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To cite this article: B Haske *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1189** 012024

IOP Conf. Series: Earth and Environmental Science 1189 (2023) 012024 doi:10.1088/1755-1315/1189/1/012024

The use of UAVs in supporting the preservation of the industrial and mining heritage in the Ruhr area

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Abstract. Over the last decades, all hard coal mines (the last one in 2018) and many industrial facilities (e.g. coking plants, steel mills) have been closed in the Ruhr region as part of an ongoing, long-term transition process. The centuries-old mining tradition is nevertheless very much embedded in the population. For this reason, the monuments of the industrial age are regarded as defining, identity-forming landmarks that must be preserved as original as possible in the future - not only in the Ruhr region, but also in many comparable regions in Germany (e.g. Saarland, Ibbenbüren or the Aachen area) and worldwide. Extreme weather conditions caused by the fast progressing climate change are affecting these structures of disused steel mills or coking plants. Cracks, paint spalling and other material damage develop, making expensive refurbishment or, in the worst case, demolition necessary. Climate change also affects the subsoil and thus the stability of the facilities by negative environmental influences such as drought or moisture. As part of a feasibility study, the Research Center of Post-Mining is developing an innovative method for non-destructively assessing the condition of monuments of industrial and mining heritage. UAVs (Unmanned Aerial Vehicle) equipped with optical, thermal and multispectral sensors are being used for the first time for this purpose. They collect high precision and high-resolution data, which is viewed and fused together, making it possible to model the complex buildings comprehensively in 3D (+ time) and to examine them for possible damage. In the long term, the highly accurate 3D-models with all their information will be integrated into the spatial data infrastructure of the Ruhr Regional Association (RVR) and thus made available to a broad public and experts from the fields of history, architecture or monument preservation.

1. Introduction

In Germany, the topic of industrial heritage is of great importance and plays a decisive role for the further development of a sustainable after-use of former mining regions. The evaluation and research on proper management in the field of post-mining is especially done at the Research Center of Post-Mining (German abbreviation: FZN) at the Technische Hochschule Georg Agricola University (THGA) in Bochum. In four different research “pillars” the hurdles of long-term effects due to active mining are identified and concepts to counteract, as well as to ensure safety for those affected regions in the future are developed (**Figure 1**) [1].

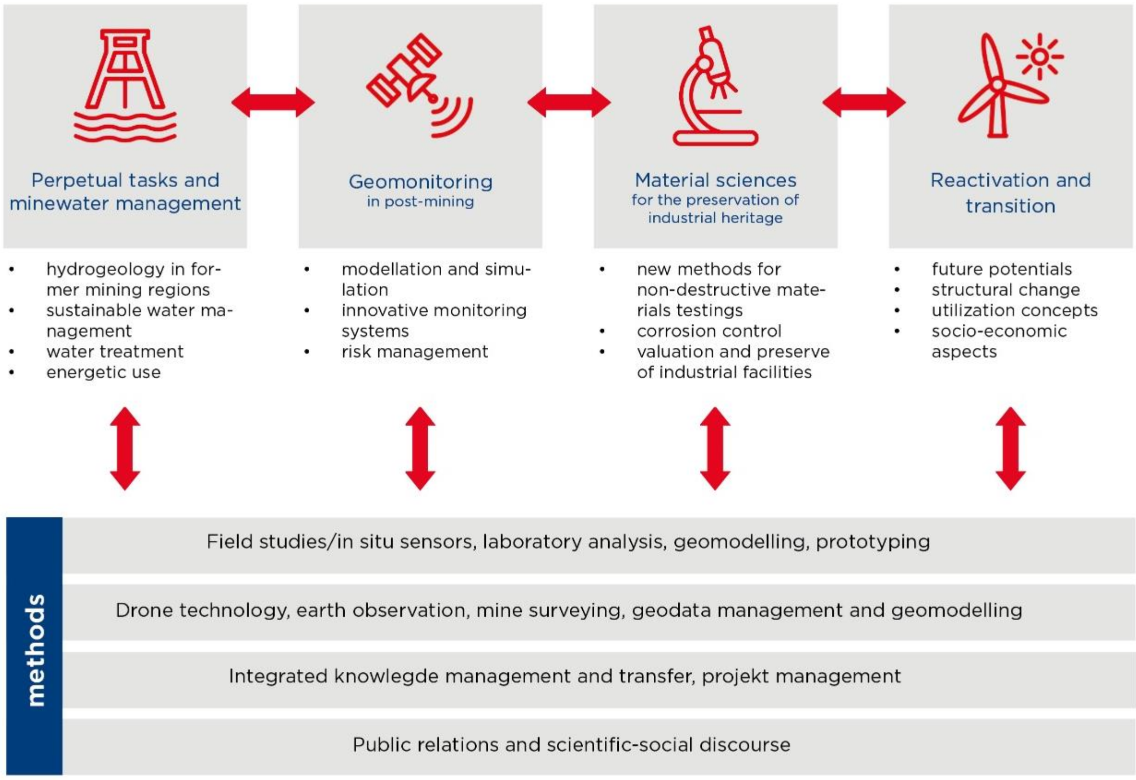

Figure 1: The four research areas ("pillars") at the Research Center of Post-Mining [1]

Over 1000 years old mining tradition embedded in the population with the monuments of the industrial age are regarded as defining, identity-forming landmarks that must be preserved. Extreme weather conditions caused by the fast progressing climate change are affecting these structures of disused headframes, steel mills or coking plants.

The goal is to work together interdisciplinary to get a holistic view on the research targets. An example of combining different expertise is shown in the project “MuM Indukult Ruhr” (German acronym: “Monitoring | Environmental Impacts | Modeling on and of Objects of Industrial Heritage in the Ruhr Area”. This projects brings together different competences from the research areas of geomonitoring, material sciences and reactivation/transition [2]. Now, before a detailed insight into the purpose and goal of MuM Indukult Ruhr is presented, the three research pillars involved here are discussed in more detail.

Geomonitoring

“We develop technical systems for the holistic monitoring of mining impacts. We combine remote sensing methods with special sensor technology and robotics on the surface” [3]. Different methods are used to get this collection of information, such as UAVs with different sensors – e.g. multispectral or thermal infrared – satellite data, in-situ-sensors, geo information systems (GIS) and high precision surveying equipment. The long-term perspective of several research processes is a deep understanding of post-mining processes above and underground, analyzed and risk assessed in digital twins [4] [5] [6] [7].

Material sciences

“For the preservation of industrial culture, we investigate the aging processes of materials. In the best case, the decay cannot merely retarded, but completely stopped. So new chances arise from old shafts” [3]. This area focuses on the analysis of aging processes of different metals or plastics. The

aim behind this is the preservation of industrial heritage, which includes not only machinery but also coking plants, disused mines and plants. To ensure this, the sites and the materials used must be regularly tested for strength. Environmental influences can promote decay and result in collapse or irreparable damage, for example [8] [9].

Reactivation and transition
"We analyze the political, economic and legal frameworks needed to successfully reactivate former industrial locations and their infrastructures. By that we consider regional and municipal objectives, as well as the involvement of the general public" [3]. Besides that the evaluation of social aspects are needed to shape concepts that benefit the whole society. Such concepts can be used for a knowledge transfer on a European or international scale as well [10].

In the interdisciplinary MuM project, the different research pillars work hand in hand and can thus complement each other perfectly.

2. Industrial Heritage Conservation

Together with external partners the Research Center of Post-Mining develops an innovative method for non-destructively assessing the condition of monuments of industrial and mining heritage. UAVs equipped with optical, thermal and multispectral sensors are being used for the first time in this special matter. **Figure 2** clearly shows the different reflection properties of materials in different spectral ranges. The rusty pit frame of the Pluto colliery in Herne (Ruhr Area), Germany, shows clear differences in the temperatures of the material in the thermal infrared images, indicating different material thicknesses. In the multispectral image, biological factors such as verdigris and lichens become visible, which are not discernible in the RGB image.

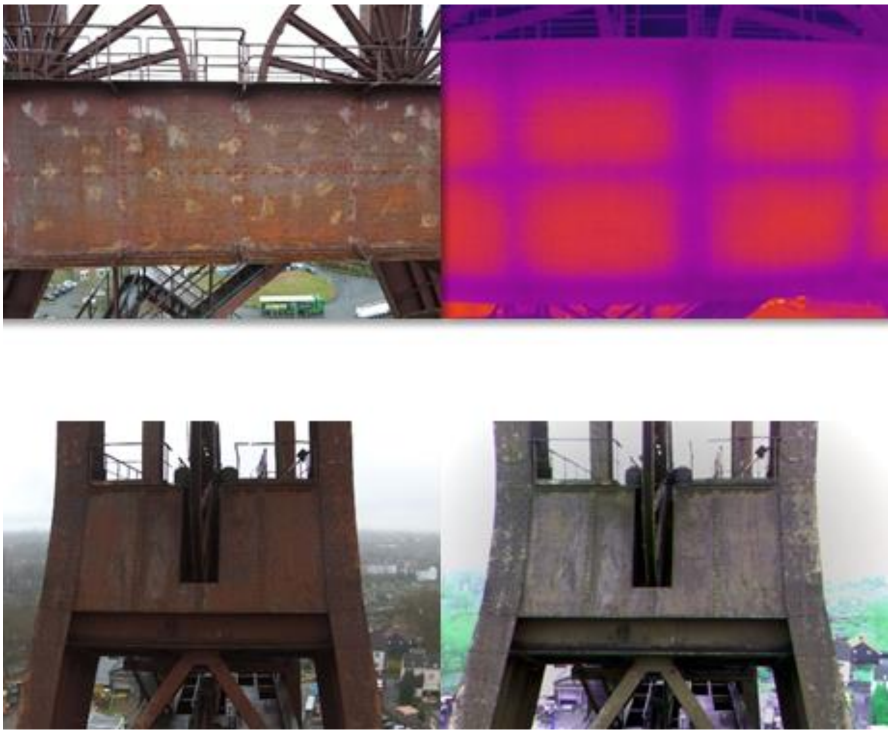

Figure 2: Comparison of the different sensors using the example of the support structure of the disused "Pluto" mine in Herne. Top: RGB and thermal infrared image, RGB and multispectral image in false color display [own image]

High-precision and high-resolution data, viewed and fused together, make it possible to model the complex buildings comprehensively in 3D/4D [6] and use AI-based methods for damage detection [11]. The modelling is particularly important because the legacy of mining, especially the large mining frames, are identity-creating landmarks. After all, at peak times almost half a million people in the region worked directly for the mining industry and countless more indirectly [12]. Since the preservation of all towers and facilities is not possible for economic reasons, this project at least offers the possibility of preserving them digitally for posterity. The 3D models are therefore to be integrated into the existing Route Industriekultur app [13] in collaboration with the Martin Luther School in Hamm [14] and the Ruhr Regional Association (RVR) and made available to the public, also with the help of augmented reality.

3. Socio-economic aspects

This cooperation between the Research Center, the RVR and the Martin Luther School takes place deliberately in order to create a transfer of the technical content and developments into society. The social aspects that go hand in hand with factors such as the large-scale closure of mines in mining-intensive regions and the ensuing structural change, as well as the handling of the mining heritage are often neglected.

The differently affected generations of older and younger residents in such regions associate different values with industrial heritage. It is therefore important to create a balance between these sometimes large gaps in order to create growth and successful structural change in such a transition [10]. In this respect, it is necessary to convey to the younger generations in particular the preservation and identity-forming cultural imprint of the primarily older inhabitants in Germany and the Ruhr Area with regard to industrial culture. This project creates a bridge by explaining the latest technology with traditional resource management in a modern and sustainable way for schoolchildren and testing it in practice. This not only helps the transition of post-mining regions, but should also create impulses to increase the attractiveness of professions threatened with extinction.

There is evidence that the number of apprenticeships in Germany is declining, and more people with specialist qualifications are needed here in particular (**Figure 3**). Through this joint project experience, occupational groups such as restoration or monument preservation will be brought into focus, but attention will also be drawn to study content with corresponding subject content. A playful approach to STEM topics takes place, which is promoted equally for girls and boys.

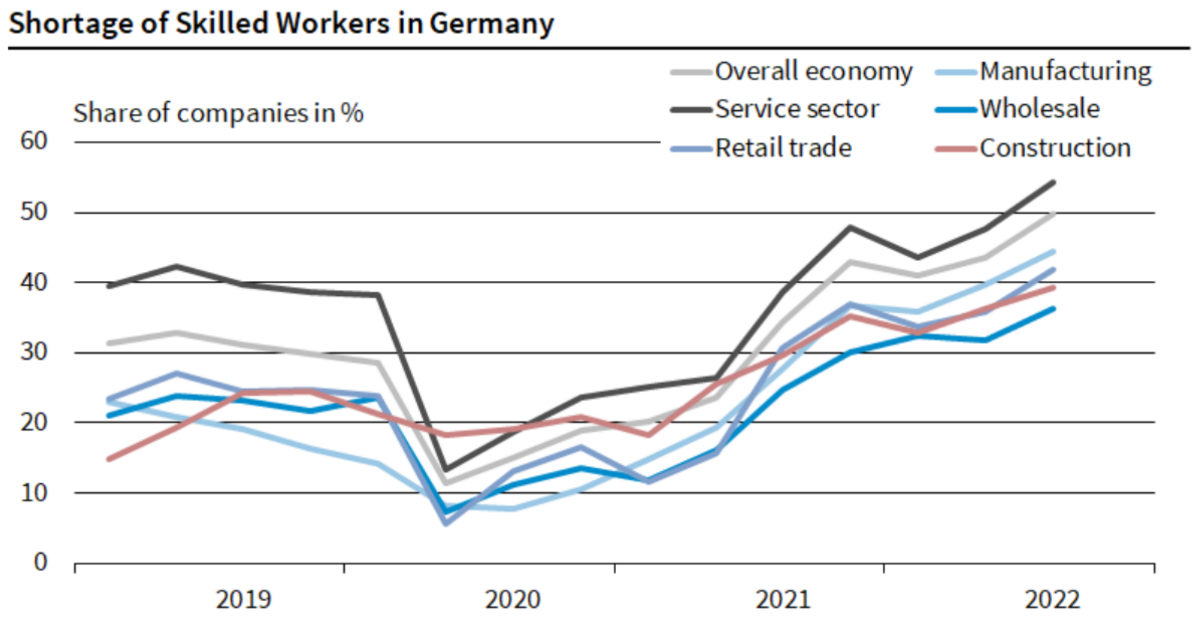

Figure 3: Shortage of skilled workers in Germany [15]

For a successful realization of this project, a student laboratory will be set up in which various practical elements will be applied. Apart from the fact that the students learn how to integrate the 3D-models generated during the aerial surveys of the sites into the existing app of the RVR, a learning process takes place that goes beyond that [13] [14]. Thus, among other things, a thermal imaging camera is being purchased. This example is intended to provide an introduction to the issues of the current critical world situation around (2022) a secure energy supply and saving electricity and gas [16]. The students learn how an energy certificate is composed and its meaning, as well as how the infrared can be used to detect missing insulation, so that damage can result in increased energy demand and are therefore not cost-efficient [6]. Another example is cross-curricular support from other teachers and their expertise to strengthen interdisciplinary teaching. This allows for broad student development opportunities and responsible use of resources and sustainability elements both within and outside of the project.
Due to the large number of factors mentioned, this transfer to society represents an important contribution with regard to the possible development of employment effects and the advancing structural change in the Ruhr Area.

4. Locations

For the MuM Indukult Ruhr project, various sample objects were selected in advance to serve as case studies illustrating the range of industrial culture (**Table 1**). The focus of the selection was on mining frames because of their identity-forming effect as widely visible landmarks, but other objects of industrial and contemporary history were also selected. All objects are to be surveyed with UAVs during the project period, digitized in post-processing, inspected for damage and made available as a 3D-model. Repeated or even regular flights will also allow changes over time to be detected, if possible.

Table 1: Industrial and mining objects used for the case study in the MuM Indukult project [own table]

Object	**Location**	**Type**	**Built**	**Time of operation (Overall)**
Zollverein Hard Coal Mine	Essen	Headframe	1930	1851 – 1986
Zollverein Coking Plant	Essen	Coking Plant	1957 - 1961	1961 – 1993
Radbod Hard Coal Mine	Hamm	Headframes	1905 - 1923	1905 - 1990
Pluto Hard Coal Mine	Herne	Headframe	1964	1862 - 1976
German Mining Museum	Bochum	Museum	1936 - 1960[1]	1930 - today
Hoesch Steel House	Dortmund	Residential building	1965	1965 - 2022

4.1 Zollverein Coal Mine and Coking Plant

Due to its status as a UNESCO World Heritage Site, the Zollverein colliery and the directly adjacent coking plant are the most prominent examples for the case study to be conducted. The colliery, which was active from 1851 to 1986, was given its current iconic appearance by the new construction starting in 1928 by the architect Fritz Schupp, who also built many other collieries and industrial sites in the Ruhr Area (including the Pluto Coal Mine and the German Mining Museum) [17].

To process the large quantities of coal mines, the Zollverein coking plant was built right alongside in the years 1957 - 1961 and was in operation until 1993. In 2001, both buildings were awarded the status of UNESCO World Heritage Sites and are now world-famous landmarks and destinations for industrial culture in the Ruhr Area (**Figure 4**) [17].

[1] The unfinished building was severely damaged by allied bomb strikes in WW2 and rebuild in the 50s. The museum's iconic headframe was built in 1938/39 for shaft 5 of the Germania hard coal mine in Dortmund. It was dismantled after closure and rebuilt above the museum in 1973/74.

Figure 4: Current state of the Zollverein Coking Plant. The coal mine can be seen in the background [own image]

4.2 Radbod Hard Coal Mine

The Radbod colliery in Hamm-Bockum-Hövel was closed down in 1990 after 85 years of operation. It gained worldwide sad fame in 1908 for the worst mining accident in Germany up to that time, with a total of 350 casualties [18]. Today it is best known for its three remaining steel winding frames standing side by side (**Figure 5**).

Figure 5: Two of the three headframes at the former Radbod Hard Coal Mine [own image]

4.3 Pluto Hard Coal Mine

Located in today's Wanne-Eickel district, the Pluto mine in Herne (**Figure 6**) was one of the most important and productive in the Ruhr Area in the 19th century. Maximum production was reached in 1913 with 1.2 million tons and 4655 miners [12]. Today, the surface facilities that remained after the mine closed in 1976 still house, among other things, part of the RAG's mine rescue service and mine fire brigade, as well as central control room, where the Ruhr mining industry's eternal tasks are monitored [19].

Figure 6: UAV picture of the disused former Pluto Hard Coal Mine headframe [own image]

4.4 German Mining Museum

Founded in 1930, the German Mining Museum in Bochum is now the largest mining museum in the world [20]. In addition to the permanent and special exhibitions, it also functions as a Leibniz Research Museum for Georesources since 2016.

With the demonstration mine and the insights into the many facets of mining in the German Mining Museum Bochum are also conveyed underground. On the 1.2 km long underground route network, visitors get impressions of everyday life underground and of the technical-historical developments in mining. From the headframe of the former Germania colliery in Dortmund, which like the museum itself was designed by Fritz Schupp and rebuilt there in 1974, the view extends far across the Ruhr Area and the area shaped by the coal-mining landscape (**Figure 7**).

Figure 7: The headframe above the German Mining Museum as an iconic landmark of Bochum, Germany. In the front: Technische Hochschule Georg Agricola University with the Research Center of Post-Mining [own image]

4.5 Hoesch Steel House

The Hoesch Steel House of type L141 is one of a total of around 200 prefabricated steel houses produced by the Hoesch Company in the 1960s and belongs to the third and last generation [21]. The houses were developed as alternatives to classic construction methods in times of steel overproduction and are thus important cultural-historical witnesses of the Ruhr Area's coal and steel past.

In Dortmund Hombruch, Hoesch built a small settlement of prefabricated steel houses in the large company housing estate from 1962 onwards, in which mainly Hoesch executives lived. The house studied in this project is still there, but is to be transferred to the Hoesch Museum in the course of 2022 [21]. It was therefore one of the first test objects to be captured (**Figure 8**). There are other preserved houses, for example in Münster [22].

Figure 8: Processed 3D-Model of the Hoesch Steel House in Dortmund Hombruch in 2021[own model]

5. UAVs and sensors

The project utilizes various UAVs (**Table 2**, **Figure 9**) as well as other surveying equipment and handheld sensors. The DJI Phantom 4 RTK survey UAV is used to capture high-resolution RGB imagery, while a commercial DJI Mavic Air 2 is used for difficult and confined conditions. A DJI Phantom 4 Multispectral is used for multispectral imaging and a DJI Mavic 2 Enterprise Advanced is used for thermal infrared imaging. With the exception of the Mavic Air 2, all UAVs have a real-time kinematic module that can be used to determine the GNSS positions of the UAV and imagery to within a few centimeters via live processing of satellite correction data. This allows images taken in different spectral ranges to be easily mapped and overlaid using the exact geo-reference, which also enables highly accurate localization of damage and detailed 3D flight plans.

Table 2: Utilized UAVs in the project [own table]

UAV	Sensor(s)	Resolution [pixel]	Remarks
DJI Phantom 4 RTK	RGB	5472×3648 [23]	RTK-Module
DJI Phantom 4 Multispectral	RGB, RE, NIR	1600x1300 [24]	RTK-Module
DJI Mavic 2 Enterprise Advanced	RGB, TIR	640x512 (TIR) [25]	RTK-Module
DJI Mavic Air 2	RGB	8000x6000 [26]	

Figure 9: Utilized UAVs in the project, from left to right: Mavic Air 2, Mavic 2 Enterprise Advanced, Phantom 4 RTK, Phantom 4 Multispectral [own image]

Although the UAVs themselves already enable very high positional accuracy, Ground Control Points (GCP) are still generally used as a reference, which are surveyed and marked with classic surveying equipment (e.g. a Trimble R12). On the one hand, these enable the validation of the flight results and, on the other hand, also allow the integration of data without geo-referencing, such as the hand-held laser scanner GeoSLAM ZEB Horizon. Even when used in conjunction with RTK UAVs, the additional use of GCPs can significantly improve photogrammetrically created 3D-models, especially in boundary areas [27]. Other equipment, e.g. hand-held thermometers and RGB-cameras, are used for in-situ validation of the gathered and processed UAV data.

6. Data acquisition, processing, fusion and presentation

For the data processing of the acquired measurement data and images, different photogrammetric software products are tested and used. Not only commercial products like ESRI's ArcGIS Drone2Map or Agisoft's Metashape Professional are utilized, but also free software like OpenDroneMap. Pre-processing of the laser scans is done in GeoSLAM Connnect, while the point measurements from the Trimble R12 are exported using Trimble Access. Depending on the use case, data analysis, fusion or presentation then takes place in additional (GIS-) software, e.g. ArcGIS Pro, QGIS or ArcGIS Online.

6.1 Flight planning

The planning of UAV flights is different for each object, but follows a fixed pattern. First, the object in question is assessed in terms of location, altitude, extent and complexity, and a rough flight plan and risk concept are created based on these criteria. Depending on the UAV used, this is done in different software, e.g. DJI Pilot, DJI GS Pro or DroneHarmony. After that, the flight is checked for any permits that may be required. The permission of the owners is usually already available, but due to the large-scale flight planning, neighboring properties may also be affected. Likewise, large-scale no-fly or restriction zones, e.g. of airports, industry, roads and railroad lines, nature reserves or residential areas can play a role. Although the Research Center of Post-Mining has a comprehensive exemption permit from the state of North Rhine-Westphalia, this does not cover all eventualities. The (web) app "Map2Fly" from Flynex has proven to be a very useful tool for this purpose, in which the approving authority is also directly indicated in the case of restrictions [28].

Once all permits have been issued, a detailed flight plan can be made. In the case of complex models, an iterative process has proven to be effective, in which the object is first recorded with a rough 3D flight plan (1 grid of nadir images, 4 grids with 60° oblique images from all cardinal directions) and calculated as a 3D-model. Based on this, a much more detailed flight plan can be created in various software (e.g. Metashape or DroneHarmony), in which it is possible to fly much closer to the object and minimize sight-dead spaces (**Figure 10**).

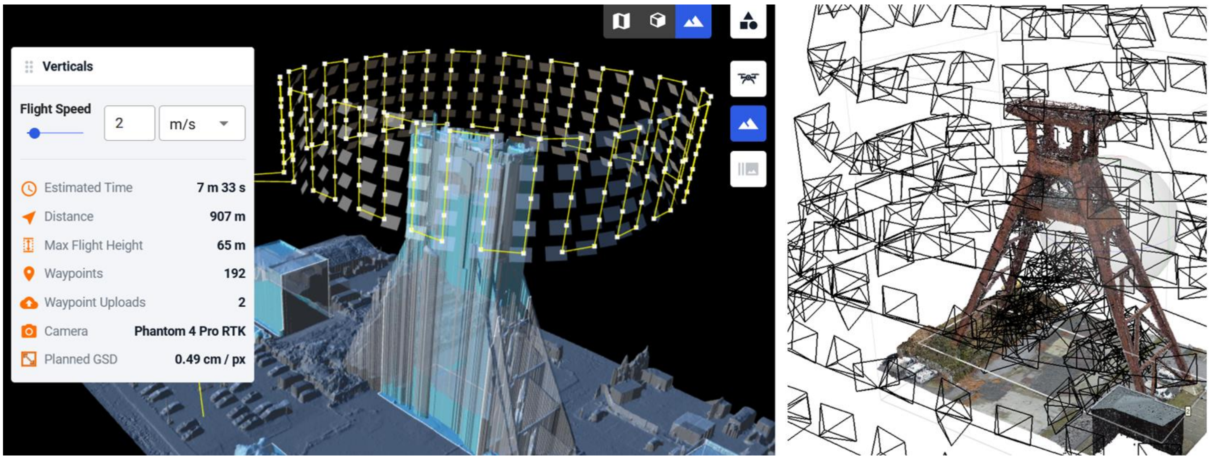

Figure 10: Different approaches to more detailed flight planning of already roughly modeled objects. Left: DroneHarmony, Right: Agisoft Metashape Professional [own models]

On the flight day itself, it is still necessary to check whether the weather is within the prescribed flight parameters for the UAV in question. Before the flight plans are executed, they must also be checked on site to take into account any obstacles that were not visible or indicated on the map.

6.2 Data acquisition

Data acquisition is performed using the flight plans created in the office and verified in the field. If possible, the flight plans of the individual UAVs shall be adjusted so that the various sensors on the object have a similar ground resolution. Before, during, and after the flights, the environmental parameters such as temperatures, cloud cover, and solar radiation have to be noted in order to draw conclusions from them later in the processing. Additional in-situ measurements (e.g. temperature) and photos should also be taken for validation and documentation.

For the radiometric calibration [29] of multispectral cameras and thus to calculate atmospheric effects, the project team uses a MicaSense calibration panel. By using the known reflectance values of its calibrated measurement surface, the values of the five spectral ranges can be radiometrically calibrated in post-processing with the help of a transfer function [30]:

$$F_i = \frac{\rho_i}{avg(L_i)}$$

With F_i as the reflectance calibration factor for band i, ρ_i as the average reflectance of the panel for the ith band (provided in a csv-table by MicaSense) and $avg(L_i)$ as the average value of the radiance for the pixels inside the panel for band i. Although this process is optimized for MicaSense multispectral cameras, it has been tested to be applied to the used DJI Phantom 4 Multispectral to calibrate each of the 5 bands independently in the post-processing.

6.3 Photogrammetry

For photogrammetric evaluation, different software products are tested as mentioned before. Depending on the type and complexity of the object, processing parameters have to be adjusted manually. However, the basic photogrammetric workflow is almost the same in all software and is briefly explained here using Agisoft Metashape Professional as an example:

1. Import of the images,
2. import of Ground Control Points (GCP), if necessary,
3. sorting of the images by sensors (these are calibrated differently),
4. radiometric calibration of the multispectral images,
5. alignment of the photos via Structure from Motion [31],

6. assignment of images and GCP,
7. creation of a dense point cloud,
8. creation of a 3D-model by meshing the point cloud,
9. creation of a texture for the 3D-model,
10. creation of 2D orthophotos, if necessary,
11. export and analysis of a quality report,
12. post-processing or iterative recalculation of the previous products, if necessary and
13. export of various 2D and 3D products.

The processing pipeline of similar software, e.g. ArcGIS Drone2Map or OpenDroneMap differs only slightly (**Figure 11**).

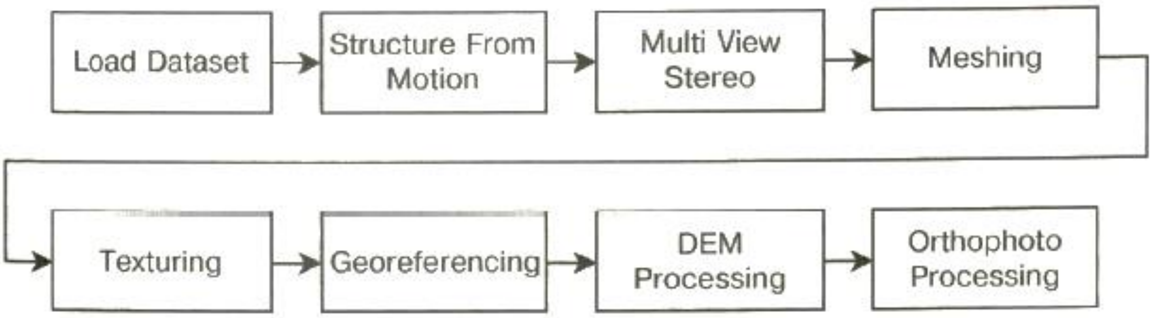

Figure 11: OpenDroneMap's processing pipeline [32]

6.4 Data fusion and analysis

The very good geo-referencing of the image data makes it possible in post-processing to superimpose the different spectral ranges as information layers with pixel accuracy and thus to analyze them together (**Figure 12**). This is particularly helpful for damage analysis, since different types of damage can be displayed differently in the various spectral ranges (**Figure 13**). In the course of the project, the information collected on the objects and in the laboratory is to be combined in a damage database in order to simplify or, in the best case, automate subsequent analyses. It will also be tested whether it is more useful to examine the 3D-models, 2D composite images, or only the aligned and geo-referenced individual images. AI and deep learning approaches will also be tested for this purpose.

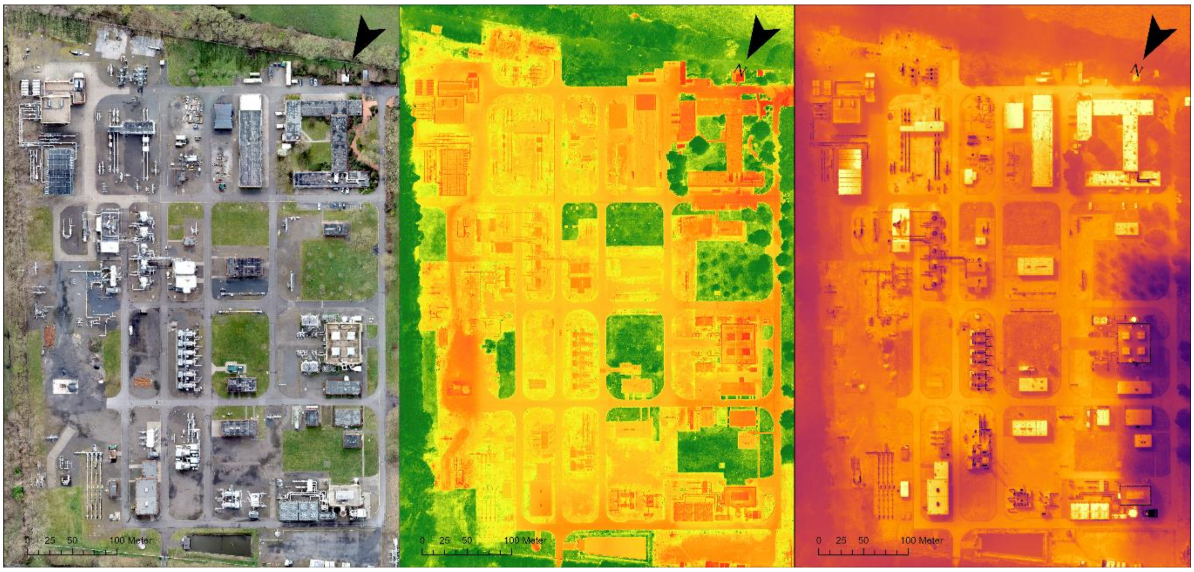

Figure 12: Superposition of the different spectral ranges based on their highly accurate geo-referencing. From left to right: RGB, Normalized Difference Vegetation Index (NDVI) calculated from multispectral images, relative temperature values from thermal infrared images [6]

Figure 13: Different types of damage show up variably in different spectral ranges. Left: Thermal infrared, Right: RGB [own image]

6.5 Presentation

The presentation and dissemination of the 3D-models created will be based on their future use. In principle, all models will be made available to the public via the AR app already described [13] [14]. However, other ways of making them available, for example via an interactive WebGIS, are also being tested (**Figure 14**).

Figure 14: Technische Hochschule Georg Agricola University with the Research Center of Post-Mining in front presented as a tiled 3D model in an interactive WebGIS [33]

7. Interpretation

Within the project duration so far, the use of UAVs could be recognized as a considerable benefit in the preservation of the cultural heritage in the Ruhr Area. The airborne data acquisition is fast, thorough and with a high resolution compared to classical surveying or building documentation methods. Various 3D-models that have already been created have so far been well received by the project partners involved and the public. The integration of socio-economic aspects and the development of a student laboratory have also been very successful so far. Great progress has also been made in the development of various approaches and algorithms for damage detection and classification, both in the laboratory and on the various objects.

8. Outlook

At the end of the ongoing project period and in the outlook beyond, the following goals are to be achieved in perspective:

- Improvement of damage detection algorithms in cooperation with geo- and material scientists.
- Creation of an extensive damage database to be applied to future research.
- Integration of the 3D.models into the existing AR app.
- Establishment of the student lab for knowledge transfer.
- Evaluation of social scientific and economic aspects.
- Finalization and usage of the student laboratory at the Martin Luther School.
- This initial evaluation with the help of a school class can serve as a hook for conceptual design for other schools to attractively integrate STEM and related educational opportunities.
- Based on the fundamentals and results achieved at the end of the project, a dedicated follow-up application is to be submitted.

So far, all project goals are well on schedule. Based on the knowledge gained and methods developed to this point, further research collaborations have already been initiated and synergy effects with existing projects have been created. The currently very fast progress in sensor technology and processing software could always be profitably taken into account, so that all findings correspond to the current state of science and technology. A continuation or even expansion of the project is very likely.

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