A Comprehensive Framework for High Resolution Image-based 3D Modeling and Documentation of Crime Scenes and Disaster Sites

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Abstract—Serious crime scenes or disaster sites with many victims after natural disasters, airplane crashes or terrorist attacks require extensive and comprehensive investigations to clarify all circumstances leading to the event, to identify the victims and to find the responsible people. The results of investigations do not only serve to prosecute the perpetrators, yet are mainly used to develop preventive strategies and to strengthen the resilience of the society. 3D reconstructions of crime scenes and disaster sites provide a quick and comprehensive method to support the work of investigators digitally. The detailed reconstruction of the scene allows not only a long term documentation, yet also the simulation of alternative scenarios. To create a 3D reconstruction a large number of parameters has to be taken into account in order to make the necessary decisions. To this point there is no standardized procedure for the reconstruction of serious crime scenes or disaster sites. The framework presented in this paper can serve as a simple guide to create a 3D reconstruction. However, it can also be easily implemented in an already existing forensic process chain of investigative services. In this sense, it can form the basis for a standardization and thus ensure the comparability of different models. Additionally, a detailed description of an application of this framework for a real crime scene is given.

Keywords–*forensic; resilience engineering; framework; 3D reconstruction; photogrammetry*

I. INTRODUCTION

A. Background

Many forensic issues require the reconstruction of crime scenes or desaster sites in order to allow a quick and detailed investigation. In addition to identifying victims, perpetrators and third parties involved, it is of particular interest to gain knowledge in order to develop preventative strategies in the context of resilience engineering. Furthermore, information obtained from ad hoc digital models can help to control the situation, especially in rough terrain, by providing a tool to support the coordination of emergency services. Using the example of the Germanwings aircraft crash in March 2015 in the French Alps, it was shown how aerial photogrammetry can be used to create 3D models to manage the situation and elucidating such major damage events [1]. Another area of application is the reconstruction of crime scenes and subsequent simulation of possible courses of events documented in way that can be presented in front of a court of law. Previously used methods are based on laser scanning technology, as shown in [2]–[8]. Disadvantages of these technologies are high acquisition costs as well as limited mobility. As a result the use of these technologies is only reserved for a few special forces. However, photo equipment and smartphones have become a nationwide standard for all emergency services. It is therefore obvious to use these devices for the reconstruction of crime scenes and allows an analytical 3D examination of each crime scene and event site.

B. Literature Review

In photogrammetry, an alternative to laser scanners, images taken with a camera are used to create 3D models. With a software these images are aligned and the corresponding camera positions are calculated. In a next step, 3D point clouds are created, which are then used to create a 3D model. For taking these pictures several camera systems are available, yet most commonly SLR cameras are used. Even though these cameras are used for photogrammetry in several areas, for example in the documentation of archeological sites [9], underwater research [10], forensics like analysis of road accidents [11], [12] and the documentation of autopsies [13], of particular interest for this paper are 3D reconstructions of larger outdoor areas and buildings based on pictures taken with SLRs. Already in 2004 Kersten et al. showed the potential of images taken with a single-lens reflex camera to create 3D models using photogrammetry [14]. At that time, they used a combination of automated and other methods, to conduct a reconstruction of a castle. In a later study they once again used images of buildings taken with an SLR camera, which were processed using open-source, proprietary and web-based software solutions. The results were compared to laser scans and

the authors found that SLR images processed with open-source software can deliver 3D models of comparable quality [15], [16]. Similar results were reported by Falkingham et al., who took photographs of archaeological objects with an Olympus Megapixel Camera and processed them with appropriate open-source software [17]. Furthermore, Ziegler et al. were also able to positively evaluate the use of SLR cameras in combination with open source software for 3D modeling in their work from 2014 [18]. Additionally, several research groups analyzed the suitability of SLR images as well as the use of photogrammetric software solutions to calculate 3D models. Kersten et al. and Falkingham et al. focused on terrestrial images, yet also on how pictures taken from a helicopter or UAV may be used as an additional source. Actually, pictures taken with the help of helicopters or UAVs, for example drones, play an essential role in the research on photogrammetric 3D models for example of disaster sites. In 2008 Püschel et al. showed the potential of taking images of the Landenberg castle using drones with SLR cameras as payload [8]. Moreover, in the review of UAVs for photogrammetry and remote sensing by Colomina et al. it becomes clear to the reader, that there is a great advantage of using drones and their corresponding payloads for the creation of 3D models of large disaster sites [19]. Furthermore, Urbanova et al. discussed in their study the use of drone-mounted cameras for the documentation of bodies and show possible applications for the forensic sectors, especially the digitalization of crime scenes. Additionally, in 2015 Resig showed that in addition to drones, other flying devices, for example a kite, can be used to collect aerial images used for 3D models [20]. However, for the reconstruction of large disaster sites, not only buildings, yet also larger areas play a crucial role. Bendea et al, Naidoo et al. and Barazzetti et al. discuss in their studies the successful application of the aforementioned methodologies for the reconstruction of disaster sites, accidents and crime scenes as well as search and rescue operations [21]–[23]. Even though the aforementioned studies all made great contributions to the research of photogrammetry for the creation of 3D models, they only focus on methodologies, techniques and technologies and do not provide a consistent approach starting with the planning process up until finishing the 3D model. Hence, Kersten et al. present a straightforward framework for creating 3D models using photogrammetry, which can be used to plan a scene reconstruction, yet unfortunately more information about how to proceed beyond the planning process is not given [15]. Again, Püschel et al. specify in their study how collected data is processed, yet keep their descriptions very general and do not provide more detailed information [8]. Zancajo-Blazquez et al. present a comprehensive workflow for the 3D reconstruction of crime scenes, but focus in their studies rather on interiors than on larger areas [24]. Similarly, in their framework Kim et al. and González-Aguilera et al. describe the 3D reconstruction of disaster sites and larger areas as well as crime scenes based on images and open-source software, yet do not give information about what parameters are available in the software applications, which makes it difficult to derive a consistent approach [25]–[27]. Even though Gindraux et al. give a basic approach for the software Agisoft PhotoScan in their study from 2017,

including recommendations for settings of software-specific parameters, it is only useful for a quick reconstruction and if the user has enough knowledge about the equipment and the image and procedural requirements. Therefore, there is no universal description for the 3D reconstruction of crime scenes and disaster sites, which gives sufficiently detailed information about all necessary process steps and parameters. Frameworks that provide an overview of necessary process steps from the planning phase to the dissemination of results are already be found in areas such as cultural inheritance as well as intelligence and reconnaissance. Makantasis et al. present a framework for the 3D documentation and reconstruction of cultural monuments from data acquisition to the processed model. They describe possible calculation errors of the 3D models and approaches to optimize the results in detail. Unfortunately, they provide only general information about the remaining process steps [28]. Xu et al. describe in their framework the 3D reconstruction of a cultural monument based on video recordings. In addition to the description of data acquisition using UAVs, information about the data processing are given by means of software applications such as VisualSfM in combination with PMVS. The framework provides a helpful overview of necessary process steps, but requires expert knowledge in many places [29]. Napolitano et al. presented a framework for the conservation of cultural heritage sites and provide additional information about incurred costs and the duration of individual process steps such as data collection. Despite the necessity of this information, unfortunately, there are only few details given about for example equipment for planning or parameterization for data processing [30]. Torres-Martínez et al. describe a comprehensive framework in the field of reconnaissance and remote sensing from the planning phase up to visualization possibilities of finished 3D models. Despite the clear and comprehensive information in some places only a few details are given such as necessary parametrization for processing collected data. Furthermore a lot of expert knowledge is required. However, this framework provides a basic overview of necessary process steps [31].

C. Objectives

To the knowledge of the authors up to this date, there is no consistent approach on 3D-reconstruction in the context of forensic investigations. Therefore, a comprehensive framework addressing this issue is presented in this paper It relies on previous research and applications in the field of photogrammetric modeling, as described in the previous section. In Section II-A the entire framework is presented followed by a detailed description of all modules and sub-steps. Section III shows the reconstruction of one test scenario and one cold case as an examples of how this framework can be implemented in practice. In addition, the influence of various parameters on model quality and computation time is demonstrated. The work concludes with a brief summary and gives an outlook on further work.

II. COMPREHENSIVE FRAMEWORK FOR CRIME SCENE AND DISASTER SITE RECONSTRUCTION

A. General Framework

The process of reconstructing forensically relevant items and complex crime scenes or disaster sites is similar, which is why the same schema can be used for all of them. The process usually consists of four to six modules (Fig. 1), which are selected depending on the purpose of the reconstruction and what data is used.

- **Planning:** operational coordination, strategy and resource planning as well as technology choice.
- **Data Collection:** parameterization, data collection, data preprocessing to ensure a uniform and consistent data base as a requirement for the following steps.
- **VSFM – CMPMVS – MeshLab/Agisoft Processing:** generation of 3D models
- **Data Integration:** integration of detailed models to supplement and complete a specific professional perspective (for example biological traces).
- **Simulation:** simulation of courses of events allow the mutual exclusion of alternative courses as well as the development of prevention strategies.
- **Documentation:** filing and court-proof documentation of all relevant model parameters, source data and results to ensure traceability of procedures and results

The starting point is always an incident or an inquiry by the prosecution, the defense or a judge. Subsequently, in the planning module decisions have to be made regarding what resources, technologies and strategies should be employed. Afterwards, within the data collection module, different ways are presented to collect the data and prepare it, after setting important parameters, for the creation of the 3D model. At this point, the decision has to be made whether to create the 3D model using open source or proprietary software. This decision is affected by factors like cost, training time, functionality, flexibility, portability as well as limitations in the image format. As a result of the respective processing module, a basic 3D model is generated. If the scene to be reconstructed as a 3D model is a more complex scene such as a crime scene, it has to be decided whether additional items, for example evidence, people or objects, should be added iteratively as 3D models. Consequently, the reconstruction of every item again starts with the planning module. Is the 3D model such an item it can either be integrated in an already existing scene or it can be documented as a separate 3D model. If no additional items have to be added, a simulation of the course of events can be done, if required. The result of the simulation is a realistic, complex, physically correct and fully parameterizable 3D model with integrated animations showing the course of events. The collected data in the form of images, the methodical procedures and techniques, which were used, the software-specific parameterizations as well as the calculated 3D models and simulations have to be documented in a way they can be used before a court of law. This can be

achieved by following the steps of the documentation module. In the following section a detailed description of each module will be given.
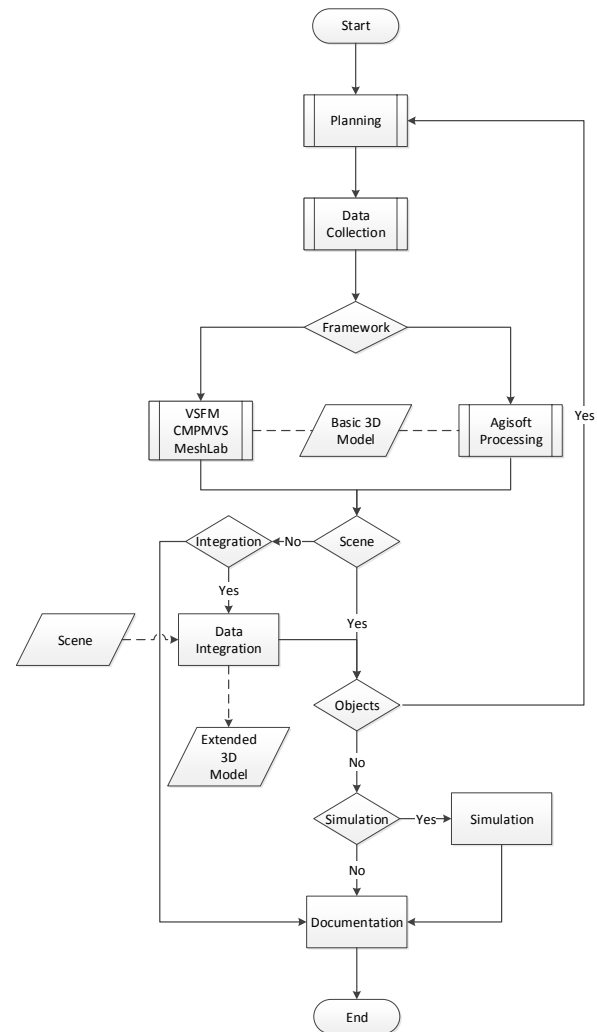

Figure 1. Framework for photogrammetric 3D reconstruction of crime scenes and disaster sites.

B. Planning Module

The "Planning Module" as illustrated in Fig. 2 is constituted of three general tasks:

1) the description of the scenario,
2) selection of an appropriate strategy, and
3) the orchestration of necessary equipment.

At the beginning, it is important to describe the item that is going to get reconstructed. The item can be a single object as part of a complex scene or the scene itself. For the latter it is
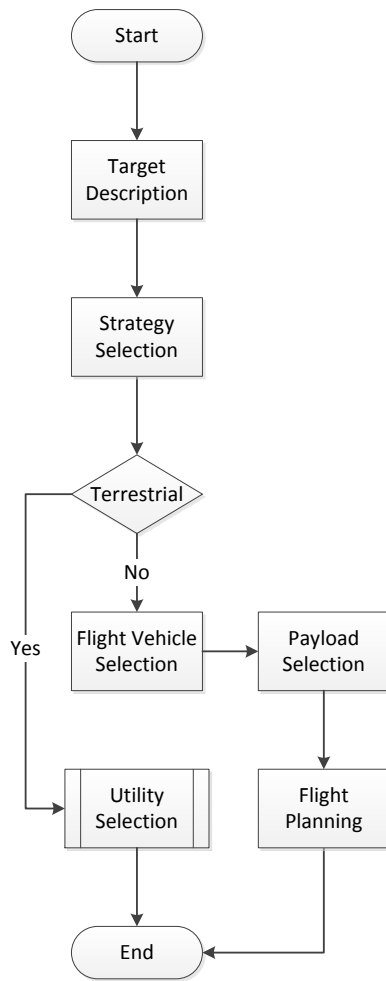
Figure 2. Description of the Planning Module.

especially for buildings with a contorted layout. After choosing the right technique, the decision has to be made, whether the data should be collected from the ground or with the help of a flying device. If the data is collected from the ground one can choose without further preparations, which hardware to use such as photography/video equipment (like camera, objective and filters) or an automatic rotator for taking pictures of single objects. Experiments showed when using an automatic rotator a homogenously colored wall in the background in combination with a stationary camera ensures a 3D object of high quality. If aerial images/videos are required, at first the flying device has to be chosen, for example a helicopter or a fitting drone type. Afterwards, one can choose the respective payload (e.g., camera, thermal sensors or gas sensors) depending on the loading capacity of the flying device and the data that needs to be collected. Finally, taking into account the description, the chosen strategy to collect the data and the chosen flying device, one can start to plan the flight using a suitable software (manufacturer-specific or open access sources like GoogleMaps) in consideration of the environmental conditions.
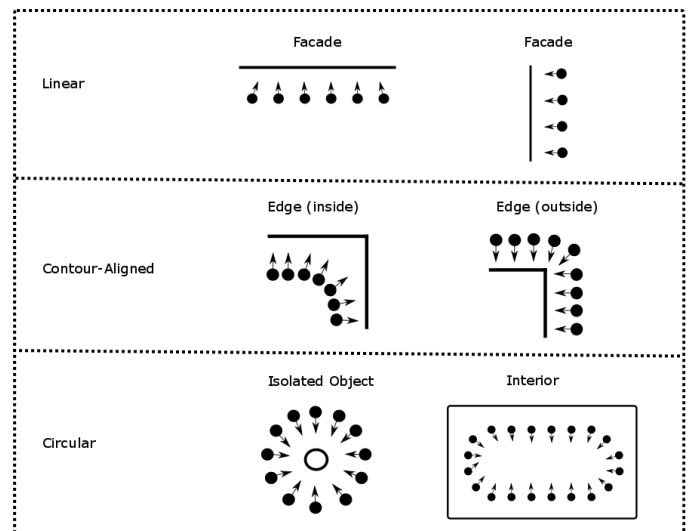

Figure 3. Overview about various strategies for data collection.

important to determine, whether the site to be reconstructed is indoors or outdoors and other aspects that might influence the process of collecting the data and the reconstruction, including vegetation, buildings and possible obstacles like high-voltage lines. Furthermore, it is important to assess the accessibility of the site in general. With the help of the detailed description it is possible to choose a suitable strategy for taking the pictures or making the video. Three different strategies are possible: linear, contour-aligned or circular (Fig. 3). In most cases taking the pictures or making the video in a circular manner is the best option, especially for small items or aerial images as long as the terrain allows to do so and the flight path is not affected by any obstacles. The linear technique is especially suitable for the reconstruction of walls (inside or outside), facades and the reconstruction of long stretches of ground for example streets or rivers. However, when reconstructing buildings the contour-aligned method has many advantages,

C. Data Collection Module

The process of collecting data as illustrated in Fig. 4 is one of the most important steps during the reconstruction process, since the decisions made here, for example about the parameterization of the hardware used, directly influence the quality of the generated 3D models.

1) Type: selection of the type of recording (video and images),
2) Parameter setting: parameterization of hardware used,
3) Collection: actual data acquisition,
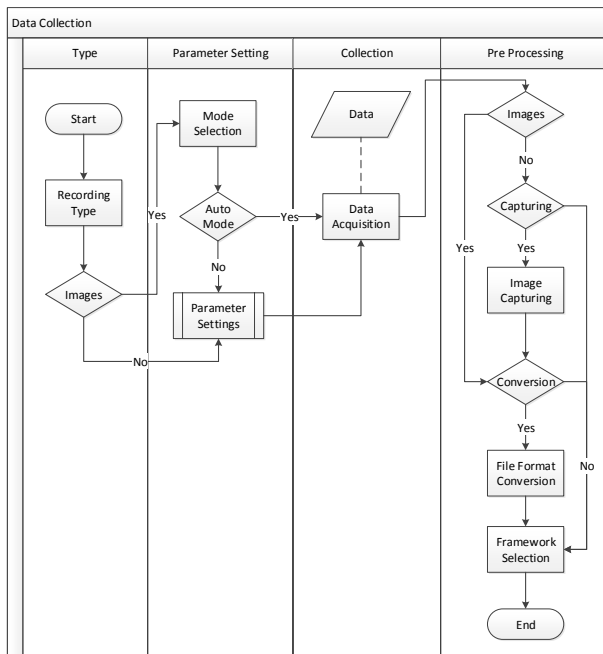4) Pre-Processing: conversion to an appropriate file format for further processing steps

Figure 4. Overview of the data collection module.

Depending on the device used, the image or video file format must be chosen. It is recommended to use video recordings, because the acquisition of data is much quicker, and to only use photographs if time is not a concern. When taking a sequence of pictures, one has to decide, which image recording mode is most suitable (for example day/night, landscape, macro, car etc.). In case of using the automatic mode, the picture taking can be started without any further adjustments. For video recordings or when using a mode other than automatic, depending on the hardware it may be necessary to set up other parameters, such as the aperture or the shutter speed, before the actual picture taking or video making can be carried out. Furthermore, it is recommended to set the ISO value as low as possible to prevent additional noise in the images and, correspondingly, use a high f-number for a sufficient depth of field. Regardless of the mode and the selected parameters, it is recommended to use the highest camera resolution that is possible (full HD resolution for videos). Additionally, for objects it is recommended to use a mode that allows taking continued shots in order to have images with a sufficient overlap. After collected the data it must be decided, which model generation software (open source or Agisoft PhotoScan) should be used. However, in the case of video recordings, single images must be extracted beforehand. Depending on what software was chosen it has to be decided whether any preprocessing steps are necessary, such as filtering, enhancing the image quality or converting it to another image file format.

D. 3D Disaster-Site Reconstruction

1) VSFM – CMPMVS – MeshLab: Open source software applications are a low-cost option to create 3D objects or complex scenarios based on images. The process to create models using photogrammetry as presented in Fig. 5 is based on the applications *VisualSFM*, *CMPMVS* and *MeshLab* and consists of the following two general tasks:

1) Structure from Motion: 3D model generation of single objects or complex scenes, and
2) Post Processing: editing and optimization of generated models.

The first step in creating a 3D model is to calculate a point cloud of the aligned and overlapping photographs. For the calculation of the point cloud one can use the software package *VisualSFM*, which is mentioned in several papers [32] [33] and was used in previous work by the authors [1] [34]. However, before calculating the point cloud necessary parameters have to be set such as the maximal number of calculated features or the maximal acceptable resolution of the photographs used. Subsequently, the process step *Execute SIFT* determines reference points in the pictures, which are saved as key point descriptors and are the basis for creating the point cloud images. Nonetheless, for the actual *3D Scene Reconstruction* a sparse point cloud, based on a minimal number of features will be calculated first. This sparse point cloud can then be used to automatically create a textured model using the software *CMPMVS*, which was mentioned in several papers [35] [18]. The process consist of the following three steps:

1) Execute CMVS (Clustering Views for Multi-view Stereo): fragmentation of the sparse point cloud into single clusters for quicker processing,
2) Execute PMVS (Patch-based Multi-view Stereo Software): enrichment of the sparse point cloud and calculation of a dense point cloud, and
3) Texturing: creation of a textured mesh

An alternative would be the sub steps CMVS und PMVS, also included as a function in *VisualSFM*. In this case the resulting model would be a dense cloud, which would have to be transformed into a textured mesh with the software *MeshLab* [36]. Afterwards, the mesh can be used in the subsequent process steps. However, our own experiments have shown that it is difficult to create good models with this method, because of the enormous parametrization. The calculated 3D model can be optimized in *MeshLab* (possible output formats: *.ply, *.stl, *.off, *.obj, *.3ds, *.vrml 2.0, *.u3d, *.x3d and *.dae). Because of insufficient quality of the pictures, it is often necessary to edit individual areas of the model, for example by deleting artefacts or filling in holes.

2) Agisoft PhotoScan: An alternative to an open-source software application is the software Agisoft PhotoScan, a proprietary software for creating 3D models using photographs or videos. The process of creating a 3D model is illustrated in Fig. 6 and can be divided into two tasks:
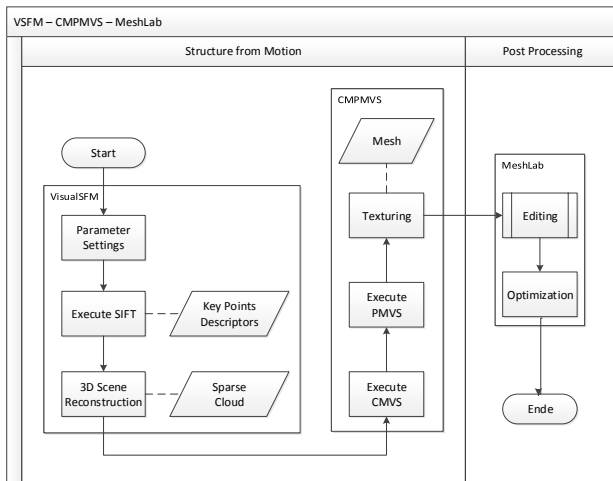
Figure 5. Detailed VSFM – CMPMVS – MeshLab processing module.

1) Pre-Processing: check image quality and camera calibration,
2) Model Generation: generation of fully textured model

After importing the photographs, they are displayed as thumbnails, which allow a visual examination of the photographs regarding their completeness and quality. An advantage of Agisoft PhotoScan is the option to quantify the quality of the photographs in a range of $[0-1]$ and the manufacturer recommends to exclude all pictures with an estimated quality of 0.5 or less. While the photographs are imported the software will automatically check by means of the EXIF data, whether a camera calibration – the compensation of the distortion of the lens – has already taken place. If the compensation is missing, it can be calculated mathematically by entering manually the lens parameters such as the radial distortion coefficient, the distortion center and the tangential distortion coefficient. After setting some parameters that influence the quality, the sparse point cloud is calculated using a similar concept as described in section II-D1. After some further optimization steps, for example removing redundant points or eliminating projection errors, the sparse point cloud is densified into a dense point cloud. Before the texture is transferred in a final step from the photographs onto the model, the points have to be interconnected to create a 3D mesh (possible output formats: *.obj, *.3ds, *.3ds, *.dae, *.ply, *.stl, *.dxf, *.fbx, *.u3d, *.wrl, *.kmz, *.pdf).

E. Data Integration

In many cases, it is necessary to integrate additional objects in the generated 3D scenes. In particular, for the simulation of possible courses of events, 3D models of, for example, evidence, victims or objects used in the commission of a crime are often essential and indispensable. In general, small objects can be added to larger scenes using the software already
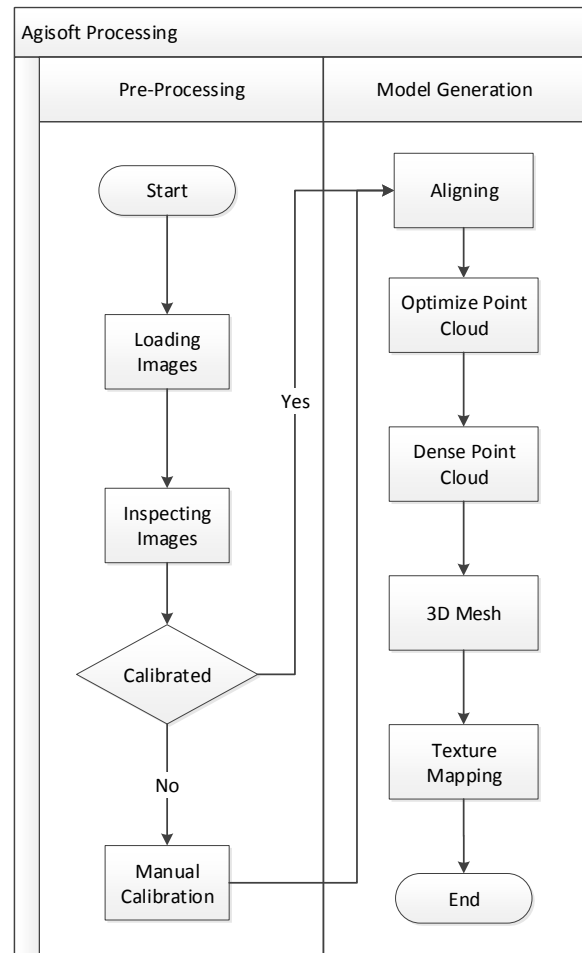

Figure 6. Detailed Agisoft processing module.

mentioned in the sections II-D1 and II-D2. However, in view of an eventual simulation it is recommendable to integrate the objects with the simulation software Blender. The simulation of the course of events can be started as soon as all necessary object are integrated in the extended 3D model. If no additional objects are needed, one can skip this part and start directly with the documentation.

F. Simulation and Documentation

For the analysis of possible circumstances of a crime the reconstructed 3D scenes can be used to carry out computer-aided simulations. The simulations can aid in comparing alternative interactions between people (e.g., perpetrator and victim), between people and objects (e.g., weapon and victim) or between several objects (e.g., a projectile and a wall) and thus may help in drawing conclusions about the actual course of events. An additional application is the simulation of the

spread of biological or chemical pollutants in accidents or investigations of environmental crimes. For the computer-aided simulations, a variety of software applications is available. At this point it is recommended to use the open-source modeling software "Blender". The integrated physics engine allows to visualize complex physical processes n form of three-dimensional simulations. After creating single objects, complex 3D scenarios and simulations, all the steps taken including all decisions made, what values for the parameters were chosen and, which software applications were uses as well as the results, must be documented in a way they can presented in front of a court of law.

III. Prototypical Application

In this section two scenarios demonstrating the utilization of the proposed framework are discussed. In addition a brief summary on technical details of used hardware is given. The first scenario involves the employment of various imaging techniques to the water tower located in Mittweida and its surrounding area, which provides an ideal test ground due to the size of the area and the tower as well as small details aimed to be captured accurately in the reconstruction process. The second scenario is a real-life application to a crime scene in Jena Lobeda. In discussing both scenarios, more details on program usage and parameterization are given, thus extending the elucidations on the proposed frameworks towards their utilization in practice.

A. Technical Details

1) Drone: The drone used in our study is a *MikroKopter MK-ARF OktoXL 6S12*, an eight-blade rotary wing drone for multi-purpose utilization. In our set-up the MK OktoXL 6S12 has a maximum slant range of 4,000 m and a maximum ceiling of 5,000 m above sea level. With fully charged batteries and optimal weather conditions, the drone achieves a maximum flight time of about 30 minutes. Besides present weather conditions, maximum flight time is reduced by hardware additionally mounted to the drone, such as a fixed SLR camera. Furthermore, the drone is equipped with a CMOS camera whose video feed can be received and post-processed on the ground. Although not-movable around the yaw axes, both the CMOS camera and SLR camera mount can be pitched and rolled. In combination with automated pre-planned waypoint flight and POI focusing capabilities as well as automated camera triggering, the user is thus able to obtain images made in-flight at pre-planned positions and altitudes. Waypoints and trigger events can be set-up and uploaded to the drone using the maintenance and control software MikroKopter-Tool (software version used in this study: V2.12a).

2) Camera Equipment: If the used drone systems do not have a built-in camera, as it is the case for the MK-ARF OktoXL 6S12, additional camera equipment is needed. In principle, any mountable camera can be used, but factors such as resolution, parameterization of images and data format should be considered. The systems used should support a minimum

resolution of 1920x1080 pixels, allow a parameterization of aperture, shutter speed, ISO and other parameters, as well as support data formats such as RAW or JPG. The camera used in this study is a Nikon D7100 SLR camera. Due to the compact design and the low weight of 765 grams, this camera is ideal as a payload for the presented drone system. The Nikon D7100 features an optical low pass filter and 24.1 megapixel CMOS sensor. There are 51 measuring fields available for the autofocus system. The camera allows continuous shooting at 6 frames per second with a maximum possible resolution of 6,000 x 4,000 pixels and video recordings with a maximum of 1,920 x 1,080 pixels. Supported file formats are RAW and JPG.

3) Motor-driven Turntable: For capturing smaller objects such as ensured traces, the use of an automatic, motor-driven turntable is recommended. In this study, a model of the company *stageonair* was used, which allows a 360° object imagery. The diameter of the turntable is 62.5 cm, the load is designed for 150 kg. The associated software allows individual adjustment of the direction of rotation and speed of the turntable as well as the number of images, which can be realized using the automatic camera release. If the possibility using such systems is not be given, due to its practicability in field utilization, lighter but not motorized turntables can be used as an alternative.

B. Test Scenario I — Mittweida Water Tower

The area in question is well-suitable for testing the proposed framework. The tower is about 38 m high and has a base diameter of 10 to 16 m. The surrounding area (about 150 m in diameter) is rather flat with no obstructing obstacles present. Small details (< 50 cm) on the tower surface provide references for qualitative evaluation of resolution and accuracy of obtained models. In Figure 7 models of the area are shown. Both models are based on images obtained by a drone-mounted SLR camera. As proposed, the drone was programmed to fly a circular flight path (50 m radius) at constant height above ground level. In this case an altitude of 50 m was chosen in order to provide a 45° look-down camera angle. Images were extracted from recorded HD video material every single second, resulting to 111 images with a resolution of 1,920 x 1,080 pixels, and processed as proposed. Although major details are discernible, smaller features with a size of about less than one meter are difficult to identify. On a standard desktop machine (eight 3.5 GHz CPUs, 32GB RAM, GeForce 750 GTX Titan), the 3D reconstruction process required about 1.5 to 2 hours of computation time and 1.5GB of disk space using the Open-Source software framework, about 2 to 2.5 hours and 2GB of disk space using the Agisoft PhotoScan framework. In a previous study, the authors showed that, in a trade-off between computation time and model quality, models can be generated using a single notebook within rather short time frames (less than 30 minutes) [1], allowing the process of drone programming, image acquisition and model processing to be conducted *in situ* in case of large-scale disaster events. In addition to the aerial images, the base of the water tower was

recorded terrestrially on a circular path around it through 57 images with a resolution of 6,000 x 4,000 pixels to demonstrate the depiction of details. Although conducted manually, the images could have been made using a drone at low level flight as well. The data set was processed with the proposed parameters and frameworks. The processing time of the open-source framework was about 12 hours with a necessary storage space of 25GB, with the Agisoft PhotoScan framework only about 4 hours with 10 GB of storage space. Both models are shown in Figure 8. Finally, high detail models like a shoe illustrated smaller objects (Fig. 9) can be included to the model using photogrammatric imaging utilizing motor-driven turntables.
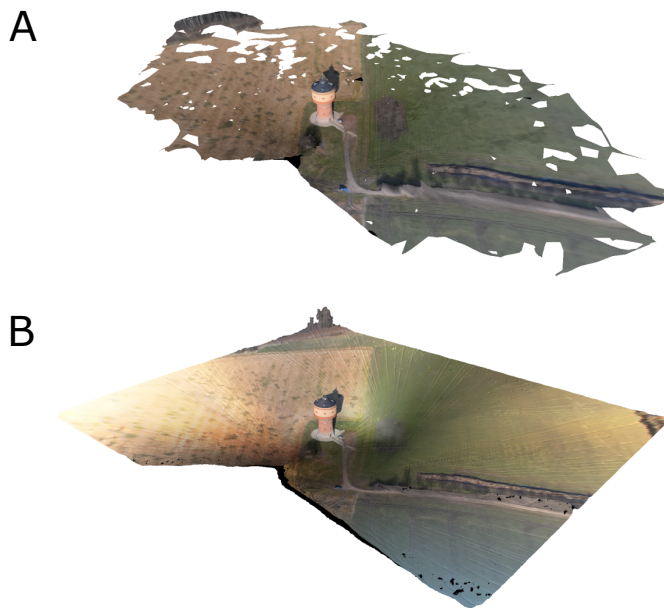
A

B

Figure 7. Watertower of Mittweida based on 111 UAV-images processed using the open source (A) and Agisoft PhotoScan (B) software.

C. Test Scenario II — Crime Scene Reconstruction in Jena Lobeda

The crime scene in question addressed in this scenario is located in a remote area of Jena Lobeda city directly adjacent to the Saale river. 3D reconstruction of the location showed to be demanding due to the site being difficult to access. In addition multiple obstacles made optimal drone flight geometry impossible to achieve. Thus, the site had to be inspected beforehand and careful planning had to be carried out. For example obstacle heights were determined during the inspection and confirmed from estimations based on areal images. Consistent visual contact to the drone had to be ensured as well (as specified by German law). In Figure 10 a schematic of the area is shown (subfigure A) and a detail with annotated minimum and maximum safe altitudes is shown. The location of obstacles as well as the remoteness of the crime
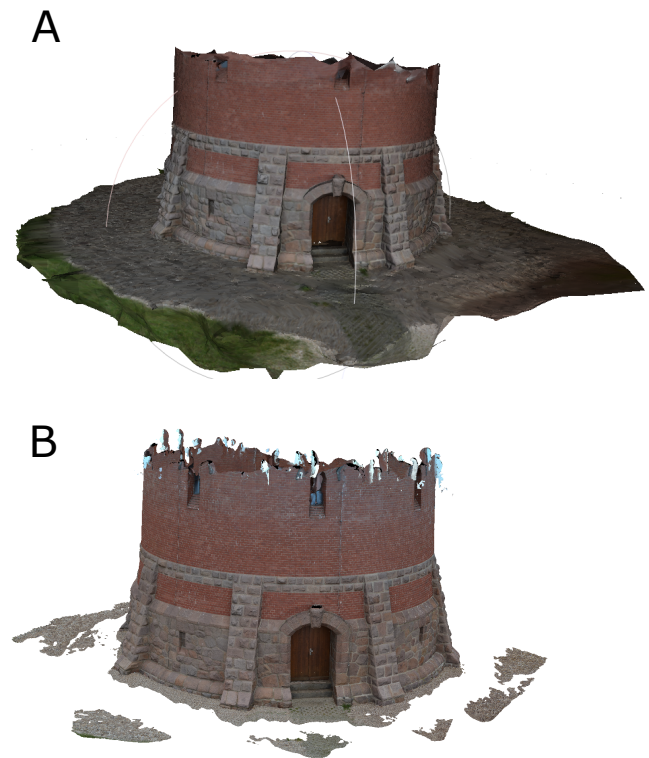
A

B

Figure 8. Watertower of Mittweida based on 57 terrestrial images processed using open source (A) and Agisoft PhotoScan (B) software.

scene only allowed the drone to be setup as well as to take off and land on the western riverbank. Furthermore, a flight plan was chosen, which provided imagery of the area of interest by flying parallel to the eastern riverbank. Multiple flights legs were conducted during this flight phase, each with individual preprogrammed camera angles and flight altitudes. The final flight phase included a 45° look-down camera angle to the crime scene from the other side of the area. In Figure 10B the chosen flight path is depicted schematically. A screenshot of the MikroKopter Tool showing the actual flight path is given in Figure 10C. During flight 120 single images were extracted from HD video recordings taken with a drone-mounted SLR camera. In addition a Eurocopter EC-145 helicopter equipped with a StarSAFIRE HD camera (resolution: 1,280 x 720 pixels) was provided by the Jena police department. 250 images were extracted from the video file recording of the helicopter-mounted camera. Laser scanning of the crime scene was conducted as well, but no satisfying data could be gathered due to dense and tall-grown vegetation and laser scattering effects caused by prevalent humidity. Hence laser scanning showed to be inferior to photogrammetric techniques under the present conditions.

D. Software Utilization and Parameterization

1) VSFM-CMPMVS-MeshLab: Prior to importing the images to VisualSFM, it is important ensure that the images

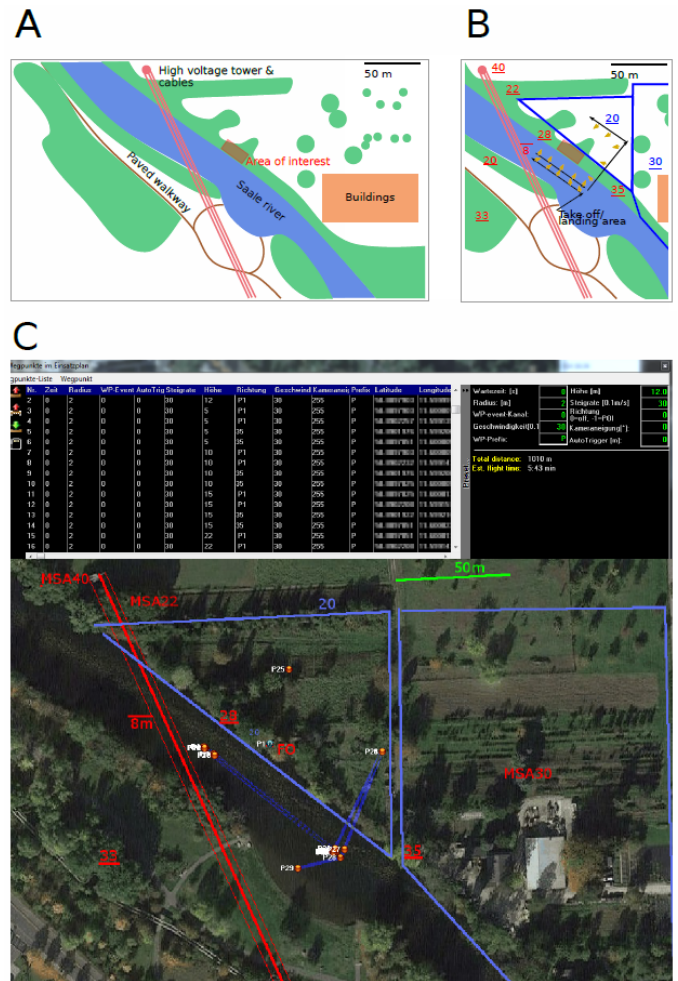Figure 9. Digitized shoe (based on 30 terrestrial images) as example for a seized trace at a crime scene.

Figure 10. Steps involved in drone flight planning for the Lobeda crime scene reconstruction. A: Schematic overview of the area in question. Multiple obstacles of varying height (f.e. trees and a high voltage power line) hinder the application of a circular flight path. The crime scene area had thus to be inspected beforehand in this case. In (B) height information gathered from inspection and areal images is annotated (red: maximum and minimum safe obstacle heights, blue: minimum safe height areas) and the flight is planned accordingly. Black and yellow arrows indicate the drone flight path and camera angles respectively. C: Screenshot of the MikroKopter Tool showing the loaded flight path.

are of proper quality. Especially in case of extracting images from video recordings, the imagery can be prone to containing unwanted artifacts, such as motion blur or lense flares. In this respect, the VisualSFM GUI provides a convenient presentation interface of all images loaded to the workspace from, which images lacking proper quality can be removed. With all images being selected, parameterizations of point cloud calculation is conducted. It should be highlighted that the primary parameter in calculation is the maximum number of underlying SIFT features to be considered. The point cloud quality can thus be increased by raising the number of SIFT features, whereas time and memory demands however increase significantly. Another aspect to address is that images with resolution greater than 3,200 x 3,200 pixels are down-scaled by default, decreasing point cloud quality. In all presented scenarios this setting was changed accordingly in order to avoid downscaling. Again these selected settings are accompanied with significant computational demands. Upon SIFT feature and point cloud calculation, storing the data in the appropriate file format (option "CMPMVS") provides a CMPMVS-compatible initialization file, which in turn can be feed to the CMPMVS executable. After computation the resulting model is stored in a WRL file for further processing. As the next step, the authors recommend to employ MeshLab for inspecting the obtained model (Fig. 11, subfigure A and Fig. 12, subfigure A) with respect to general quality and artifacts. MeshLab can also be employed to perform first model corrections and removal of existing artifacts.

2) Agisoft PhotoScan: The framework (Fig. 6) for creating 3D scenarios using the commercial software application Agisoft PhotoScan (Professional Edition, version used in this study: V1.4) can be subdivided into the two consecutive

modules "Pre-Processing" and "Model Generation" , which in turn consists of specific sub-processes. The initial phase of the "Pre-Processing" module consists of the selection and import of the previously obtained images. As with the utilization of VisualSFM, the user has to ensure proper file formatting and quality. In its current version Agisoft PhotoScan also supports the direct processing of video data. Here convenient video import and eventual image extraction is available. Similar to VisualSFM images are displayed in a dedicated graphical interface for quality assessment and selection. The information about the resolution of the images and/or EXIF data are essential to decide whether a camera calibration is necessary. Camera positions are computed next. However, considering
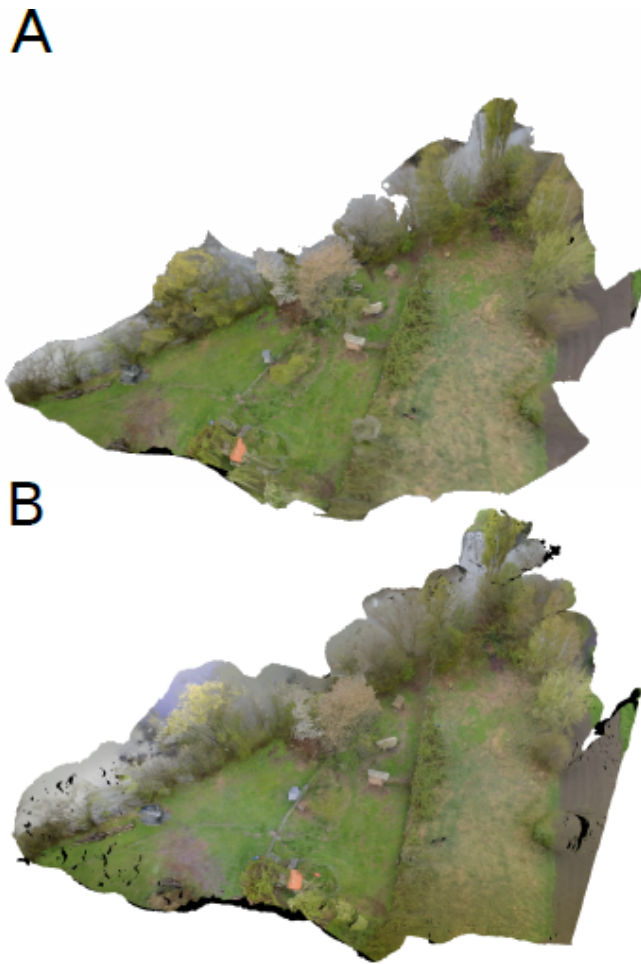
Figure 11. Saale in Jena based on UAV-images processed using the open source (A) and Agisoft PhotoScan (B) framework.

Figure 12. Saale in Jena based on helicopter images processed using the open source (A) and Agisoft PhotoScan (B) framework.

the data collection conditions and parameterizations presented in the "Data Collection" framework, this processed (referred to as a manual camera calibration) can be avoided in most cases. In the forensic context it is important that the created model has a high quality. This can be achieved in Agisoft PhotoScan by using the maximum values for all parameters. However, the resulting computation afford makes it necessary to decrease some of the values while keeping the quality of the model high. In own experiments sets of parameters (see Table I) have been evaluated and used in creating models with a sufficient quality for subsequent simulations. After creating the 3D models, they were edited and textured (Fig. 11, subfigure B and Fig. 12, subfigure B).

E. Results

It was shown that helicopters are only partly suitable for the aerial photogrammetry (Fig. 12). Possible scenarios in, which a helicopter can be of advantage are reconstructions of huge areas without high level of degree. Disadvantages in the
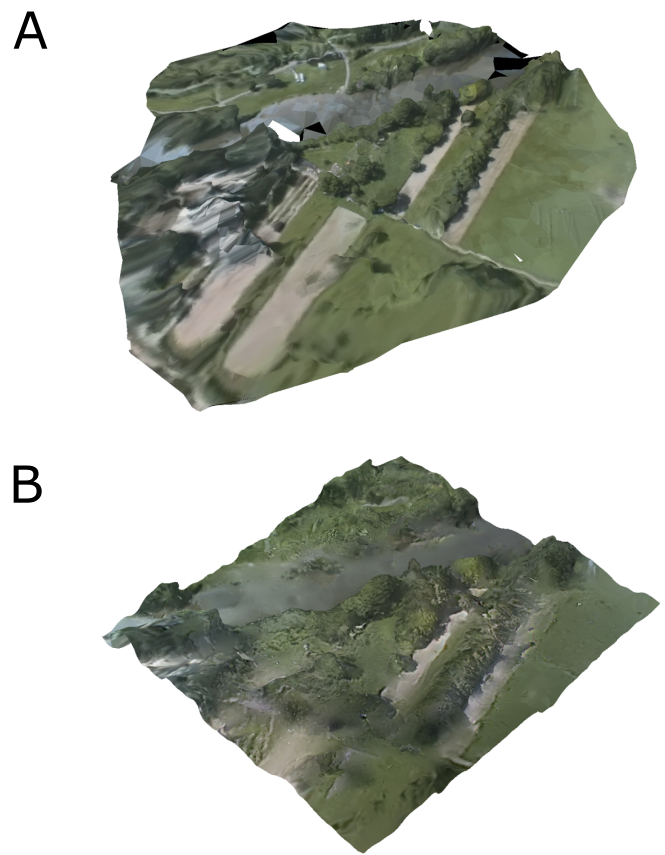
TABLE I. Recommended specific parameter sets for the generation of models in Agisoft PhotoScan.

task	parameter	min	max	recommended
aligning	tie point limit	0	n	10,000
	key point limit	0	n	400,000
dense cloud	accuracy	lowest	highest	high
mesh	surface type			Arbitrary
	face count	low	custom	default

described scenarios were next to the low resolution of the camera, especially the relatively high flight altitude. Because the drone can fly in lower altitudes and the payload can be chosen flexibly a high level of degree can be ensured. Additionally, the compact design allows its operation in many scenarios. The only limiting factor besides the weather is its limited battery service life. Doing a reconstruction using terrestrical photographs is suitable for the reconstruction of objects with an extremely high level of degree and a manageable size. However, difficult terrain and obstacles (e.g., branches or high grasses) can lead to problems.

IV. Conclusion and Future Work

The 3D reconstruction of objects, complex crime scenes or disaster sites provide a quick and comprehensive method to support the investigators digitally. Photogrammetry-based methods to creating 3D models are an inexpensive alternative to laser scanners. Even though various approaches exist, to this point there is no standardized process for the reconstruction of crime scenes or disaster sites. Therefore, in this paper the authors present a comprehensive framework for the 3D reconstruction process using terrestrial and aerial photogrammetry. The advantage of the presented framework is twofold. It can serve as a simple guide to create a 3D reconstruction, yet it can also be easily implemented in an already existing process chain, for example as used by investigative services. Additionally, the complete framework from the planning phase up until the final 3D model is presented by means of a test scenario as well as one cold case. It could be shown by the authors, that 3D models of sufficient quality for subsequent simulations can be generated using the presented framework. With respect to the two presented frameworks we focused on discussing model quality and processing parameterization. In practical use one has to consider these aspects as a trade-off of computational demands and resulting model resolution and quality. Future work thus has to address the definition and evaluation of quality measures as well as eventual quantification of best-practice standards, including guidelines for optimizing modelling strategies. Future prospects should also consider a quantitative comparison to established laser-scanning strategies. Finally the adaption to a wide range of practical usage scenarios by means of utilizing alternative software packages and/or payloads (e.g., thermal imaging or gas sensors) could be discussed.

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