THERMAL PHOTOGRAMMETRY IN USE FOR CULTURAL HERITAGE IN THE CITY OF VARNA, BULGARIA

Nadya Stamatova, Antoni Angelov

Abstract: *The case study demonstrates the two methods of thermal photogrammetry, developed by Architectural Spies EOOD for producing 3D models via volumetrizing two-dimensional thermal vision scans. Both methods were tested at the cultural heritage building at 25 Dragoman St in Varna. The first method is manual, which uses the thermal component of the scans as input data and places them onto the 3D model of the building, which could be either BIM or photogrammetrically created. In this case study BIM was used. The second method is automated, using the photo and thermal components of the FLIR scans simultaneously.*

Keywords: *thermal photogrammetry, thermal survey, thermal data acquisition, 3D thermal energy model, energy efficiency, BIM, FLIR*

Three-dimensional thermal models present the thermal condition of buildings, facilities, and nature (flora and fauna). They could be very useful in construction, reconstruction, and support of buildings. The 3D model provides better visibility and assists in the analysis of defects in the thermal insulation. It describes the type of work needed to fix them, so that the workers know what changes are needed and why.

The R&D team of the company Architectural Spies EOOD developed two methods for creation of 3D thermal models. The older but easier one is to create a thermal model based on applying the thermal scans as textures onto a CAD model (1–5).

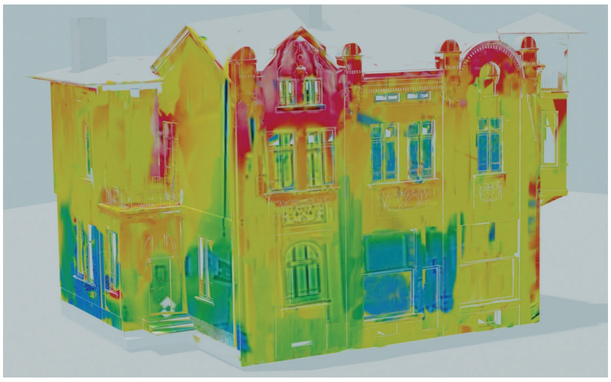

Fig.1. *Thermo-textured CAD model*

This model has clear and visible geometry, as is characteristic for CAD models, and is perfect for when we have a low number of scans, but we also have a 3D CAD model. These models are designed not only for the construction of the new buildings but also for renovations (incl. the cultural heritage buildings (6)). The 3D CAD model not only allows a visualization of the project by itself but is the main model out of which drawings and other characteristics can be exported. Without it the risk for a mismatch between the drawings and the different branches of the project is unacceptably high. The use of 3D CAD models and the use of 3D thermal models have similar purpose in keeping the consistency, quality, and visibility over the project.

There are many factors in the direct use of thermal scans that may cause inconsistency such as time delays between the photos, different settings, confusing different walls with one another and so on. Scans are usually made in a very close distance to the object and as such the visibility is often poor and it's hard to make out which side is which. Or in the cases where distance is possible, there is an obstruction, traffic, and so on. Either way digging through a folder with hundreds of photos each time a part of the model needs to be seen is a very inconvenient task, which also carries a high risk of errors.

That's the reason our team developed the thermal 3D model. Initially it was made via thermo-texturing of a CAD model, however the method's downsides are not just a few. The main issue is of course the accuracy. Due to the manual application of thermal textures, human error, such as inaccuracy of the applied textures, unnoticed mistakes, and possible attempt of "correcting" the model via human bias, make the method unsuitable for documentation such as certification, technical documentation of the materials and tools used, and so on.

That's our reasoning behind the creation of a second method for the creation of a thermal 3D model: the thermal photogrammetry (1, 2, 4). One such example is shown on (Fig. 2). Removing the human factor and its mistakes turns the method into a cold tool with a higher trust factor. The requirements of course are different and while the thermo-texturing of CAD may not be as accurate, it is suitable for internal analysis and use inside the company. Its creation is also faster and has lesser requirements (as long as a 3D CAD model is present).

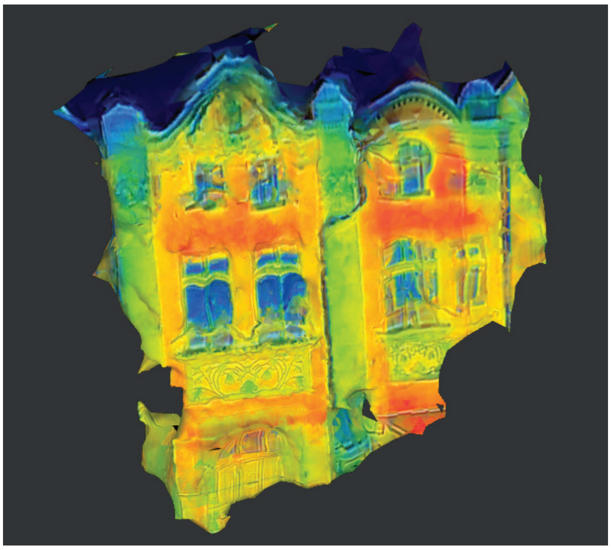

Fig. 2. *Thermal photogrammetry*

The thermal photogrammetric model on Fig.2 has a higher accuracy regarding the textures despite its incomplete geometric model. The main reason for the incomplete model is the use of thermal scans that aren't made specifically for thermal photogrammetry. While the first method (3) could be used with thermal scans created for direct observation of the thermal situation of the building, the second one (4) requires special preparations such as: observing every geometry from every angle, higher density of photos, observing the building from every side, and avoiding vision obstructions such as trees, cars, and even shadow. Also, it's important to have full view of the building and then start with the details so the program knows how to build up the model and not simply reject the photos as different parts that have nothing to be matched with. Its easier to match with the full picture than with one another.

The software we use starts building up the model from the location of the first photos, and then builds up the model. If the first photos are looking closely at an object such as a door and without a smooth transition to the next photos, showing different parts that can't be directly connected to the first photos, instead of building two different models and trying to combine them later, the software will just reject the photos that can't be connected to the first photos. Hence it is better to start with an overview of the building and then get close to the details. Another factor of photogrammetry is that the model will look good only from the distances where it was scanned from. Meaning if it is scanned from a distance longer than the model is being observed from or if the resolution of the photos is lower than the resolution of the viewport than the model is being looked at, some geometric defects may be visible. However, it is not a problem to have the scans from different distances, more distant for a clearer view of the building and closer for clearing out the details of the building.

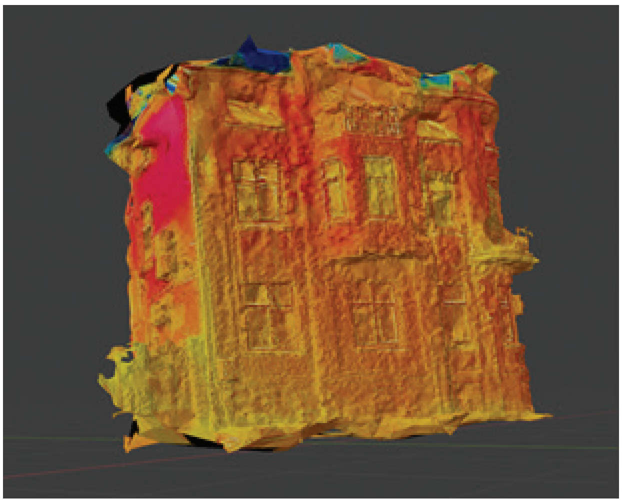

Fig. 3. *Thermal photogrammetry*

The walls on the model on Fig. 3 are not smooth and some artifacts are present. However, the generated model is a completed product of the scans and the computer without human interference or bias and can be considered as raw data that is viable for analysis. A good quality model would require about a 1000 to 3000 for a smoother, clearer model. This result has been obtained by a very tight time window of between 10 and 15 minutes due to the change in the thermal situation during the scanning process. The scans made for the model on Fig. 3 are taken as photos with about 3 seconds or more between them due to hardware limits. A proper model would require a video that is later separated into frames before being added to the photogrammetric software.

The 3D thermal model on Fig. 3 is created in the autumn with low contrast between the building and outside air, no heating or cooling turned on and no human or animals present in the building. It was created to stress test the method and check if the low contrast will reflect on the geometry or quality of the model. For a viable 3D thermal model, a higher contrast is necessary to check and isolate the factors we are interested in. For analysis on the heat insulation, the efficiency of the heating system and such, it is best to make the scan in the coldest day of the winter with the heating turned on. It's preferable that the time be early morning before the sun can be a factor in heating up the building but it's still visible as we use the visible specter photos from the scans to create the geometry.

For analysis of the cooling of the building the process is the opposite as we scan the building during the hottest day of the summer with both the air conditioner on and off. Many buildings have a strong passive cooling factor thanks to their deep underground stone/concrete foundation which acts as a thermal ballast as well as contact with the earth below the surface. The mass of the foundation and the earth around it can be cooled off during the winter and partially during the night with which it can provide sometimes life-saving cooling for the inner space of the building.

The creation of the actual thermal model via photogrammetry requires two parts: a visible specter photo and a thermal one. From the visible specter it only needs the edges seen on the photo, so it can use it to create the geometry of the model. With each scan we are provided with these 2 photos, which may be taken with the same camera or 2 cameras close to each other. On Fig. 4 the visible specter photo passed through a filter for edge detection is seen and Fig. 5 shows the pure thermal photo. The thermal photos used in photogrammetry need to be consistent with the same thermal margins, color gradient type and no difference in the focus with their corresponding visible specter photos. If the focus is static, it would be best.

Fig. 4. *Edge detection*

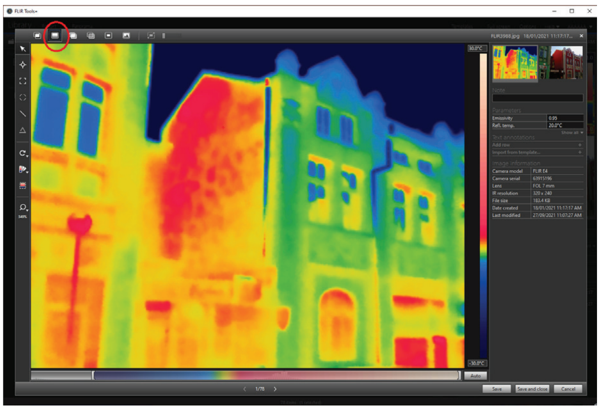

Fig. 5. *Thermal photo*

In this situation there are two submethods to use photogrammetry. One is the harder, where we make the geometric model via the visible specter photos (the so-called photogrammetric model (7–9) and then combine with its corresponding thermal photo during the texturing phase.

The other, simpler and preferable submethod, is to combine the above two photos into one as shown on Fig. 6.

The thermal photos use a color gradient that makes no use of the black color of the edge detection lines. The software can recognize the black lines as edges and use them to create the geometry and after that it can apply the same photos as its textures. The black edges are not seen on the actual model as seen on Fig. 2 and Fig. 3. Both models are created via this method.

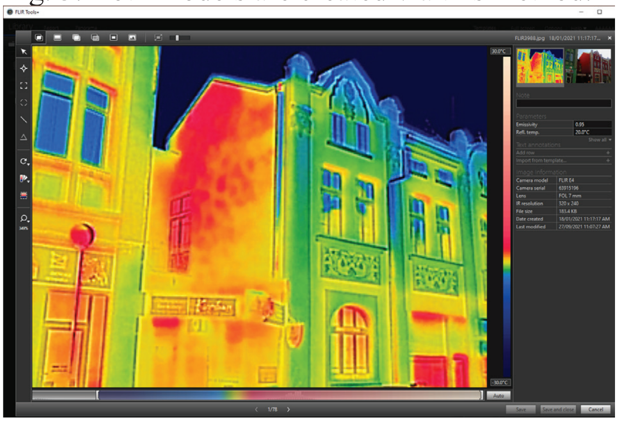

Fig. 6. *Combined visible specter photo with the thermal scan*

Another reason we have decided to pick this method is that it's the default view of our thermal scans in our software for viewing and exporting the thermal scans. However, with different softwares it is required to understand the reasoning behind the method and how to achieve the same result regardless of the software or thermal camera that is used.

One of our current limitations in making the 3D thermal models is the inability to mount the camera onto our drone, and with that we have limited positions from which the thermal scans can be made. Both models on Fig. 3 and Fig. 2 were created from the ground position, at human height.

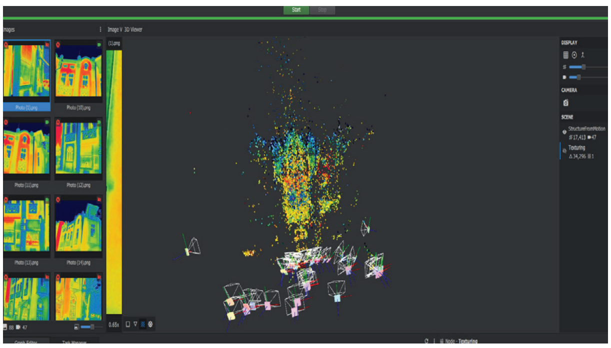

Fig. 7. *Creation process*

On Fig. 7 could be seen the creation process of the model on Fig. 2. On the figure's right side are the photos that were used by the software for the creation of the 3D model. As it can be seen they are from a similar height, not many in number and only looking at one facade of the building. For a proper model, every single geometrical aspect needs to be looked at, at every angle, so a proper geometric model can be created. If choosing a thermal camera is possible, the ability to save a thermal video is a highly important factor. Another factor is the resolution, and the ability to mount it onto a drone. Its gimble should have 2 degrees of freedom. Even though the rotation of the gimble along the vertical axis matches the same rotation that the drone is capable of, the accuracy of the gimble is much higher and finer than the one of the movements of the drone. A small rotation can provide depth from the difference in the perspective on the photo. This has a chance of providing much finer geometric structure of the geometric models from the close-distance scans. The resolution of the thermal camera is recommended to be 640x480, which is significantly higher than the camera used in our case study, as well as most thermal cameras on the market.

With a proper toolset the creation of high-quality 3D thermal models via photogrammetry should not be a difficult task. And once the 3D thermal model becomes a common tool, its evolution into industry standard will not be far off.

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