Application of terrestrial LiDAR for 3D modelling of the Bulgarian Antarctic Station “St. Kliment Ohridski”

Adil E. ARSLAN, Turkey
Asparuh KAMBUROV, Bulgaria

Key words: terrestrial LiDAR, 3D laser scanning, GNSS, Antarctica

SUMMARY

During the 25th Bulgarian Antarctic Expedition (2016/2017), a joint international project in the field of geospatial 3D modeling between the University of Mining and Geology "St. Ivan Rilski" - Bulgaria, the Bulgarian Antarctic Institute, the Association of Polar Early Career Scientists – Bulgaria, and the Istanbul Technical University took place on Livingston Island. A field campaign of LiDAR 3D and GNSS data collection activities was organized, resulting in the development of precise georeferenced 3D models of the interior and exterior of the Bulgarian Antarctic Station "St. Kliment Ohridski", and evaluation of the short-term movement of the Perunika Glacier. The paper reveals some key field data collection and data processing details, illustrated with 3D examples from the Livingston Island chapel “St. Ivan Rilski” and parts of the main buildings.

Application of terrestrial LiDAR for 3D modelling of the Bulgarian Antarctic Station “St. Kliment Ohridski”

Asparuh KAMBUROV, Bulgaria
Adil E. ARSLAN, Turkey

1. INTRODUCTION

The Bulgarian Antarctic Station “St. Kliment Ohridski” is located on Livingston Island, the second largest island of the South Shetland Archipelago. The station’s first accommodation barracks were transported on the Soviet research vessel “Michael Somov” in April 1988 by a team of Bulgarian scientists – Prof. Christo Pimpirev and Borislav Kamenov. Ever since, it had become the center of the Bulgarian polar science, providing accommodation and scientific infrastructure to a number of national and international research projects. The 25th annual Bulgarian Antarctic Expedition took place during the 2016/2017 austral summer. Widely known as the “Jubilee” expedition, it continued the tradition of geodetic and geospatial research activities on the island, commenced by Assoc. Prof. Dr. Eng. Borislav Alexandrov (UACEG) and Prof. DSc. Eng. Dimitar Dimitrov (BAS-NIGGG) in the season 1998/1999, and continued by others.

During the current expedition, one of the most advanced geospatial technologies - the terrestrial laser scanning (TLS) - was implemented on the island for the first time. This ongoing project is realized through a joint international cooperation between the University of Mining and Geology "St. Ivan Rilski" (UMG), the Bulgarian Antarctic Institute (BAI), the Association of Polar Early Career Scientists (APECS) – Bulgaria, and the Istanbul Technical University (ITU). The main objectives of the project are:

- Capturing of 3D geospatial data of the main buildings’ interior and exterior;
- Monitoring of the dynamics and volume variations of a local glacier;
- Development of web-based resources for 3D visualization and virtual reality access to all buildings, including the first SCAR historical site on the island – the Lame Dog hut, and the chapel “St. Ivan Rilski”.

Considering that the Station’s buildings are subject to constant extreme environmental conditions, with some infrastructure vanished under snow for many years, and other experiencing severe damage, obtaining in-situ information is a vital source for their future preservation and digital exhibition. On the other hand, the global warming effects are quite sensible on the Livingston Island. One of the glaciers – the Perunika Glacier, due to its proximity and ease of access, is rather feasible for TLS studies.

1.1. International cooperation

The project ideology was initially outlined at the First APECS Balkan Meeting, which took place in the Bulgarian city Kardzhali in October 2016. The Association of Polar Early Career Scientists (APECS) is an international and interdisciplinary organization for undergraduate and graduate students, postdoctoral researchers, early faculty members, educators and others with interests in Polar Regions and the wider cryosphere [URL-1]. The meeting provided efficient communication platform between members of APECS International on the Balkan Peninsula: APECS Bulgaria, APECS Turkey/Turkish Polar Research Center and APECS Romania (via Skype call). The Chair of APECS International, Mrs. Gerlis Fugmann, connected to via Skype call as well. The national expedition operator – the Bulgarian Antarctic Institute, patronized and funded the meeting.

During the event, two of the participating parties - Bulgaria and Turkey - signed an official Memorandum of cooperation in the field of Antarctic science. Following this meeting, APECS Turkey decided to send two scientists in the upcoming 25th Bulgarian Antarctic Expedition – a marine biologist and a geomatics engineer from ITU, the latter becoming the senior LiDAR data processor for the project.

Figure 1. Participants in the First APECS Balkan Meeting (1-2 October 2016), supported and co-organized by the Bulgarian Antarctic Institute

1.2. Related works

Most of the laser scanning projects performed in Antarctica are airborne, due to the larger area coverage and time efficiency. Some notable examples are:

- A joint NASA/U.S. National Science Foundation/U.S. Geological Survey project for digital elevation model (DEM) extraction using airborne laser topographic mapping in the McMurdo Antarctic Station area on Ross Island (Csatho, B. et. al. 2005);(Csatho, B. et. al. 2008)
- SIPEX-II (Sea Ice Physics and Ecosystem eXperiment II) - a multidisciplinary project which includes airborne LiDAR remote sensing from a helicopter in combination with snow and ice depth measurements. The acquired DEM contributes to a three-dimensional picture of snow and ice thickness, and topography (Lieser J.L., 2008).

Although fewer, there are some quite intriguing TLS implementations as well, including:

- 3D white light/laser scanning of Scott’s huts at Hut Point and Cape Evans and Shackleton’s hut at Cape Royds on Ross Island, performed by the University of Waikato (New Zealand) in 2011. The resulting scan data supports multidisciplinary studies and development of 3D models for broader public interest to these heritage sites from the Heroic age of Antarctic exploration (Gibb R. et. al. 2011)
- A project for development of a high resolution DEM of the “Boulder Clay” moraine, adjacent to the Italian Research Station “Mario Zucchelli”, intended to support the construction of two airplane runways (Abate D., 2013).

Apart from the high costs of the equipment and its insurance, some specific limitations, which hinder the implementation of LiDAR technologies in Antarctica, are the severe environment conditions (e.g. strong winds, low-temperature and high humidity), which overpass the technical capabilities of many instruments, as well as the complicated logistics required to bring the equipment to the areas of interest.

2. FIELD CAMPAIGN

2.1. Logistics

The field campaign on Livingston Island lasted 30 days, spanning the period between 21 January and 21 February 2017. The two-way travel and transportation required 10 more days. The members of the geospatial engineering team, representing UMG and ITU, together with six other Bulgarian scientists assembled in the Chilean city Punta Arenas, from where an Antarctic Airlines regular flight took them to the island of King George – the largest of the South Shetland Archipelago. The group then boarded a Spanish oceanographic ship - “Sarmiento de Gamboa”, and after two nights of travel disembarked on the shores of Livingston Island. The geospatial equipment’s transportation boxes were carried as hand luggage at all times, as this was the requirement of the insurance policy.

Figure 2. The pier of King George Island, waiting for the transportation ship to Livingston Island

Figure 3. The area of the Bulgarian Antarctic Station "St. Kliment Ohridski"

2.2. Equipment

The following equipment was utilized for the project: a 3D laser scanner Stonex X300, a pair of dual-frequency GNSS receivers (Trimble R4-2 and Stonex S8+), a total station Zeiss Elta, tripod, survey rods and a variety of accessories.

2.2.1. <u>Laser scanner</u>

Stonex X300 is a lightweight mid-range (1.6 – 300 m) laser scanner, able to receive color and intensity information alongside three-dimensional data (Tab. 1). Is has a 32 GB internal memory, capable of storing up to 50 scans at maximum resolution (~700 MB each). The instrument has a built-in Wi-Fi interface, which was used for field setup via Android smartphone.

Table 1. Technical parameters of the laser scanner (best mode)

Scan mode	**Value**
H. res. (360°)	16000
V. res. (90°)	4000
Total points	64000000
H. step (‘)	1.350
V. step (‘)	1.350
Time x 360°	1h 6m 0s
Columns/sec.	4
Grid step at distance	
Distance (m)	**Grid step (Hz and V, mm)**
10	3.9
30	11.8
50	19.6
100	39.3
200	7.8540
Environmental and physical	
Operating temperature	-10°C to +50°C
Protection class	IP65
Weight (with battery)	7 kg

2.2.2. <u>GNSS receivers</u>

The GNSS technology is utilized in the project with two main objectives:

- to provide georeference data for the 3D models via static relative GNSS positioning;
- to perform static campaign on the permanent GNSS station KOH2 (IERS DOMES number 66026M002) for various international scientific projects.

Two GNSS receivers with appropriate environmental durability specifications were transported to the island (Tab. 2).

Table 2. GNSS equipment specifications

Specifications	**Trimble R4-2** 	**Stonex S8plus** 
GNSS signals	• **GPS**: L1C/A, L2E • **GLONASS:** L1C/A, L1P, L2C/A, L2P	• **GPS**: L1C/A, L2C • **GLONASS:** L1C/A, L1P, L2C/A, L2P • **BeiDou**: B1
Channels	72	120
Accuracy in static mode *(RMS, maximal values)*	• 3 mm + 0.1 ppm (Hz) • 3.5 mm + 0.4 ppm (V)	• 5 mm + 0.5 ppm (Hz) • 10 mm + 0.5 ppm (V)

Internal memory	11 MB	256 MB
Field software and controller used	Trimble GPS Configurator on Windows 7 laptop	Carlson SurvCE on Stonex S4 Windows Mobile 6.5 controller (806 MHz processor, 256 MB RAM, 4 GB internal storage, IP67)
Communication used	Bluetooth – setup and data download	Bluetooth – operation, 7-pin Lemo – data download
Operating temperature	-40°C to +65°C	-30°C to +65°C
Protection class	IP67	IP67
Weight (with battery)	1.34 kg	1.2 kg

2.3. Data collection

2.3.1. Terrestrial laser scanning

Due to the unpredictable outside weather conditions and the exploitation of the buildings by the expedition's both scientific and technical crews, data collection was scheduled with an opportunistic manner, by overlapping several data acquisition target groups and carrying out surveys whenever and wherever possible. A total of 82 point clouds were collected, equivalent to more than 100 working hours of the scanner.

The main building's interior was scanned mostly during nighttime, when it was possible to place the scanner at all desired locations. The chapel interior, due to the lack of electricity inside, was scanned either with open doors at bright sunny days or with artificial light during the rest of the time. The aim of both main building and chapel scans is to obtain in-situ 3D models of their current condition and transfer it to a virtual environment where it can be analyzed and altered according to the necessities should they arise.

Figure 4. Instrument setup during 3D data collection of the main buildings' exterior.

The Perunika Glacier was monitored periodically through a 5-day gap. All data was being downloaded on a daily basis and backed up on several external hard drives. Sequential cloud-to-cloud registration, georeference, 3D mesh, and cross section extraction were performed on site through a 30-day demo version of the JRC (Stonex) 3D Reconstructor software.

2.3.2. GNSS

All GNSS observations were performed in static relative mode. The GNSS base receiver (Trimble R4-2) was set up on the permanent geodetic marker KOH2, established in the season 2015/2016 in the framework of a project headed by the National Institute of Geodesy, Geophysics and Geography (Fig. 5-a). Twenty-three daily datasets were acquired in the period January 21 - February 13, 2017. The receiver was powered through a solar panel, which proved to be a great advantage considering the fast battery drainage in cold weather conditions. The raw observations are recorded in 1 sec interval, converted to RINEX format and subsequently decimated to 15 sec interval via the open source tool GPSTk. As a project follow-on, the data is exchanged with the Spanish GNSS Research Group from the Cadiz University, supporting a seasonal GNSS station on the same island. GNSS data from the KOH2 point is also sent to the SCAR GNSS database [URL2] for participation in the GIANT-REGAIN [URL3] and other international projects.
The rover receiver (Stonex S8+) was used for positioning of the buildings’ roof corners and other characteristic objects, aimed for georeferencing of the TLS data (Fig. 5-b). All points are measured in 15 min sessions with 1 sec sampling interval. Additionally, the GNSS geodetic network, established in the vicinity of the Bulgarian Antarctic Station in the season 2012/2013 by a team UMG “St. Ivan Rilski” (Kamburov A. et. al.,2017), was re-measured for data comparison studies.

Figure 5 (a, b). a - Base receiver set up on the permanent GNSS marker KOH2; b – Rover receiver measuring the chapel’s roof corners for TLS data georeferencing.

3. DATA PROCESSING

3.1. General Processing Workflow

The general workflow followed in the project is illustrated in Fig. 6.

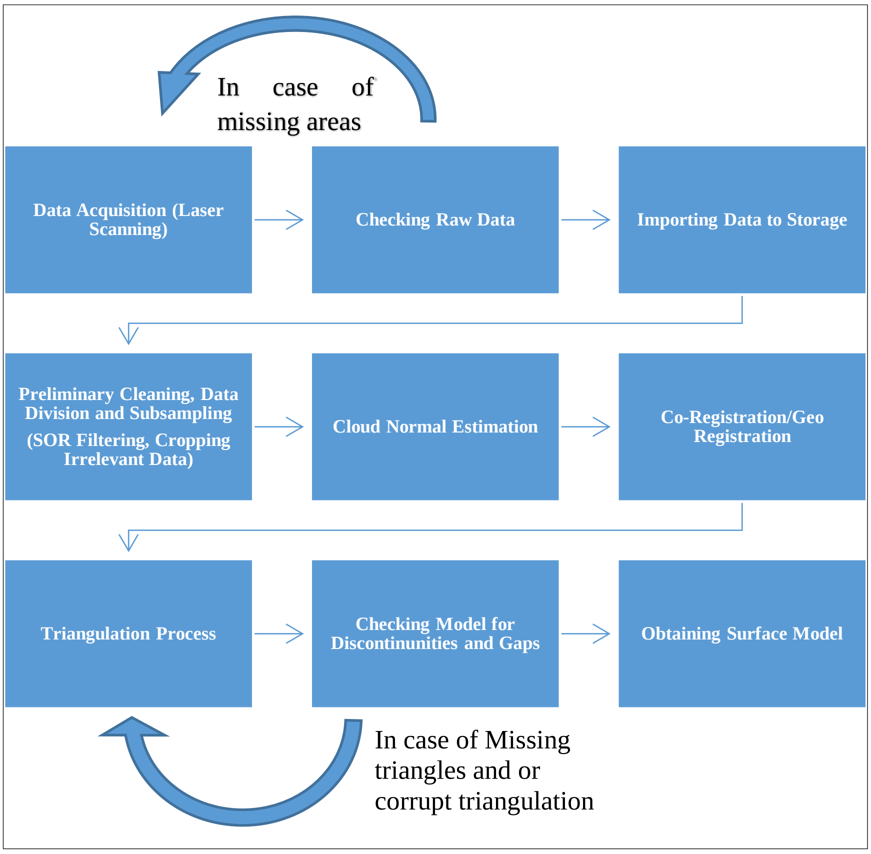

Figure 6. Processing Workflow

3.2. Data import

The field data collection campaign produced large point cloud datasets, recorded in proprietary Stonex .x3a format. They are subsequently exported via the Stonex 3D Reconstructor software to standard text XYZRGBI format ("XYZ" stands for the coordinate portion of the data, "I" is the intensity of the returning signal strength from target to the instrument, "RGB" stands for Red-Green-Blue color format). Thus all coordinate, reflectivity and color information from the raw data was obtained (Fig. 7).

Eventually the project data exceeded a billion points, which required significant workload and processing power. For that purpose, the Department of Geomatics Engineering at ITU dedicated a powerful workstation running an edition of the Leica Cyclone software. There the data was sorted, preprocessed and classified as areas of interest, and separated in three main groups and several subgroups:

- Chapel (interior and exterior);
- Main Base Building Area (main building, auxiliary buildings – interior and exterior, critical infrastructure);
- Perunika Glacier.

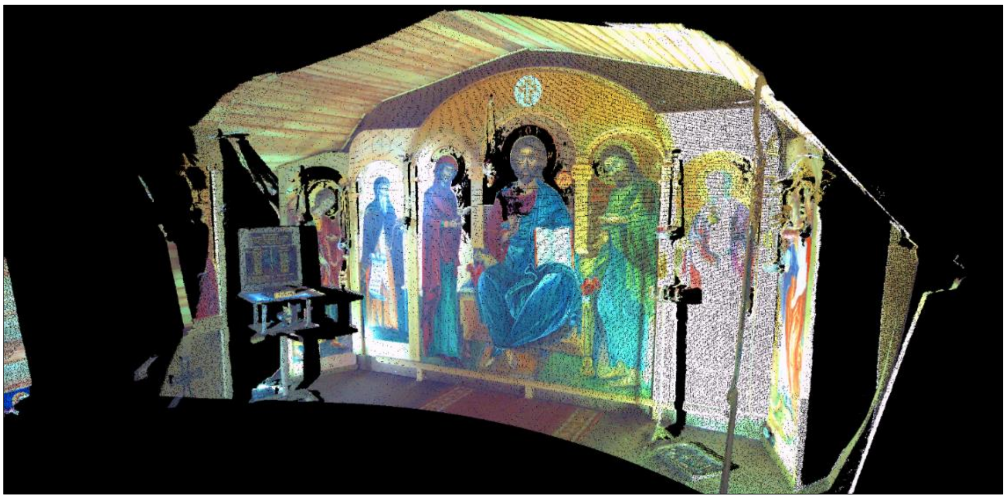

Figure 7. 3D point cloud view of the chapel's altar

The subsequent co-registration and geo-registration of the data required creation of a database, which structure is according to the aforementioned dataset grouping (Fig. 8). The size of the data in the database exceeds 290 GB, resulting in time-consuming import process due to the "normal computation process".

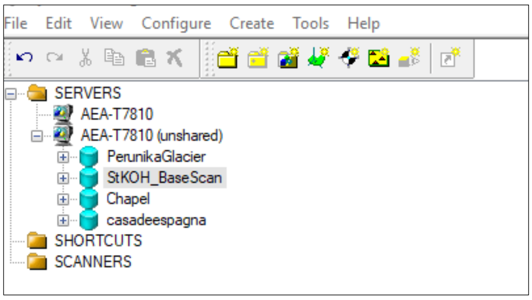

Figure 8. Project database structure in the Leica Cyclone software

3.3. Cleanup

Cleanup is a sensitive and time consuming but necessary step, implemented in the project for:

- elimination of unnecessary data which burdens the database, clogs the process and consumes computing resources;

- removal of irrelevant areas that can interfere with the actual area of interest.

The data was “cleaned” automatically and - where it fails - manually. This was carried out using a statistical outlier removal (SOR) filter based on k-means clustering. Generally, this algorithm “clusters” point clouds and removes “outliers” which does not fit into the group statistically (Wolff K., 2016). However, because this method frequently deletes necessary parts as outliers, it was supervised and optimized with utmost care. A manual cleaning was also required in order to intervene to the more information sensitive areas.

3.4. Registration

The process of registration involved two main steps - co-registration and geo-registration. Both were performed over common points from overlapping point cloud models (Fig. 8). For proper subsequent co-registration of the point clouds, certain amount of overlap was ensured during the data collection. By marking the common points (Fig. 10) in the overlap areas, the software performs statistical evaluation of all neighboring points and deduces 3D 7-parameter transformation parameters between the point clouds (three rotations, three origin center shifts and a scale) Besl P.J., 1992). This co-registrations accuracy is dependent on the overlap quality, scan resolution and proper selection of tie points between point clouds.

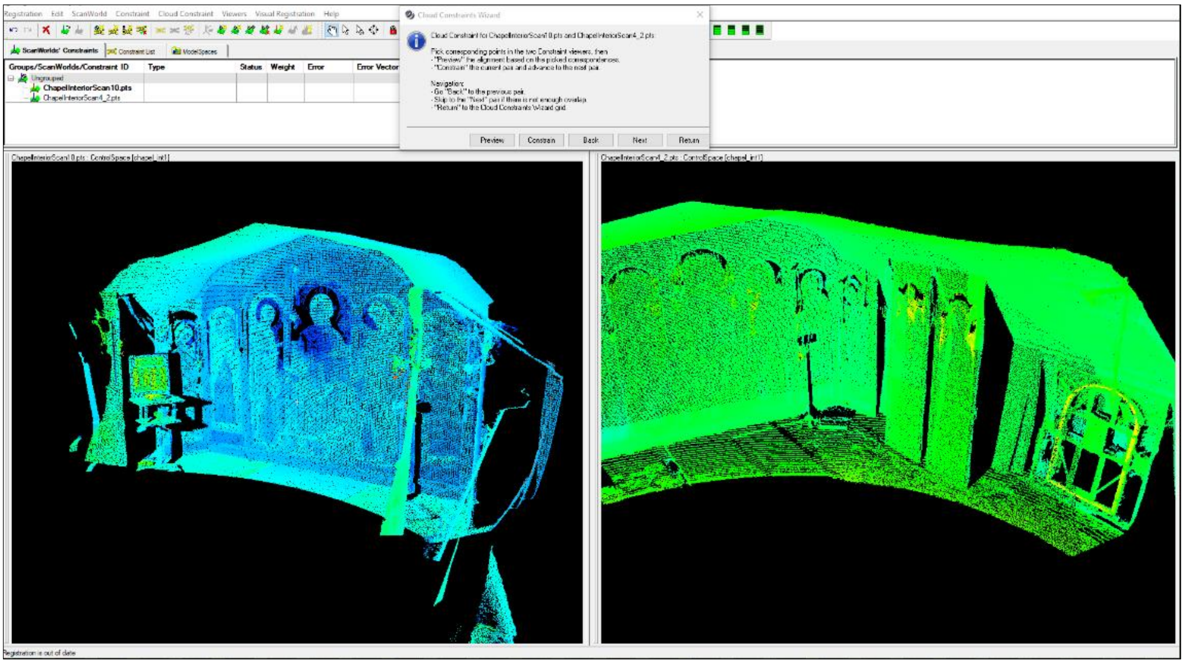

Figure 9. Overlapping scans of the chapel interior

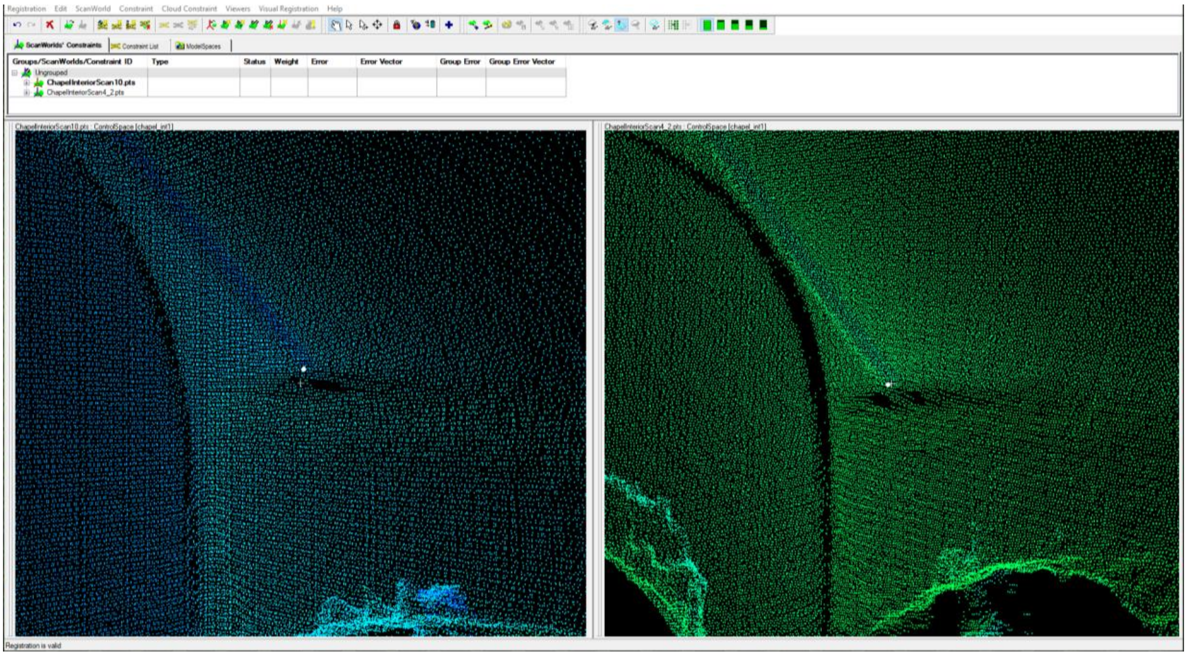

Figure 10. Co-registration points in the chapel interior corners

The geo-registration process was carried out by converting the local coordinates of the co-registered point clouds (received from the scanner itself) to ITRF2008 coordinates, received from the GNSS campaign data processing. The average co-registration error vector, computed from all datasets, is 8 mm, and the final geo-registration accuracy - 15mm.

3.5. 3D mesh modelling

After the end of the project, several types of geoformation products will be available, aimed for both professional and academic community, as well as for wired audience, interested in the Bulgarian Antarctic Station and the Antarctic Region in general. These will include, among others:

- A virtual reality model of the base;
- 3D models, ready for printouts at different scales;
- Web-based interactive environment;
- Glacier movement dynamic model.

Since the project is ongoing and extremely time-consuming, up to the deadline of the paper submission only a limited amount of geoformation products are ready: a mesh model and a 3D printout model of the chapel (Fig. 11) and the base building area (Fig. 12).

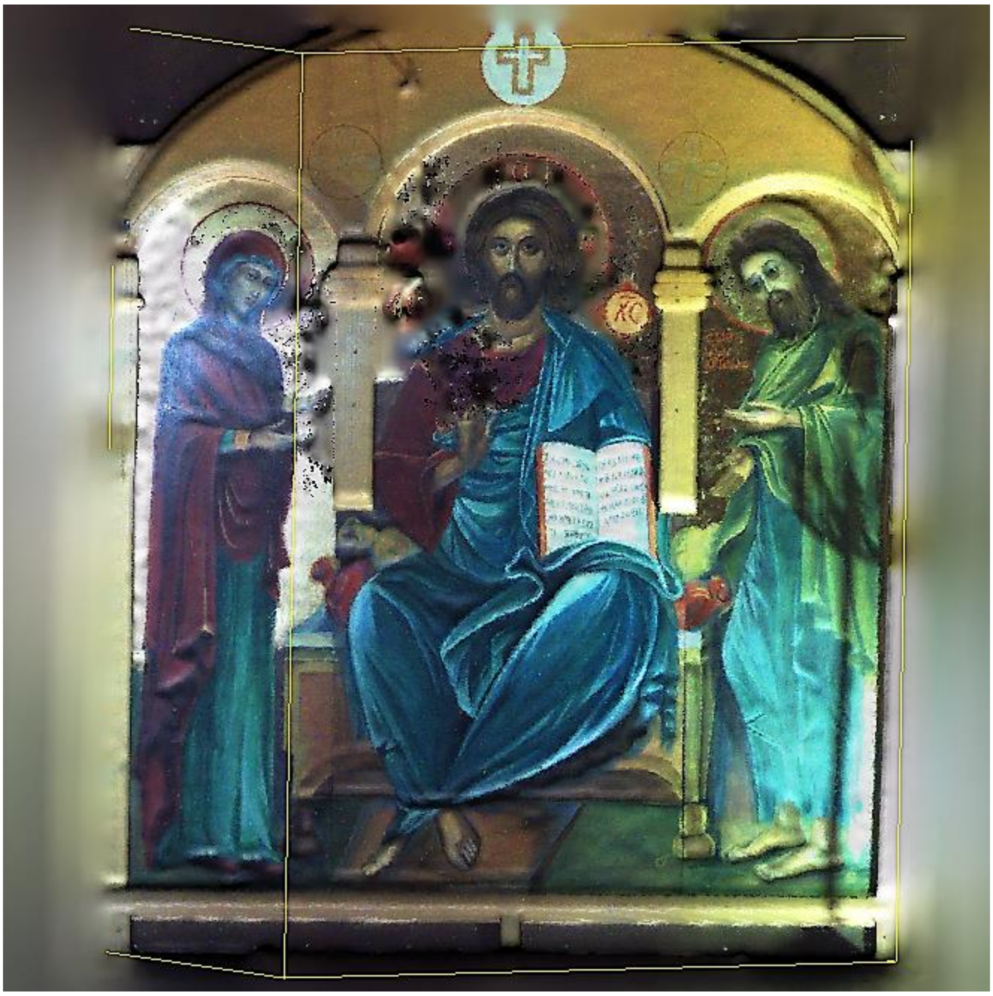

Figure 11. Mesh model of the handmade Jesus Christ icon inside the chapel

The mesh model of the Chapel exterior has been obtained as 3D printable model, which can also be embedded on a virtual reality environment after optimizing the polygon count (Fig. 12). The detail level of the mesh model can be seen on the wireframe detail in Fig. 13.

Figure 12. Chapel Exterior Mesh Model

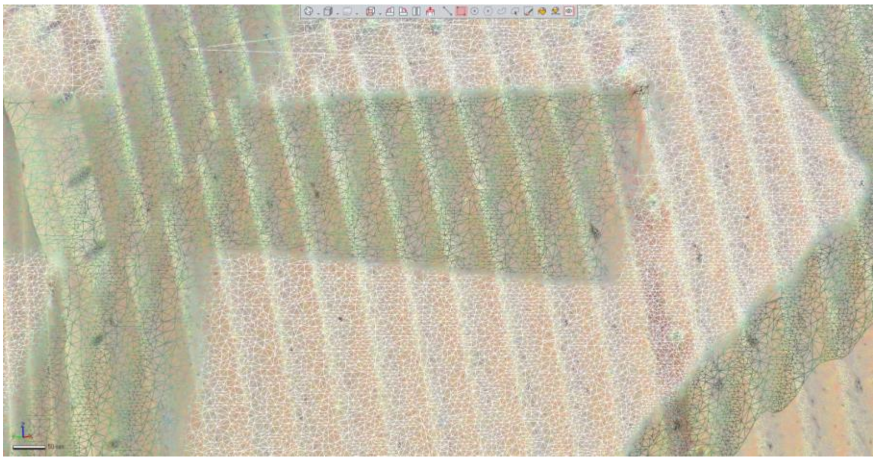

Figure 13. Chapel Exterior Wireframe detail

There is also a deformation detected in the point cloud model of one of the residential building Casa De Espagna (Fig. 14). In the point cloud data after co registration the model indicated that the center beam of the ceiling on first floor is deformed close to 4 cm from a definitive straight line (Fig. 15).

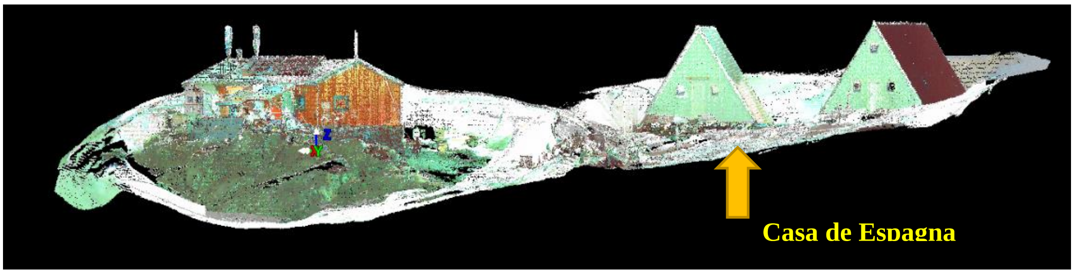

Figure 14. Casa De Espagna

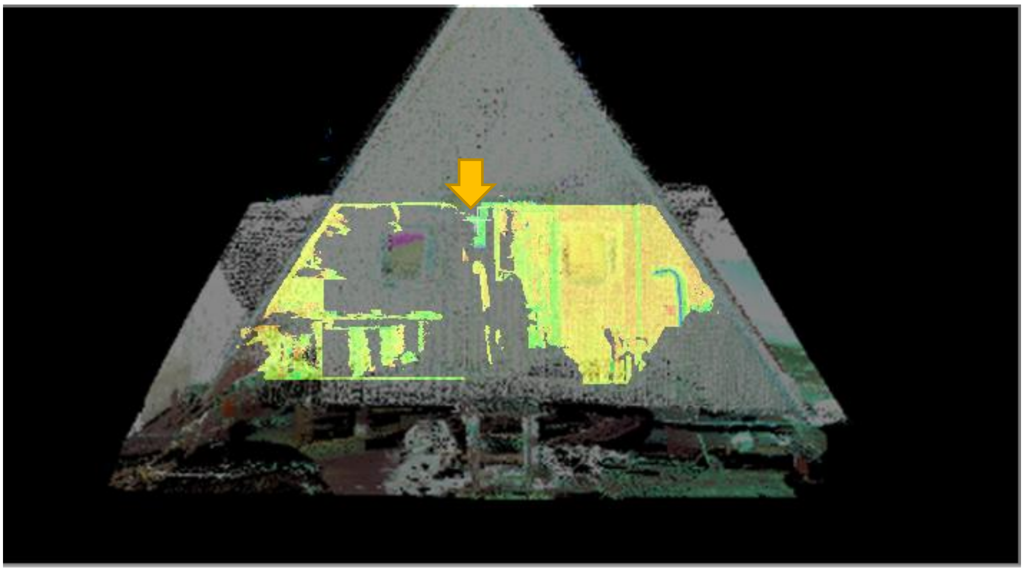

Figure 15. Casa De Espagna deformation area

4. CONCLUSIONS AND FUTURE WORK

The terrestrial laser scanning campaign at the Bulgarian Antarctic Station "St. Kliment Ohridski" provided a unique experience for geospatial research and production in extreme conditions. Some unique and diverse LiDAR and GNSS datasets, feasible for implementation in various interdisciplinary fields (e.g. historical documentation, Virtual Reality, GIS, civil engineering, architecture, geodesy a.m.) were acquired for the first time on Livingston Island. Within this project several important buildings (the main living quarters, the orthodox chapel, and the oldest standing building in Livingston island - "the Lame Dog hut", were scanned and documented. In addition, the Perunika Glacier's movement was also observed and modeled.

However, much of the processing effort is yet to be performed, and will be published in time. Ultimately, a virtual 3D model of the whole station will be created, which will allow the end users to analyze and manipulate its configuration without altering anything physically. The project may also influence extensive geospatial documentation of other buildings with historical and artistic value over the whole Livingston Island. Furthermore, since the base buildings are under constant extreme weather conditions and snow load, they should be checked periodically for deformation, including via TLS technology, in order to preemptively repair any deformation and extend the longevity of the base both physically and economically, removing any structure-caused hazards along the way.

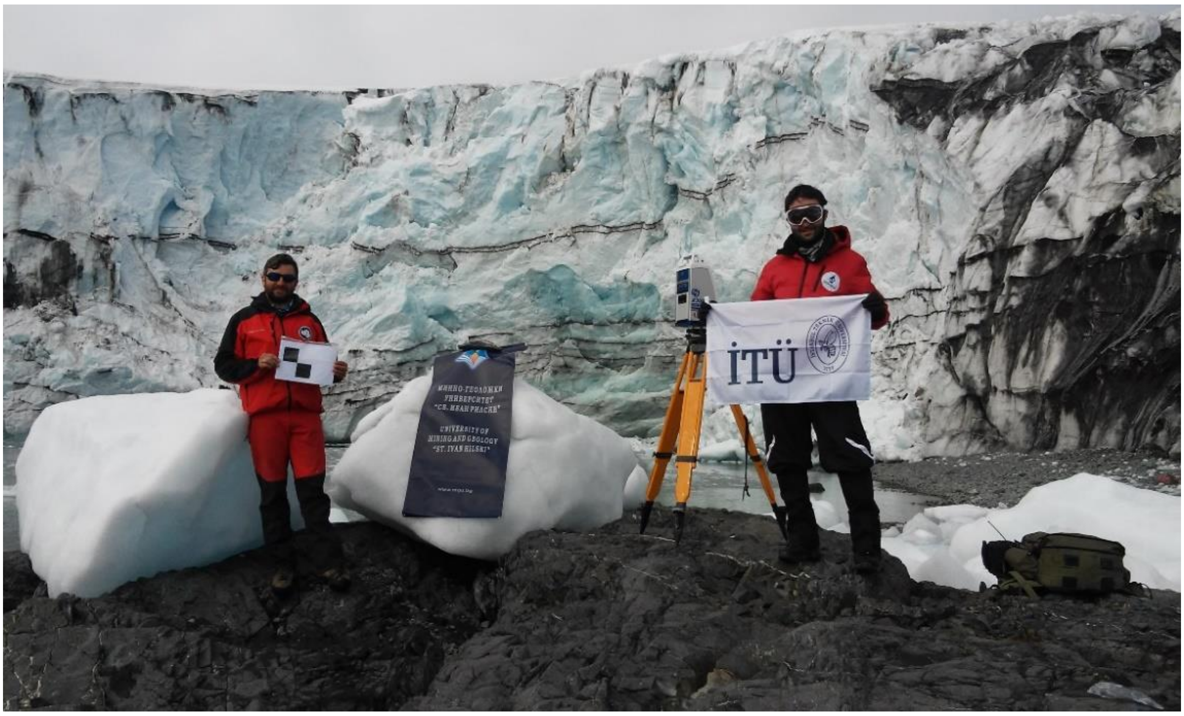

Figure 12. The team in front of the Perunika Glacier’s face

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to:

Prof. Christo Pimpirev – Chair of the Bulgarian Antarctic Institute; Prof. Lyuben Totev – Rector of the University of Mining and Geology “St. Ivan Rilski” – Bulgaria; Prof. Dr. Mehmet KARACA – Rector of the Istanbul Technical University; Assoc. Prof. Dr. Burcu OZSOY – Head of the Istanbul Technical University Polar Research Center (ITU PolREC); Assoc. Prof. Stanislav Topalov – Head of department “Mine Surveying and Geodesy” at UMG “St. Ivan Rilski”; The management and technical crews of the Bulgarian Antarctic Station “St. Kliment Ohridski”; NetCAD Inc. and Zeliha KAYA from NetCAD Public Affairs; **Quentin Tarantino**

REFERENCES

Abate, D., Pierattini, S., Bianchi Fasani, G., 2013, LiDAR in extreme environment: surveying in Antarctica. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-5/W2, pp.1-6. 10.5194/isprsannals-II-5-W2-1-2013..

[URL-1] Association of Polar Early Career Scientists. 2014. Who we are. [ONLINE] Available at: https://www.apecs.is/who-we-are.html. [Accessed 5 September 2017].

Besl, P.J., McKay, N.D. A method for registration of 3D shapes, 1992, IEEE Transaction on Pattern Analysis and Machine Intelligence 14(2), pp. 239-256..

Csatho, B., T. Schenk, W. Krabill, T. Wilson, W. Lyons, G. McKenzie, C. Hallam, S. Manizade, and T. Paulsen. 2005, Airborne Laser Scanning for High-Resolution Mapping of Antarctica. Eos Trans, AGU, 86 (25), pp. 237-238. doi:10.1029/2005EO250002.

Csatho B., Schenk T., Kyle P., Wilson T., Krabill W.B., 2008, Airborne laser swath mapping of the summit of Erebus volcano, Antarctica: Applications to geological mapping of a volcano. Journal of Volcanology and Geothermal Research, Volume 177, Issue 3, pp. 531-548..

Gibb R., McCurdy D., Farrell R., Bathow C., Breuckmann B., 2011, Use of multi-resolution laser scanning/white light scanning and digital modelling of the historic huts of Scott and Shackleton in Antarctica. Journal Geoinformatics FCE CTU, Volume 7.

Kamburov A., Gourev V., Berrocoso M., Prates G., De Gil, A, Knöfel C., 2017, Establishment of geodetic GNSS network on Livingston Island, Antarctica. Geodesy. ISSN 0324-1114, Volume 22, Sofia.

Lieser J.L., 2008, Determining sea ice thickness with an airborne scanning laser. Antarctic Magazine, Australian Antarctic Division, Kingston, Tasmania, 14, online, pp. 16-17.

[URL-2] SCAR GNSS database KOH2 log file. 2016. Available at: https://data1.geo.tu-dresden.de/scar/stations/KOH2/KOH2.log. [Accessed 6 September 2017].

[URL-3] SCAR. News from the Geodetic Infrastructure of Antarctica (GIANT) Expert Group. 2016. Available from: http://www.scar.org/giant/giant-news. [Accessed 6 September 2017].

Wolff K., Kim C., Zimmer H., Schroers C., Botsch M., Sorkine-Hornung O., Sorkine-Hornung A. 2016, Point Cloud Noise and Outlier Removal for Image-Based 3D Reconstruction..

BIOGRAPHICAL NOTES

Asparuh Kamburov is born in 1980 is Sofia. He graduated M.Sc. and Ph.D. levels at the University of Mining and Geology – Bulgaria, where he currently works as Assistant Professor. He has participated in the 21st and the 25th Bulgarian Antarctic Expeditions on Livingston Island, performing GNSS and LiDAR geodetic research projects.

Adil Enis ARSLAN is born in 1985 in Istanbul, Graduated from Istanbul Technical University Geomatics Engineering Division on 2008. Working at the Geomatics Engineering division and also a PhD Student in Geomatics Engineering PhD program, specializing in Laser Scanning. Member of ITU PolREC (Istanbul Technical University Polar Research Center).

CONTACTS

Asparuh Kamburov, Assist. Prof. Dr., University of Mining and Geology, e-mail: asparuh.kamburov@mgu.bg

Adil Enis Arslan, Eng., Istanbul Technical University, e-mail: arslanad@itu.edu.tr