paper format: A3 and A4, fig. 10) for 2019. Furthermore, a virtual tour of the façade of Hanfelden Castle was created in the form of a video using the CloudCompare software from the photo-textured 3D model. The 10 resulting orthophotos of the façades of Hanfelden Castle, which were created using terrestrial photogrammetry and geodetic measurements, are in JPG format (incl. World File) and in 7 plans in PDF format (paper format: A3 and A4; scale 1: 100, fig.10) provided. The geometric resolution of the Orthophoto is 2 mm/pixel (fig. 9).

Figure 9. Orthophoto with an original resolution of 2mm

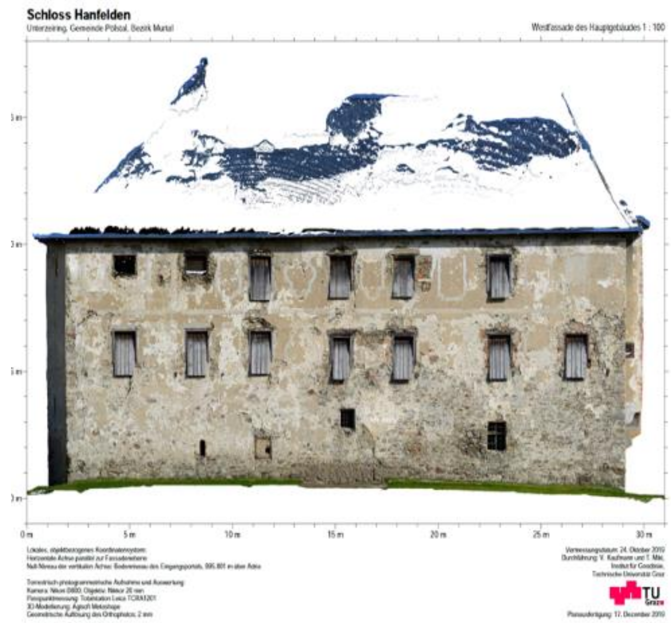

Figure 10. Orthophotomap 1:100

The SfM method for the UAV data was used to generate DEMs and orthophotos of the western façade of the castle for 2019 and 2022. The resolution of 2022 compared to 2019 and 1986 allows for a high level of detail (tab. 1). See the table for resolution details. These differences in resolution – which corresponded to the technology of the time and the purpose of the photos at the time – and thus in the details that can be derived from the recording, must be taken into account in the interpretation.

Table 1. Information about UAV images and SfM statistics.

Year	Resolution	Cameras	Points Dense Cloud
2019	4.23mm/pix ortho & 1.69mm/pix DEM	539	3,886,370
2022	0.838mm/pix ortho & 3.35mm/pix DEM	1191	35,953,993

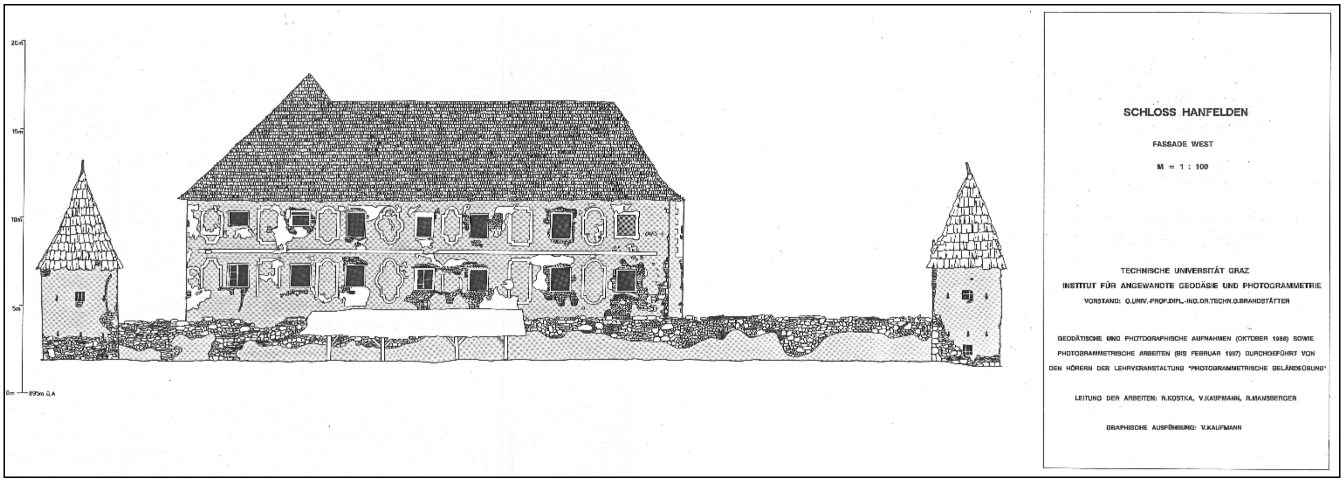

Figure 11. Sketch Map of the western façade and ring wall in 1986.

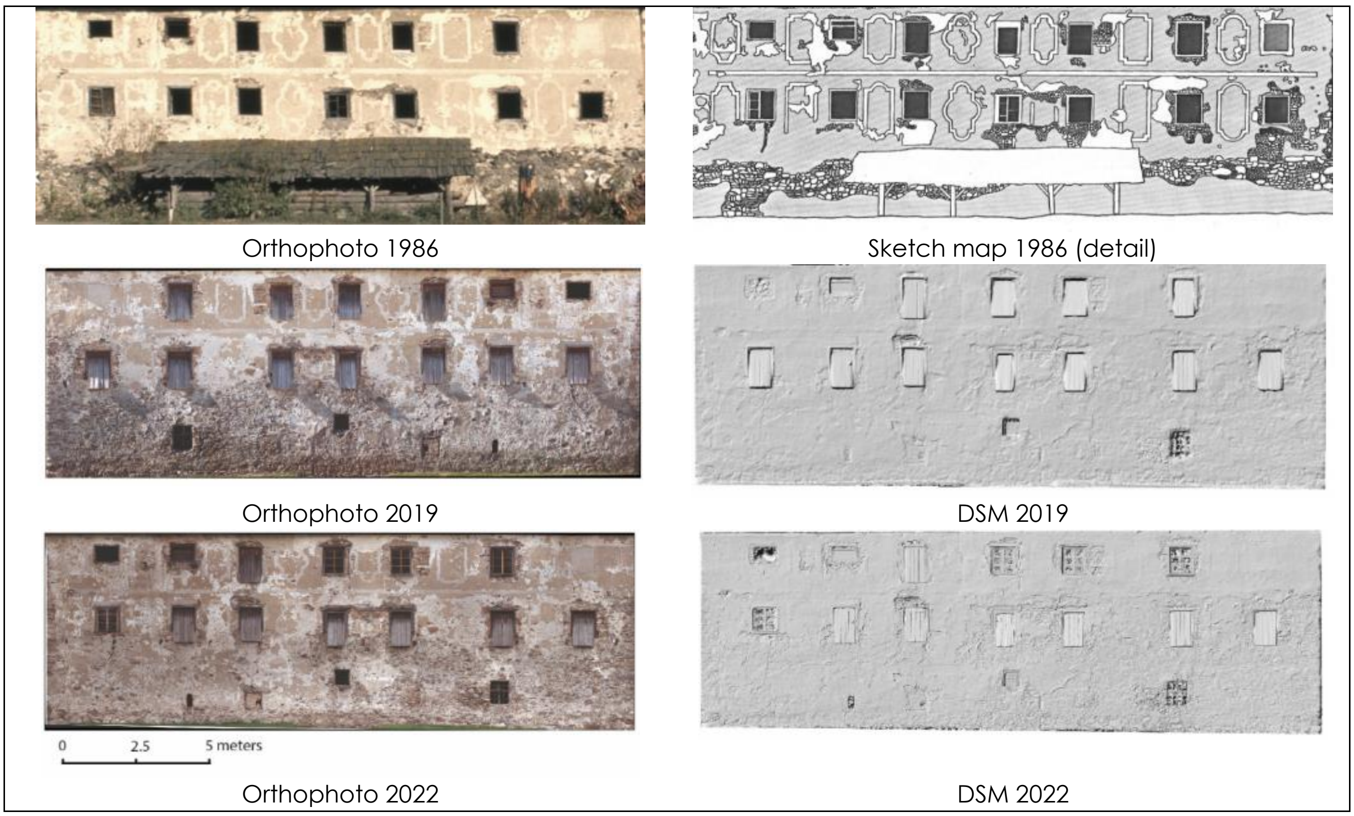

Figure 12. Orthophotographs (1986, 2019, 2022), Sketch map from 1986, and Digital Surface Models (DSM) from 2019 and 2022

Figure 13. Terrestrial Laser Scanning: Digital Surface Model (DSM) from 2022 (detail)

Figure 15 documents the potential of high-resolution Digital Surface Models (DSM). Structural elements of construction history (vertical crack in the middle) which represents the additional, newer part of the castle on the right side. Left side was part of the older one. Different plaster layer can be distinguished and identified (see fig. 15), and areas where the layers are upwelling. Especially this damage has to be fixed, to protect the plaster layers again further and ongoing destruction.

The capture (fig. 14) shows the initial scan result, the point cloud consisting of approx. 25 million points was not processed; but merely coloured to improve the display.

Figure 14. Raw scan of the west façade; the red circles mark the reflectors attached to the wall for georeferencing and comparison with the other partial scans

As a result of the scan of the west side of the main building of Hanfelden, which was carried out at 300 kHz with a (horizontal) frame resolution of 0.020 rad and a (vertical) line resolution of 0.019 rad, a point cloud with a size of approx. 1 GB was created with a relatively short runtime of about 20 minutes. After removing the scattered or background pixels that were not relevant for the investigation, a total of about 23 million measurement points remained for further processing. At this point it must be noted that due to the relatively wide horizontal scan angle, different distances to the detected object naturally occur, which in the present case range between 7.8 m in the nadir and 18.8 m in the lateral areas. Using the information provided by the device manufacturer, an approximate point distance of 2.7 mm is calculated for the first (optimal) case, which corresponds to approx. 137,175 points converted to an area of 1 m². In the worst (lateral) case, 1 m² contains only about 23,700 dots (average point to point distance: 6.5 mm). Although the printing conditions can only imperfectly reproduce the level of detail of the original data set (Gspurning et. al., 2021). Figure 15 shows very well the high dot density and which details can be identified.

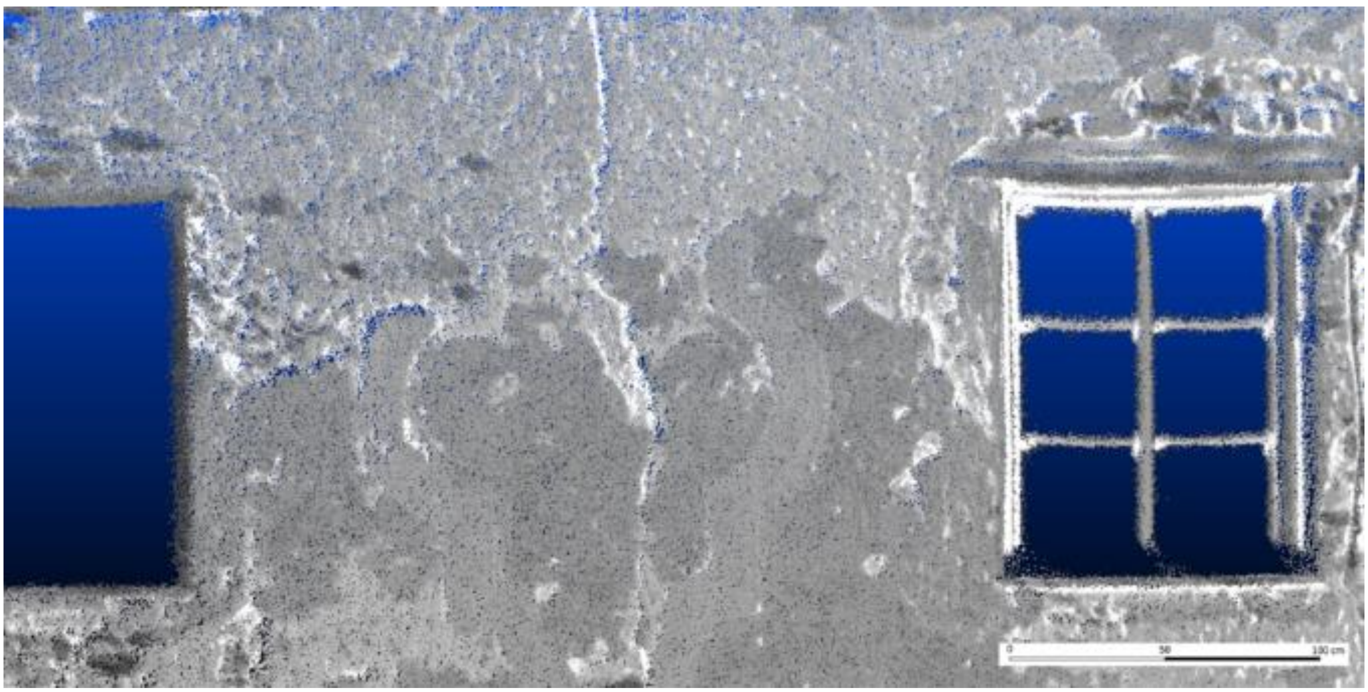

Figure 15. Section of the façade; due to the different reflectance of the wall surfaces, structural details such as ornaments on the wall or even structural damage can be seen very well

Figure 15 show typical structural damage and represents the limit of what is possible; while the approximately view cm deep edge as well as larger structural damage are still reflected in the generated point cloud. Finally, an additional problem inherent in the system is the geometrically induced flowing decrease in point density from the central to the lateral areas of the scan, which is responsible for the fact that the level of detail of the representation also decreases analogously. From a methodological point of view, this is equivalent to a necessary compression of the required scan positions with the help of which these problem areas can be kept as small as possible. However, this procedure would be tantamount to an increase in effort and raise the question of more favorable alternatives (e.g. flying with UAVs).

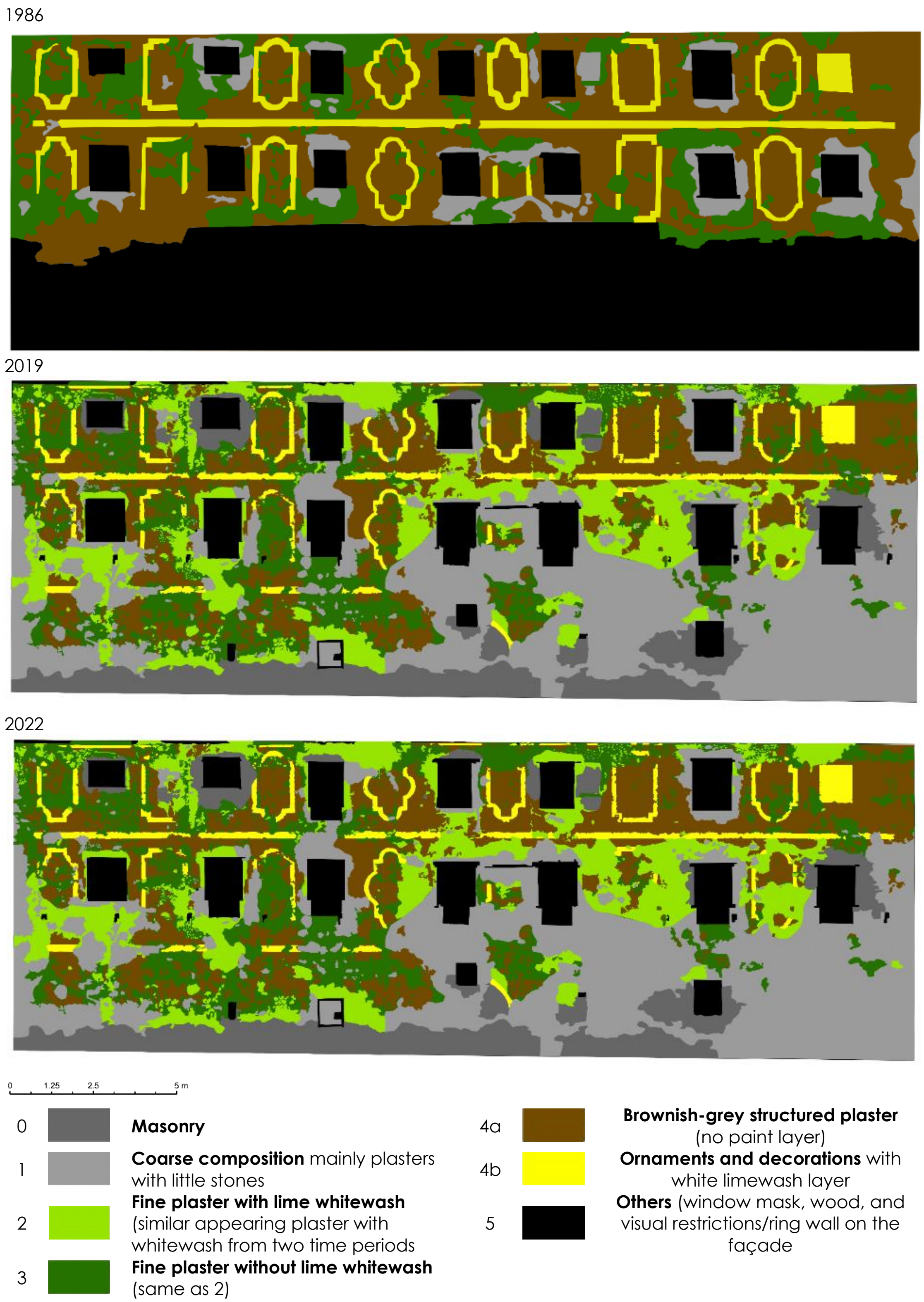

Figure 16. Object-based Classification of the western façade 1986, 2019, and 2022

The comparison (fig. 16) of the years shows, as expected, that the west façade suffers the greatest visible deterioration on the mesoscale (cm to m) (Viles et al., 2011) from 1986 to 2019. However, it shows that the southern part in particular - i.e., the right part of the façade - is more vulnerable, which is particularly illustrated by the appearance of the lower layers such as the masonry and the coarse composition. The comparison of the years 2019 and 2022 also shows that the most significant differences take place in this part and shows that there is a need for action in this area, even if the changes take place on the microscale (mm to cm). Overall, numerous changes in the mm and cm range were determined, bearing in mind that non-visible deterioration on the nanoscale (<mm) cannot be examined with this method.

The comparison of 2019 and 2022 shows that the condition of the façade can only be seen on a small area or in the details. A total of 70 differences (+) were identified, but not all of them are of significant importance (6 of 70 concern significant changes, which are larger and therefore more noticeable; these crosses are marked in fig. 17).

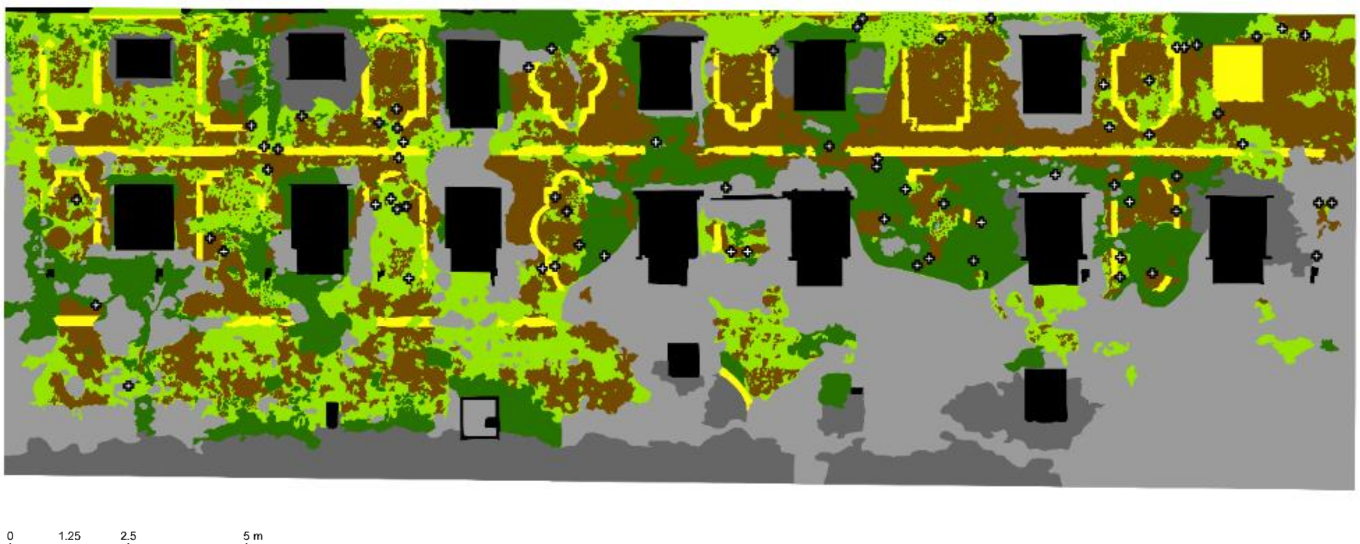

Figure 17. Spots (+) in the western façade, where changes occur between 2029 and 2022

Figure 18 documents a change detection analyses of the obtained object-based image classifications of the orthophotographs 1986, 2019, and 2022. 2022 (green) means, that there are intact layers (ornaments and plaster layers, 4a and 4b in fig. 16) which do not exist in 2022 anymore. Yellow (2019) means the changes between 2019 and 2022, respectively those parts which do not exist in 2022). The red color represents the plaster layers (4a and 4b in fig. 16) which are still intact in 1986. The greyish colored parts were not existent in 1986 and weathered before. Black colored areas represent other not visible parts of the façade like window mask, wood, and visual restrictions such as caused by the ring wall). Figure 19 represents 3 examples (details) from the western façade to enhance the small changes caused by the weathering from 1986 up to 2022.

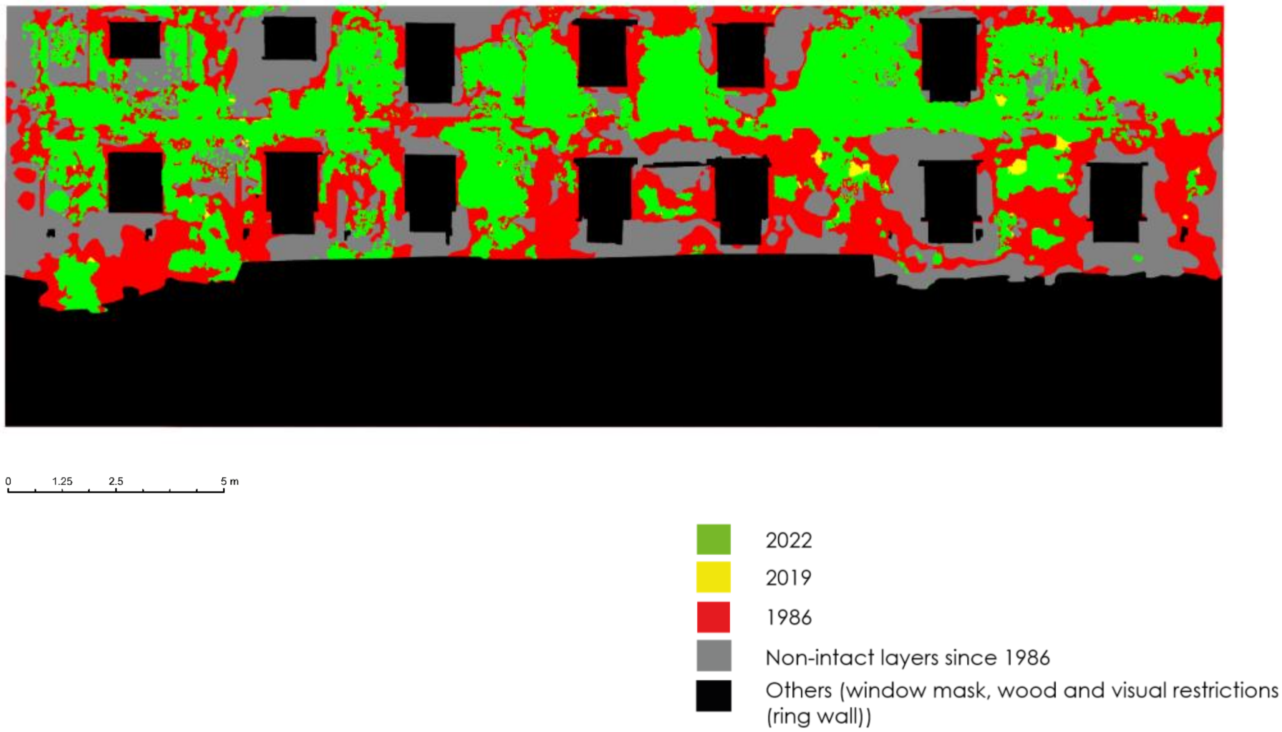

Figure 18. Changes on the western façade between 1986, 2019 and 2022 (explanations see text)

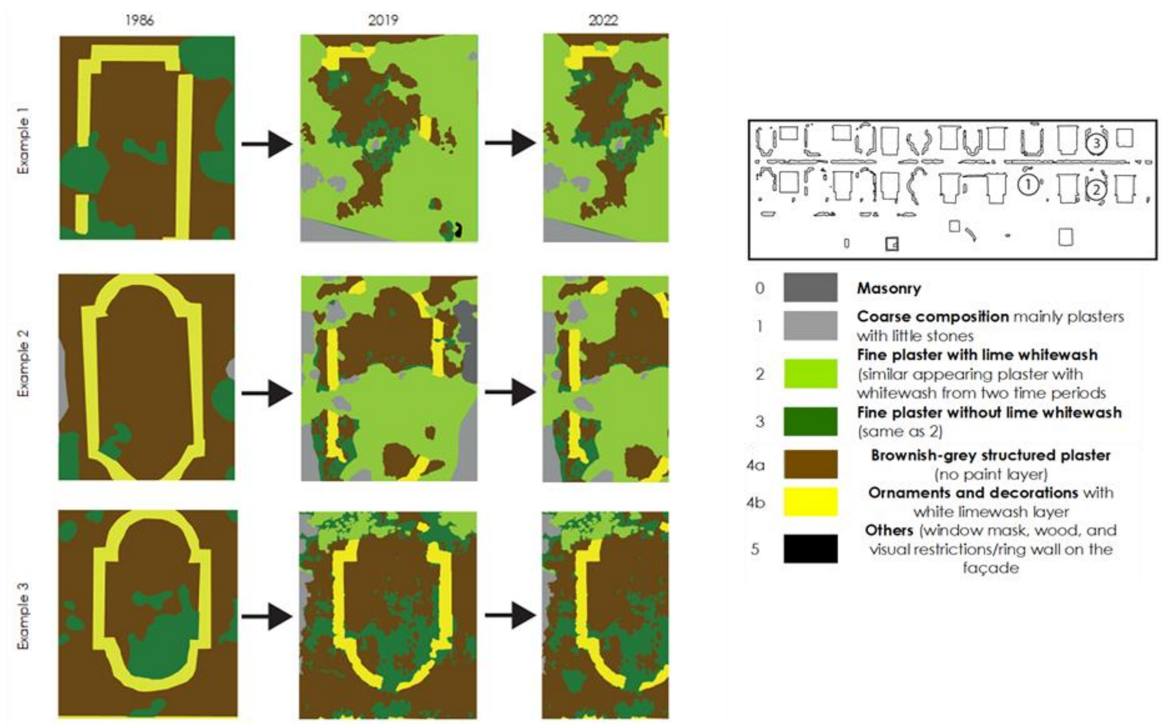

Figure 19. Detailed change on the western façade 1986, 2019 and 2022

5. Discussion

As already mentioned, the collection of methods presented here first serves to create a sustainable data basis, which through its conception (especially method and scale of acquisition, but also integration and possibility of use of the data) eliminates any future limitations as far as possible. This means that the investigations can be repeated almost at will, which is particularly well documented about the multitemporal investigation of façade development presented in this work. In this case the implemented methodologies of Geospatial Technologies proofed very suitable for the data and information acquisition of the western façade of the castle Hanfelden. A multitemporal and multisensorial analyses provides important information about the condition and the almost continuously destruction due to weathering influences. The example discussed here, provides a good estimate of the scale up to which structural irregularities in the building fabric or their changes can be documented using this method.

When looking at the individual 3D techniques (photogrammetry, SfM and TLS), the following can be noted in the specific example of Hanfelden:

The advantage of photogrammetric acquisition is mobile and flexible object capture on site. In the given Hanfelden example, contactless recording of the facade is often not possible due to the proximity of the castle's surrounding wall, and the recording angle is often only dragging. The high geometric resolution and the use of RAW data, however, allow a high level of detail in the images and this benefits the very good documentation of the surface condition. In the processing process of the photos, photorealistic 3D models can be further processed into rectified, dimensionally accurate photos and plans. Terrestrial photogrammetry thus achieved the highest comprehensive geometric accuracy of all methods used. A major disadvantage was the lack of a surface model in 1986, which was not available (fig. 12).

For 3D capture in the SfM process using conventional UAVs, a digital camera is usually used, the quality of which cannot be compared with a full-format camera (Nikon D800). These include, on the one hand, the poorer camera geometry and, on the other hand, irregularities that occur during data acquisition. This primarily includes irregular aerial photo block structures (angled shots, variable image scales at different flight distances from the facade, changing image coverage, etc.). A clear advantage of UAVs is that the geometric resolution of the image data can be increased due to the variable distance to the facade. Due to the proximity of the surrounding wall, the distance of the UAV to the facade must be reduced to approx. 5m (to keep a safe distance from the façade and surrounding wall). However, this procedure leads to a relatively large number of images (around 1200 images for 2022, see tab. 1), which itself has a negative impact on data processing.

Although the use of a terrestrial laser scanner brings undoubted advantages, it is also subject to several potential problems, which - apart from the technical limitations of the equipment - are primarily based on the local conditions. Particularly noteworthy in this context are the shadowing caused by the structural conditions of the object under investigation, which on the one hand prevent optimal placement of the scanner (e.g., minimum distance to the object versus scanning angle) and on the other hand make it impossible to record certain parts of the building (e.g., roof surface sloping towards the inner courtyard).

Another problem of TLS solution results from the (theoretically possible) high sampling density, which commonly leads to extremely large point clouds (30 GByte) and thus requires special resources for further processing (both data management and surface generation and analysis). Finally, a problem typical for these project phases should be mentioned: At the beginning of the search for the optimal workflow, it must be expected that data from other acquisition methods are not yet available.

The orthophotos and Digital Surface Models (DSM) created using Photogrammetry, SFM and TLS represent optimal documentation of the façade surface and allow building research and restoration to record and map a wide variety of observations on the plastering phases, their dating and materiality, special craftsmanship and various phenomena of damage. It is also possible to monitor changes by regularly repeated photo campaigns and to determine whether the deterioration has been stopped or is continuing after the implementation of conservation measures. The methodologies are suitable to be applied in the context of façade inspection.

A challenge in multisensorial and multitemporal analysis lies in the different resolution and accuracies of the image products used. On the one hand, a balanced compromise must be achieved when integrating historical data that cannot be changed and is not of such high quality, but on the other hand, future technological development of the methods and tools used should demand higher resolution and accuracy. It is precisely these aspects that must generally be discussed with all disciplines involved at the beginning of a monitoring concept (e.g., when analysing facade changes).

With regard to the methods and techniques presented in this document, it has become clear how valuable the cooperation of geospatial technologies can be in the field of historical building research; this applies above all to the different acquisition methods that are seamlessly intertwined here and thus optimize the achievable result. In addition, this type of data acquisition also enables the problem-free transfer to geographic information systems, where the traditional GIS analysis functions are of less use than the storage and documentation of the collected information. Provided that the workflows developed are used to optimize future workflows or to develop sample workflows, the results can serve as a basis for permanent monitoring of the building fabric and thus make a valuable contribution to future research on the Hanfelden property. This could finally achieve a historical cultural heritage building information system (BIM).

6. Conclusion

Within a specific application of Photogrammetry, Structure from Motion (SfM), Terrestrial Laser Scanning and object-based classification tools detailed information about the historical and status of façade from a last middle-aged castle was obtained. New information about the structure and development of façade with the applied methodologies of Geospatial Technologies could be received, by a data homogenization of historical data (1986) and recently recorded data material (2019 and 2022).

This could also be achieved by the application of an automatic, object-based classification of the images. Besides the optical image data, results from the Terrestrial Laser Scanning carried out additional information about the construction history, by visualizing building structures (construction joint). The final benefit was to give valuable data and information to assist conservation and reconstruction activities.

As soon as the knowledge gained allows the recording process to be automated as far as possible, the observation intervals can be shortened to such an extent that, in the sense of the initial intention, the structural changes can be documented for each area of the object in high temporal resolution. This enables researchers from neighboring disciplines to draw valuable conclusions for their research. In addition, the data material is of course also designed so that it can be used - for example in the context of 3D virtualization - in the sense of a science-to-public information transfer.

Acknowledgements

The Authors thank all students and colleagues who did fieldwork and the owner of Hanfelden Castle Georg Neuper for his helpful support and possibility to apply research.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statements
Studies involving animal subjects: No animal studies are presented in this manuscript.
Studies involving human subjects: No human studies are presented in this manuscript.
Inclusion of identifiable human data: No potentially identifiable human images or data is presented in this study.

Conflict of Interests
The author declares no conflict of interest.

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