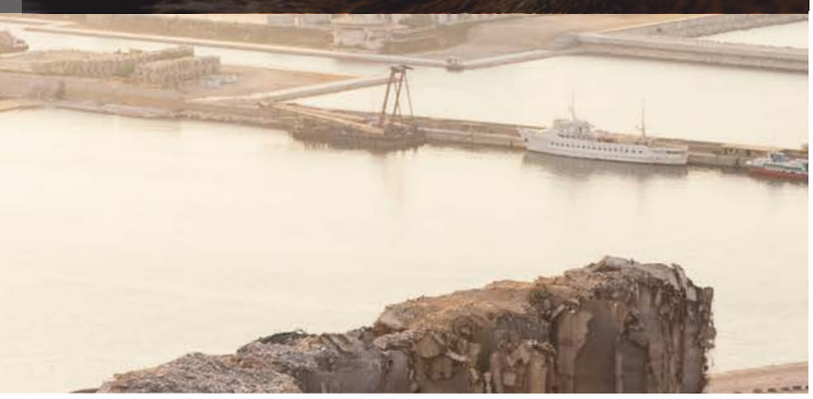
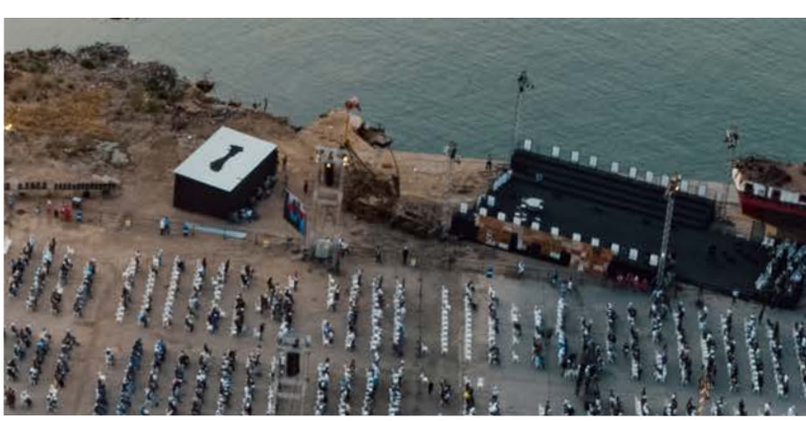
How we build reality

Zoller+Fröhlich



Case Study

Non profit structural monitoring in Beirut



Company Overview

Z+F is one of the world's leading manufacturers in the field of non-contact laser measurement technology. Due to years of research, development and numerous successful engineering projects, Z+F is the forerunner in this field with a wealth of knowledge, experience and success.

When it comes to implementing future developments Z+F has always encouraged innovation and open-minds. Our loyal and long-standing customers appreciate our continual innovations, support and the services we provide.

A project of Amann Engineering amann

Heritage buildings affected by the blast, Gemmayze, Beirut

An Introduction to the Project

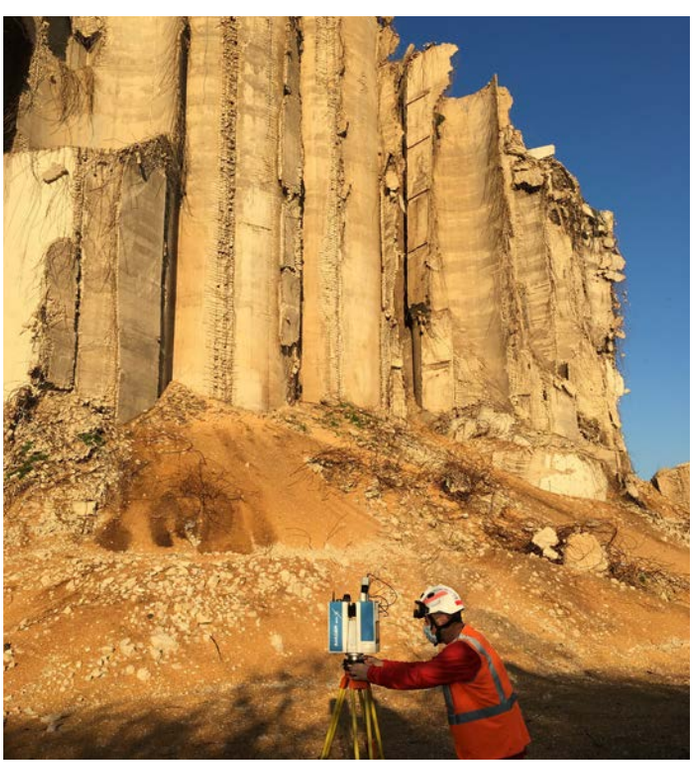
On August 4 in 2020 a large fire in the warehouse number 12 started at the port of Beirut. The fire was followed by a catastrophic explosion that sent a blast wave, which radiated through the city of Beirut. The explosion caused grave damage and was heard and felt as far afield as Cyprus that is about 200 km across the Mediterranean Sea. This explosion obviously left marks. Thousands of people injured and homeless, even dead, beyond this, immense damage in properties, large parts of the harbor and neighbouring buildings were caused.

Beirut silos after the August 4, 2020 explosion

Beirut port silos, Lebanon

It is considered to be one of the most severe non-nuclear explosions in world history, which devastated the whole port area of Beirut. A crater approximately 140 meters wide, which was flooded with seawater, emerged. Apart from damaging considerable parts of the city of Beirut, also the country's grains storage silos, the Beirut port silos were affected. The explosion is supposed to be a consequence of the detonation of more than 2000 tons of ammonium nitrate, a highly explosive substance under certain conditions, which was stored at the warehouse in the port.
It is assumed that flying sparks during welding work started the fire which then initially ignited fireworks which were stored nearby. Shortly after the fire outbreak, the first firefighters already arrived, but the fire continued to spread. The first explosion occurred after 15 minutes. This was followed by the above mentioned detonation, which finally caused an immense shock wave.

The explosion intensified Lebanon's acute economic and financial crisis. Because the state no longer has sufficient budget, electricity and water are failing with increasing frequency.

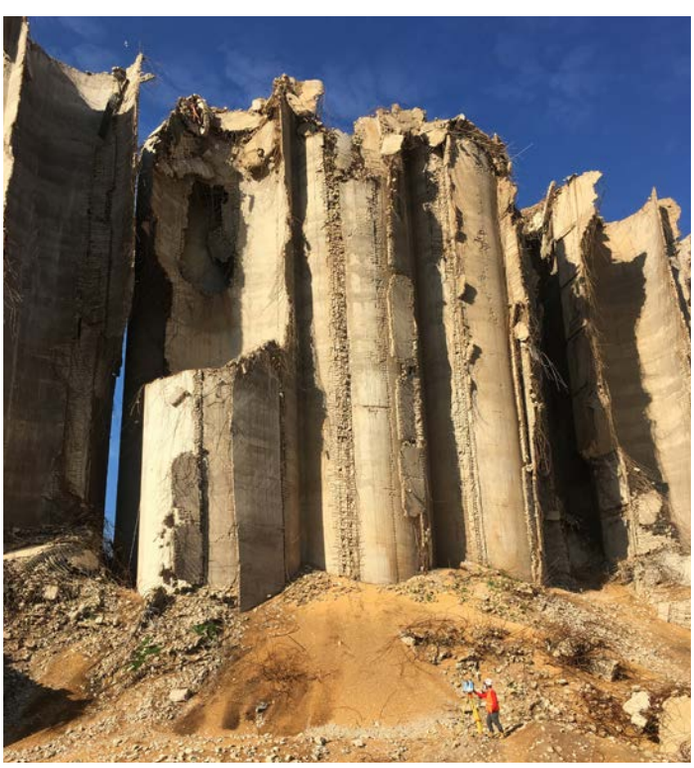


In front of the blasted silos

Gemmayze historical „Blue House“ after the explosion, Beirut

Emmanuel Durand, French civil engineer and silo expert of the Swiss Amann Engineering GmbH travelled to Beirut on his own initiative and supported the team on site with his work force, expertise and knowledge on a volunteer, pro-bono base. He spent several weeks in Beirut scanning the affected area and gathering digital data for his analysis of the silos. The second time he went to Beirut, he was supported by Zoller + Fröhlich who provided him with the necessary equipment, a Z+F IMAGER® 5010X and the infrared camera T-Cam.

Top priority of this scanning project in Beirut was to identify and assess the stability of the silos and to evaluate whether the silos are stable enough or whether they have to be demolished soon due to danger of collapse, what could happen at any moment, Durand said.



Blasted silos

Affected heritage housing in Mar Mikhael area, Beirut

It is nearly impossible to calculate when this could happen. From a distance the silos may look structurally robust, but they are tilted and their foundation is broken, which has caused vertical cracks in two of the silos.
“Silos are very strong as long as they have integrity, just like an egg,” Durand said. “Now if the shell of the egg is slightly broken, it becomes very weak and you will have no difficulty in crushing the egg.”
Additionally the 3D scanning process aimed to judge the heat development within the silos and to determine the remaining substance of the silos.

Acknowledgements
This case study, picking up the incidents happened in Beirut, is based on the information extracted from two articles which were written by Sahar Ismail and Wassim Raphael, both from the Saint Joseph University of Beirut, and Emmanuel Durand from Amann Engineering. The first one is called “Case study of the Beirut port explosion using 3D laser scan and nonlinear finite element model” and was published in June 2021 in the journal “Research on Engineering Structures & Materials”. Further reference is made to the article “Monitoring the Beirut Port Silos‘ Structural Health Response a Few Months after Blast Loading Using 3D Laser Scan” published in the “Jordan Journal of Civil Engineering” in July 2021.

Amann Engineering

Amann Engineering GmbH is a Swiss company based in Geneva, with a mission to give support and expertise with civil engineering matters, 3D representation for the industry as well as heritage and cultural organizations. As a structural integrity consultancy, the team of Amann Engineering around Emmanuel Durand offers reliable, yet affordable services to offer the most efficient diagnosis to clients (3D laser scanner, reverse engineering, digital data acquisition, GIS), to help estimating as accurately as possible costs to repair. Further focus lies on the prevention of accidents and damages on all customers' sites.
Providing professional inspection based on Swiss technology and 25 years of experience over five continents, Amann Engineering continuously optimizes its operations, processes and costs.
As an industrial expert and construction professional with years of experience on large international turnkey projects and plant maintenance at a global level, Emmanuel Durand and his team always try to successfully turn around complex project situations in multicultural environments.

Following the events occurred in Beirut in August 2020, Amann Engineering offered a free technical assistance to measure the damage to the Higher School of Engineering ESIB – USJ.
Subsequent to the scan project in Beirut, Z+F donated a 3D laser scanner to the Saint Joseph University of Beirut for further investigations.

In front of Beirut port silos

During his stay in Beirut, Emmanuel Durand realized that for his volunteer activities in Beirut locally an NGO (Non-Governmental Organisation) structure is required to provide an easier understanding for the locals. According to Durand, people actually tend to not really conceive that a private company is willing to do something for free, without any payment.
Therefore the idea of "SinA" emerged, an organisation for assistance in cases of disasters, also located in Geneva.
SinA (= Scan in Action) is basically the NGO arm of Amann Engineering, dedicated only to volunteer activities such as the ones conducted in Beirut.

Emmanuel Durand, Amann Engineering

The pictures of this case study were created by Emmanuel Durand (Amann Engineering), Dia Mrad (Lebanese architecture photographer) and Joe Kallas (Lebanese architect).

Photo of a ship wreck that was lifted out of the water by the shockwave

Data Capture

After obtaining the permission from the investigation judge and as well the one from the Lebanese army, the Saint Joseph University of Beirut and the Swiss team of Amann Engineering, escorted by the Lebanese army, performed the complex 3D laser scanning project at the port of Beirut in several phases.
Starting in September 2020 the main focus during the three project phases was on monitoring and assessing the damage and deformation of the silos. The scan project was continued in November 2020 as well as late March and mid-April 2021. From phase 2 on, Emmanuel Durand and his team were equipped and supported with a Z+F IMAGER® 5010X to capture the data and to obtain 3D measurements with high precision and fine details. These 3D scans detect the silos' deformations that can not be captured by the naked eye and therefore need detailed scan recording.

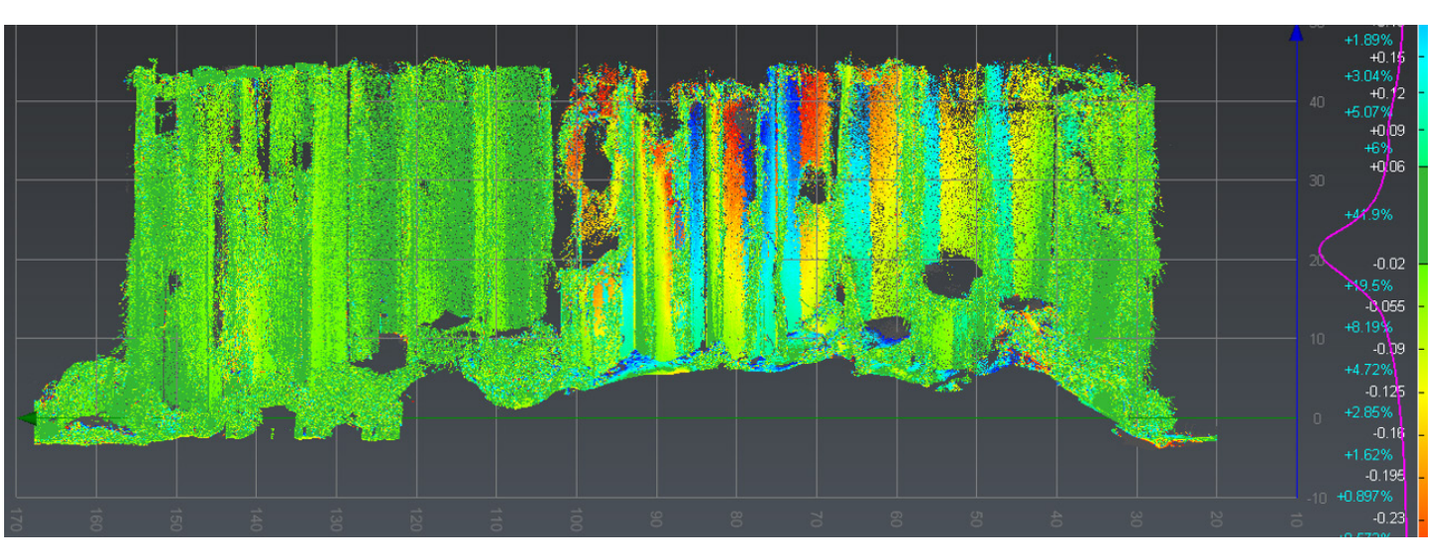


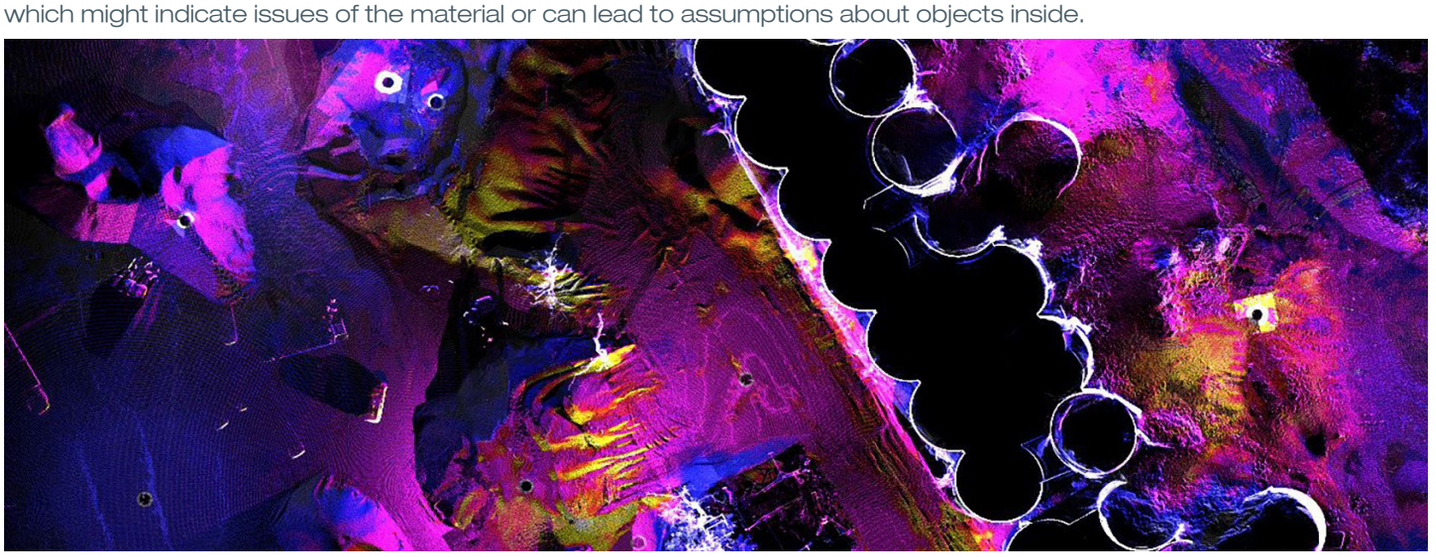
Illustration of the 3D deviation analysis of the scan data over several months

Z+F Imager® 5010X in front of Beirut port silos

Infrared camera T-Cam

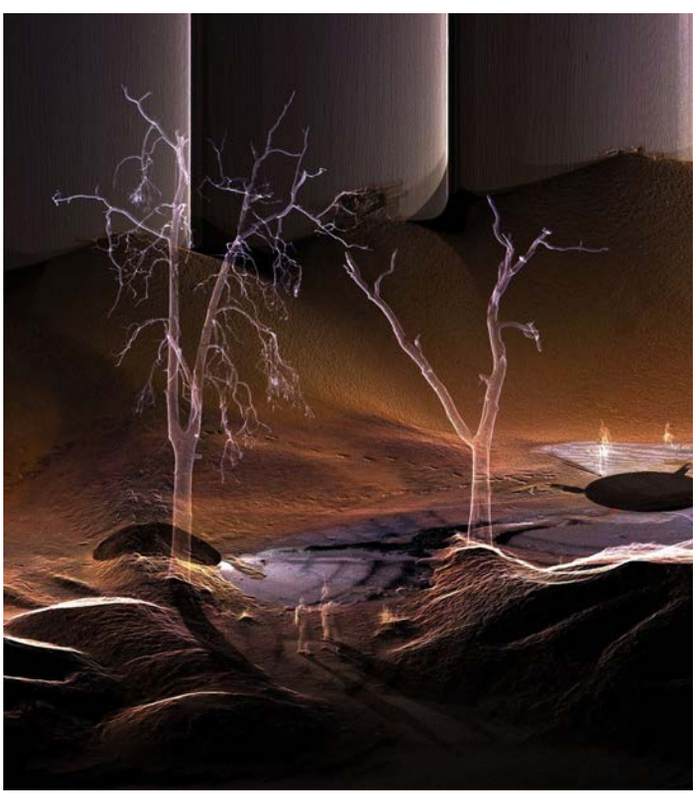
The Z+F IMAGER® 5010X scanner was combined with an external infrared camera, the Z+F T-Cam, which covers an infrared spectrum of 8 to 14 µm. The solution generates 360° "full dome" thermal panorama scans in a fully automatic process in less than two minutes. By means of the thermal camera, Durand measured the heat development within the silos and determined possible temperature rise of the grains.

Thermal images illustrate the temperatures in false colors. Starting with colder areas in blue, the colors will shift to red and eventually yellow with increasing temperatures. While with enough expertise, the T-cam can be used to determine absolute temperature measures, the thermal images are usually used to visualize changes of differences in temperatures, which might indicate issues of the material or can lead to assumptions about objects inside.



Recording of the infrared camera T-Cam

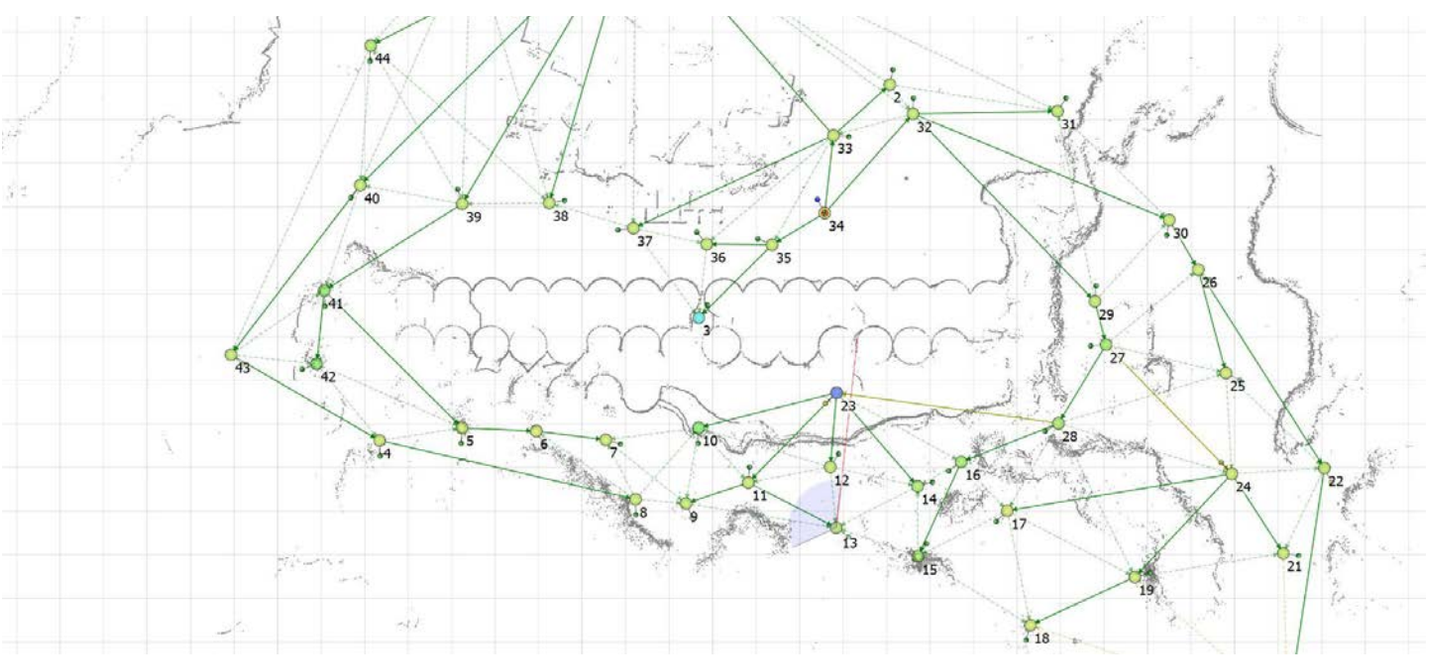
The scanner in difficult environment



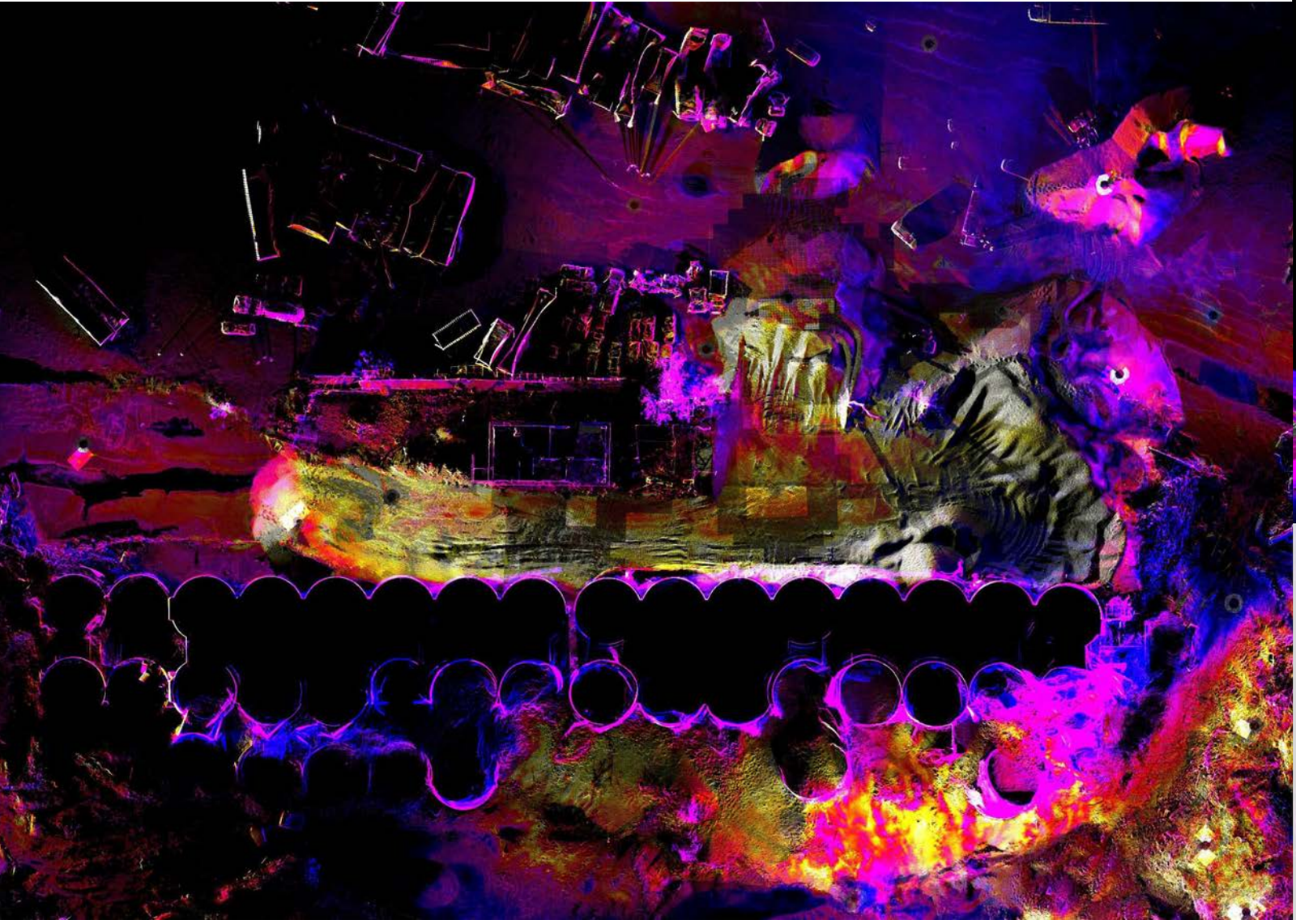
Silhouette view of the resulting point cloud

Aerial view of the Beirut port

The Z+F IMAGER® 5010X allowed the team to sweep a volume 27 times larger per scan in a noticeable smaller amount of time, since it has a larger scope range than other scanners. Also Z+F scanners come with integrated HDR cameras for best colour scans even in scenes with challenging illumination. The solution is complemented with the blue workflow allowing to complete the registration of all scan data while still on site.



Several scan positions as part of the project



Recordings of the infrared camera T-Cam

Results

The north block has been rotating vertically, respectively tilting, by an average of 0.85 mm per day (seen at the top of the silos) since the August 04th, 2020 blast, endangering the safety of the whole structure. The rotation of the north block is in direction of the explosion crater, so west to east. The rotation speed is not linear, it depends on weather (wind, rain) and season (sun orientation, ambient temperature).

The highest tilt at the top of the silos was measured up to 2 mm/day and the lowest tilt determined was 0.2 mm/day. The maximum total displacement measured so far since the explosion is 450 mm at the top of the silos. To obtain more precise results, regular 3D scanning campaigns are performed by the end of November 2020 using the Z+F IMAGER® 5010X.

The silos are beyond repair and have lost most of their structural integrity. The damage is due to the original blast and caused a constant tilt. In their current state, the silos would not pass any safety regulations and should not be reused. The site will not be usable for new silos construction. Either the inner part (inside half cylinder) of the silos is damaged and/or the pile heads have been deformed beyond the elastic range and therefore broken.

Right after the explosion, Durand quickly realized there was a huge concern coming, the grain fermentation. Leaving huge quantities of grains outside, exposed to any weather conditions like rain or heat, can cause a process of internal fermentation followed by immense temperature increases.
When detecting this, Durand did not have the tools to prevent the fermentation since that is a very special tech field. Searching for a solution, Durand asked for technical support from Zoller + Fröhlich, who consequently provided a suitable scanner and a T-Cam.
After instruction training from Z+F support, the equipment was brought to Lebanon. Durand was now able to perform the job and to produce graphical data, which immediately convinced the decision makers/politicians and clarified that those high temperatures are a big problem. Temperature was reaching 80 degrees and was still going up. When catching 100 degrees, a fire could have broken out and this would have been inextinguishable.
The ability of the T-Cam in combination with the Z+F IMAGER® 5010X to transform an incredible amount of technical information (temperature, 3D over a vast area) into a single sigificant document has been instrumental. It was decided to send off the Lebanese army with suitable equipment and to split the grain piles into much smaller ones. By doing so, it was possible to avoid another fire and save the whole area from a new catastrophe.

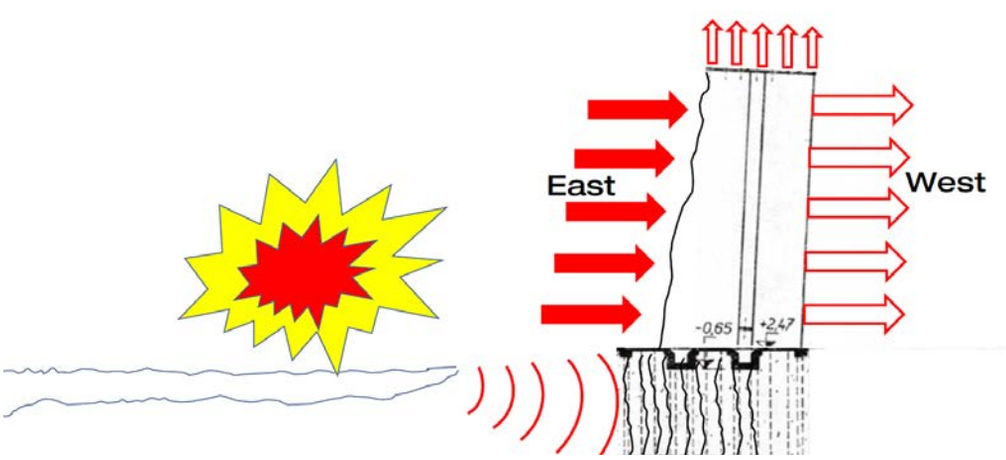
Based on the collected (thermal) 3D scans and site observations the following has been recommended:

- not reusing the pile foundation to construct new silos at the same site because the silos are structurally beyond repair. Any intent to “restore” would put lives at risk.

- funding, designing and building new silos and searching a new location in a different area, because piling the same area will be too costly and technically complex.

- performing further monitoring of the silos’ structural response in the upcoming months to check development, status and movement of the remaining standing silos.

- consulting all Lebanese stakeholders for whatever relates to the memorial status of the silos.

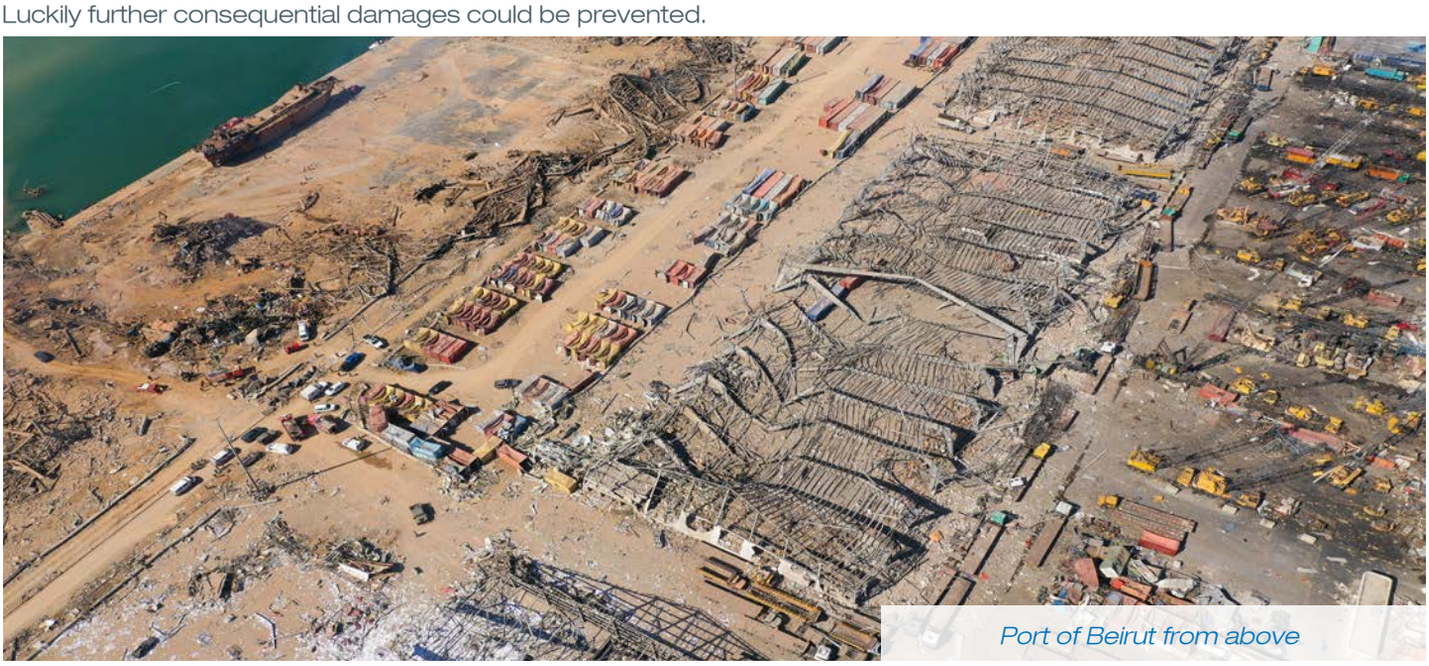


Illustrated inclination of the silos caused by the blast

In the middle of the silos

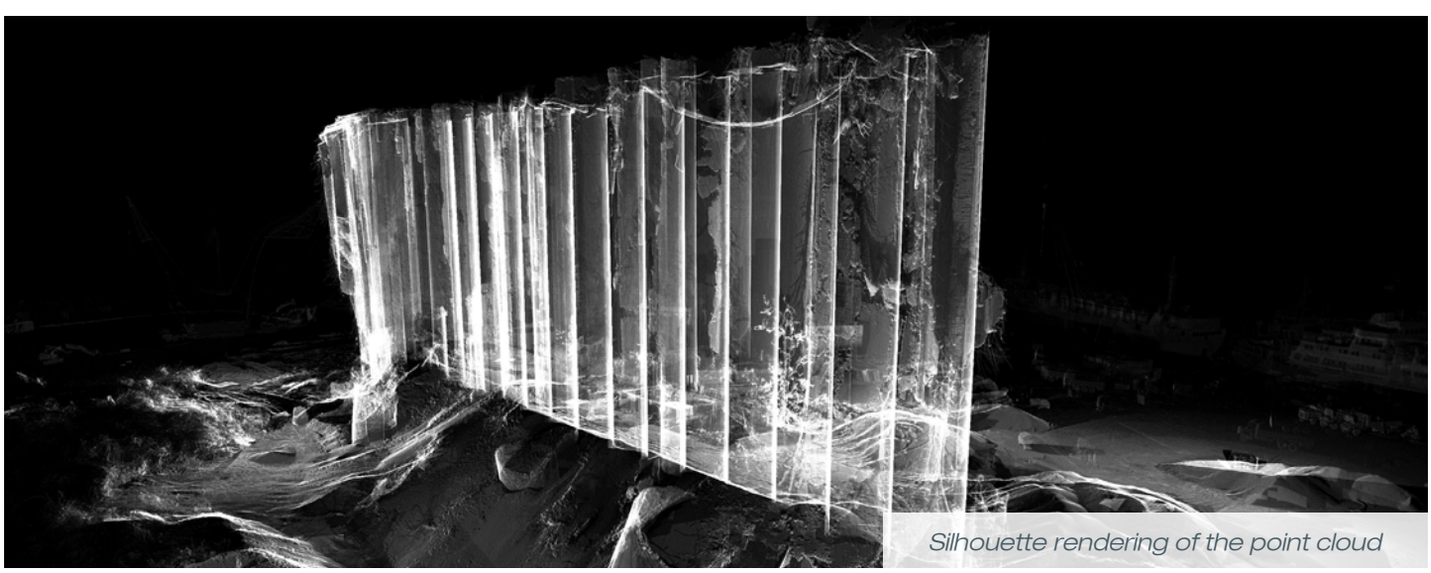
Conclusion

The 3D laser scan measurements of the Beirut port silos were performed by the “School of engineering ESIB” at Saint Joseph University of Beirut in collaboration with the Swiss structural integrity consultancy “Amann Engineering” in three scanning campaigns taking place in September and November 2020 and late March and mid-April 2021. The Z+F IMAGER® 5010X was used to obtain measurements with high precision and record fine details. The 3D scan technique, used in several industries, such as engineering, structural health monitoring and medicine, among others, allowed to model and capture the structural and damage response of Beirut port silos, which provided a better understanding of the problem. Luckily further consequential damages could be prevented.

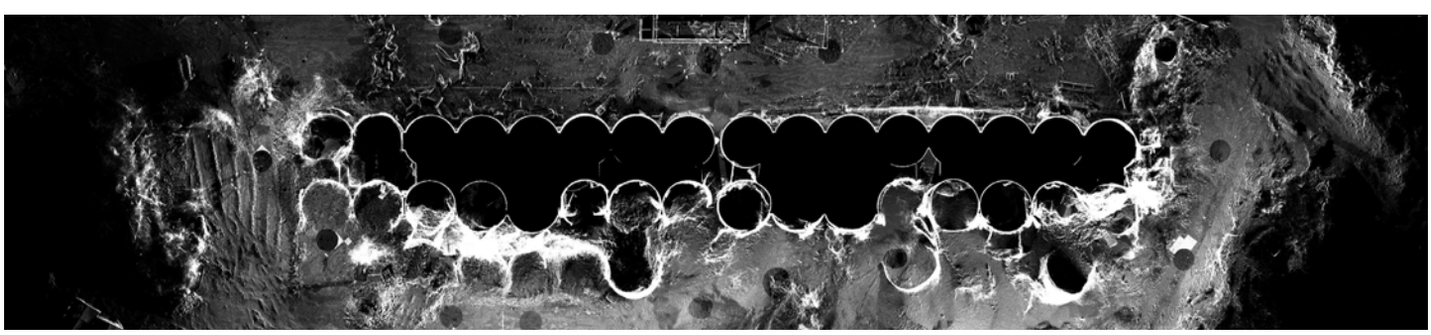


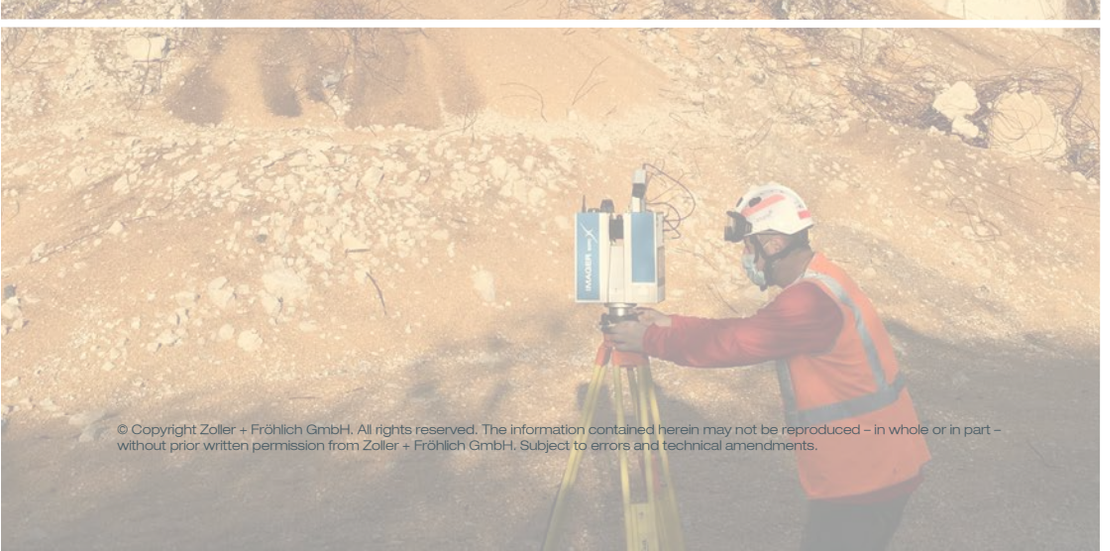
Port of Beirut from above

Beirut port silos



Silhouette rendering of the point cloud





Zoller+Fröhlich

Head office – Germany

Zoller + Fröhlich GmbH
Simoniusstrasse 22
88239 Wangen im Allgäu
Germany

Phone: +49 7522 9308-0
Fax: +49 7522 9308-252

www.zofre.de
info@zofre.de

Subsidiary – USA

Z+F USA, Inc.
700 Old Pond Road
Suite 606
Bridgeville, PA 15017
USA

Phone: +1 412 257 8575
Fax: +1 412 257 8576

www.zf-usa.com
info@zf-usa.com

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