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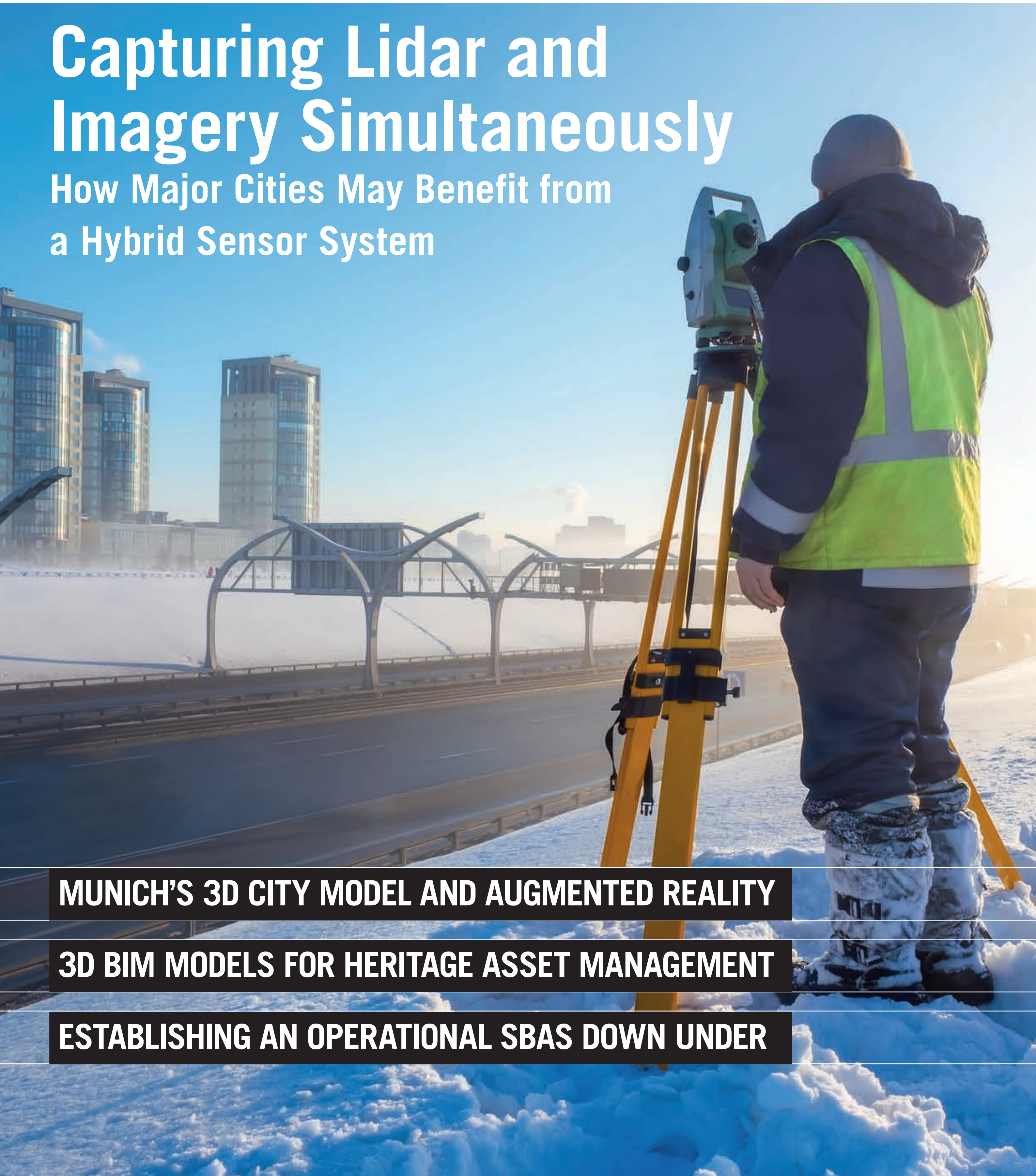

Capturing Lidar and Imagery Simultaneously

How Major Cities May Benefit from a Hybrid Sensor System

MUNICH'S 3D CITY MODEL AND AUGMENTED REALITY

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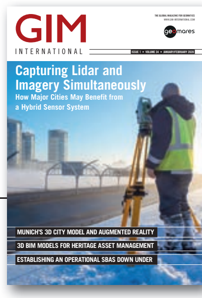
COVER STORY

Since it is winter in the Northern Hemisphere, GIM International's first issue of 2020 contains two articles involving lots of snow and ice. One of them takes you on a Lidar mapping journey across Greenland, and the other to Antarctica, where a British Antarctic Survey base has been digitally documented. Enjoy reading this issue!



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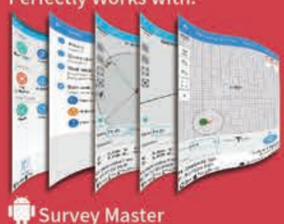

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Work to be done

Sometimes everything comes together in both a good and bad way. As I was editing the article for this issue on the Sharjah 'geoid' project performed by Fugro (page 20), it reminded me of my own first use of RTK dGPS. That was back in 1998, when the Dutch 'de Min' geoid of 1996 was still new and fresh. We're now two decades further on, and just last year the Dutch government announced the 2018 revision of, amongst other things, the geoid model. Then just as I was writing this column, the news broke that the Sultan of Oman had passed away. That reminded me of a course I taught to the Oman Navy last autumn about the requirements for using accurate GNSS heights. We started with the GNSS side and then moved on to the geodetic requirements, which I found out were not (yet) fulfilled. Apart from the global models, no local model existed. During those five days, the students became increasingly aware of the need for a local model, and of the huge number of measurements required to create one. Which in turn reminds me of how much of the world is still lacking what is nowadays a basic geodetic requirement at centimetre (or ideally millimetre) accuracy. So there's clearly work to be done!

Huibert-Jan Lekkerkerk, contributing editor, GIM International

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The democratization of Lidar data

The geospatial technology of Lidar is still relatively unknown to many members of the general public, but it looks as if this is about to change. The automotive industry is making rapid advancements in the use of Lidar to support autonomous driving, for instance, so the term 'Lidar' may soon become as familiar as the likes of 'radar' or 'sonar'. Lidar data offers endless possibilities, especially now there is a growing trend to make it publicly accessible. The Current Dutch Elevation (Actueel Hoogtebestand Nederland/AHN) is a good example of this. Helicopters and aeroplanes fitted with Lidar technology are used to collect 3D height information. The result is a detailed digital elevation map providing insight into the height of every square metre of the Netherlands with 5cm ground-level accuracy. What makes this tool so special is that the Dutch government has fully – and unconditionally! – shared the AHN in the form of open data to encourage its reuse. The dataset of the entire Netherlands encompasses over 1TB of data, which is a substantial amount to download. To make life easier for users, the country – and hence the dataset – has been divided up into approximately 1,100 rectangles covering 6.25km north-south x 5km east-west, each with a unique number. These so-called map sheets make it easier to download and handle the digital elevation data. Organizations such as municipal and provincial authorities, water boards and the Netherlands Directorate-General for Public Works and Water Management (Rijkswaterstaat) can already take full advantage of the detailed and precise height data the AHN offers for spatial planning. I firmly believe that further democratizing access to Lidar topography in this way increases the impact of this data, enabling it to be used for a variety of other purposes, including research, education and commercial applications. Feel free to play around with the Current Dutch Elevation yourself: www.ahn.nl.

Wim van Wegen, content manager

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Time for optimism

We're experiencing hurricanes, melting glaciers, earthquakes, bush fires, droughts and floods and, because of all that, hordes of people migrating across the globe. It sounds like an almost biblical description, but it's the harsh reality – the list of disasters tormenting Earth and its inhabitants seems endless. According to a recent survey, climate change has now ousted immigration as the topic Dutch citizens worry about the most. No doubt the two will swap places again, but they will both continue to jostle for the top spot for a long time to come. In large parts of Europe and North America, concerns about these two issues are making headlines every day; in other parts of the world, the effects of both climate change and immigration are felt in real life on a daily basis. In the slums of Monrovia, Liberia, young boys are encouraged to embark on a dangerous trip to Europe – crossing the jungle, the desert and the sea to achieve success for the sake of their families left behind in Africa. In Australia, people have been fleeing to the beaches to escape bush fires that are destroying their homes and their towns, while in Syria civilians seek refuge from the violence of war in Turkish camps. In many of these natural and 'not-so-natural' disasters threatening humanity, climate change and mass immigration are closely interlinked. And at the root of both these topics, the 'elephant in the room' is the very unfair distribution of wealth, causing extreme poverty in large parts of the world and unimaginable wealth in others. I find it striking that this matter is not at the top of the list for policymakers. Those who are financially better off should use their resources to not only distribute wealth more fairly but also to tackle climate change. Otherwise, even though in their hearts they would much rather stay where they were born and grew up, those at the poorer end of the scale will seek better lives for themselves and their loved ones, no matter what. Despite all the gloom in the word, the days are getting longer and the darkest days of the year are behind us (at least in this part of the world), so it's time for some optimism! In this new decade's first issue of *GIM International*, you will find articles describing deployment of technology such as airborne Lidar, satellite imagery and also terrestrial surveying to analyse, monitor and help address some aspects of these societal challenges. Geoinformation is at the root of every solution for the problems troubling the planet. Many geospatial professionals have a 'green' heart and are dedicated to contributing to a fair distribution of wealth and resources. Many initiatives and organizations like UN-GGIM, the World Bank and GEO share the same dedication. In our role, let's actively strive to make a positive change. Happy New Year!

Durk Haarsma, director strategy & business development

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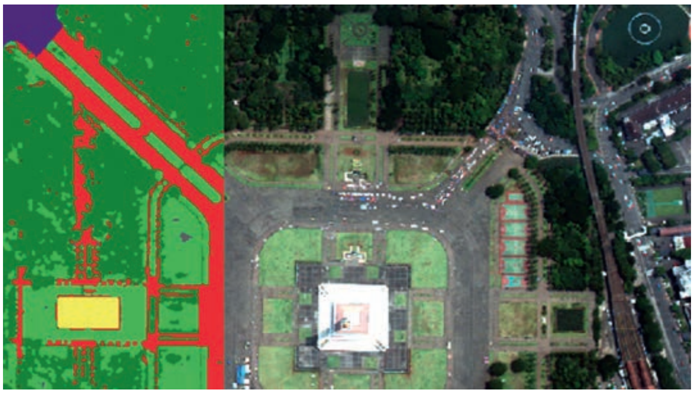
Copernicus Data and AI to Combat Climate Change

Europe's Earth observation programme Copernicus provides open access to up-to-date information on topics such as climate and land management. Such data holds huge potential for companies, entrepreneurs and start-ups to develop new solutions to tackle global challenges. Green City Watch combines big data from space with artificial intelligence (AI) to measure the quality of urban green space. This pioneering technology was honoured as the 2019 Overall Winner of the international innovation competition Copernicus Masters during the awards ceremony on 4 December in Helsinki, Finland.

▸ https://bit.ly/2EsqwgO



▲ *Green City Watch combines big data from space with AI to measure the quality of urban green space.*

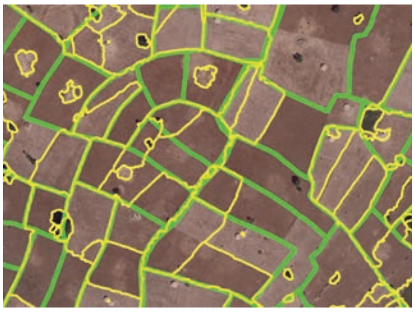
Portable Lidar Technology Provides Archaeology Students with New Insights

How can modern geospatial technology be used to preserve the past? Archaeology students from Wheaton College in Illinois, USA, have utilized a long-range Lidar sensor during an excavation project in Tel Shimron, Israel, to conduct daily high-resolution scans of the area. The scans gave the students a high-precision record of what they uncovered every day as the basis for further analysis. Velodyne Lidar provided its portable Ultra Puck sensor to enable a new generation of archaeologists to reconstruct life from thousands of years ago.

▸ https://bit.ly/35vM6fJ

▲ *Mapping the Tel Shimron site with the Velodyne Ultra Puck.*

How Machine Learning Makes Cadastral Mapping Faster and Cheaper



▲ *Automatically generated boundaries.*

Estimates show that nearly 75% of the world's population still do not have access to formally accepted land registration systems. According to University of Twente PhD student Sophie Crommelinck, cadastral mapping can be automated using an intelligent and interactive computer program she developed and described in her thesis. As a result, parcel delimitation takes 38% less time. A large part of the world does not yet have reliable land registration systems, including several East African countries. The lack of cadastrally registered land rights leads to uncertainty about land ownership and sometimes to life-threatening conflicts. Documenting borders is often the most expensive part of a land administration system. "You need a lot of technically trained manpower to perform cadastral measurements, but also expensive technologies to measure the borders," says Crommelinck.

▸ https://bit.ly/35yDEw8

InSAR Satellite Technology Data Enhances Forest Inventory

▲ *New Zealand seen from space.*

Remote sensing is a great way to learn more about our forests and manage them accordingly. Scion, a New Zealand government-owned research institute, is exploring new information-capture methods such as synthetic aperture radar (SAR). A recent study found that, while Lidar is still much more precise for predicting forest attributes, interferometric synthetic aperture radar (InSAR) has several other benefits to consider. Remote sensing involves recording data about an object without making contact with it. The recent study was the first time InSAR satellite technology has been used on the challenging, dense canopies of radiata pine in New Zealand's mountainous terrain.

▸ https://bit.ly/2M3dF8y

Laser Scanner and Drone Capture 3D Point Clouds for Military Heritage Restoration Project

In conjunction with Eyefly, Dutch surveying company Geomaat has produced a complete 3D model of the exterior, interior and roof of the Emma building at the Johan Willem Friso Kazerne, a former military site in Assen, the Netherlands. The result is a unique 'total solution' for Rijksvastgoedbedrijf, the country's Central Government Real Estate Agency. Several techniques have been cleverly combined to create a complete 3D point cloud, mesh and Revit model.

▸ **https://bit.ly/2YXpyC3**

▲ *3D model of the exterior, interior and roof of the Emma building at the Johan Willem Friso Kazerne.*

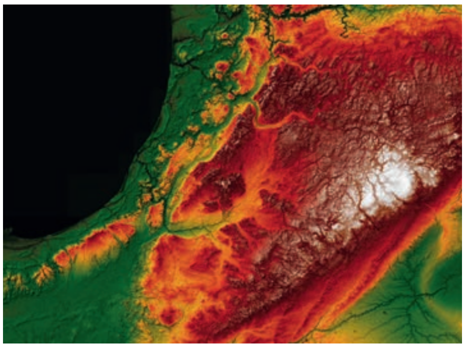
New Platform Connects Construction and Surveying Professionals

▲ *The Geo4Construction website.*

Publishing company Geomares, the name behind the leading international geomatics magazine *GIM International* and the product platform for surveying, positioning and machine guidance *Geo-matching*, is launching *Geo4Construction*. This new online platform brings together construction engineers and geospatial professionals in order to disseminate surveying knowledge in the Architecture, Engineering & Construction (AEC) industry and pave the way for the digital future. As an independent and technology-driven information source for the AEC industry, *Geo4Construction* brings you insights and trends in both technology and management, focusing on the application of geospatial technology in the construction business.

▸ **https://bit.ly/2qYIP9y**

How Lidar Has Changed the View of Michigan's Terrain



▲ *Elevation of the Southern Lake Michigan region. (Source: MAS Context)*

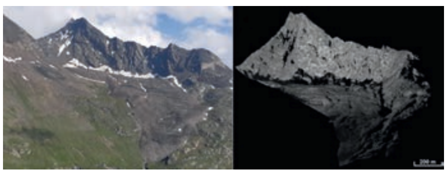
Staff from the Michigan Department of Environment, Great Lakes, and Energy (EGLE) in the USA are using Lidar technology to view the topography (elevation) of the state at a resolution that is 50 times greater than previously existed. "In fact, Lidar has fundamentally changed how we view and interpret the landscape," says John Esch, geology specialist. "Often, subtle features can be seen in the high-resolution Lidar topography data that are not visible on aerial photography, topographic maps and in some cases right under our feet." Lidar emits an intense, focused beam of light at the ground and measures the time it takes for the reflected pulses to be detected by a sensor. This produces a densely spaced network of highly accurate georeferenced elevation points as a point cloud with a point spacing of approximately 60cm.

▸ **https://bit.ly/38QYsBh**

Lidar Monitoring of Rock Glaciers with Improved Measurement Frequency

The 3D Geospatial Data Processing Group from Heidelberg University in Germany is conducting studies of rock glacier dynamics in a high-Alpine permafrost environment. The team is utilizing a RIEGL VZ-2000i terrestrial laser scanner and a UAV equipped with the RIEGL miniVUX-1UAV unmanned laser scanner. This fascinating research project is leading to new insights into rock glaciers. Short-interval (e.g. less than monthly) topographic Lidar monitoring has begun to provide new understandings into a range of geomorphic processes. Such 4D data helps to provide a better understanding of the dynamics of rock glaciers, which are creep phenomena of mountain permafrost. In the era of climate change, rock glaciers are important water reservoirs and potential unstable slopes. Their surface exhibits a range of change processes which feature different spatial characteristics, magnitudes and timescales of occurrence that are not yet fully understood.

▸ **https://bit.ly/36TqSc3**



▲ *Photo and 3D point cloud of the entire rock glacier. (Courtesy: Vivien Zahs, 20 July 2019; point cloud: Jack Williams)*

Indoor Mobile Mapping Goes Mainstream

In my previous column about the future of indoor mobile mapping, I made the case for why this technology was on the brink of widespread adoption. That was just over a year ago, and a lot has changed since then: brisk expansion of the products and services on offer, together with a widening field of applications. So after another incredible year, I believe that mobile mapping is well past the tipping point and is about to go mainstream. The emphasis now is on assessing data quality and establishing universal standards in this rapidly growing industry.
The most concrete proof that the technology is entering the mainstream is in the number of devices – even among the biggest names in the industry – that are flooding the market. Many of the established vendors who traditionally manufacture total stations and terrestrial laser scanners seem convinced that today's market is mature enough to add to their product offering a mobile scanner that can tackle indoor environments. For users, it's no longer a matter of if they should add a mobile device to their toolkit, but instead of what kind they need.

CONGRATULATIONS TO THE EARLY ADOPTERS

For early adopters in the surveying and engineering industry, this represents a clear vindication of their commercial instincts. They recognized great potential when this new technology first emerged, and they worked hard to win the trust of their customers and deploy it successfully. Since then, they have seen indoor mobile mapping grow in terms of both value savings and broader acceptance, and they're now poised to reap the benefits. For those who came on board a bit later – or are still thinking of doing so – they can feel much more confident about the future… not only because of the selection of proven tools now available to them, but also because of the best practices, performance benchmarks and lines of support that are increasingly being established within the indoor mobile mapping industry.

▲ *Mobile scanning is increasingly being used to capture indoor environments, thanks to SLAM-based systems that improve data quality.*

STANDARDIZED BENCHMARKS BENEFIT EVERYONE

A discussion about best practices is especially relevant here. While the quality and accuracy of the point clouds generated by mobile mapping solutions continue to improve in leaps and bounds, every user will benefit from having a common understanding that enables them to make the best choice between devices. After all, not all indoor mobile mapping devices are the same – and not just in terms of their hardware platforms (handheld, wearable or pushcart). When it comes to data quality, it's the software that will make all the difference in mobile devices. Much depends on the sophistication of the simultaneous localization and mapping (SLAM) algorithms, and how well the machine learning pipeline turns the data captured from multiple perspectives and angles into one consistent and accurate dataset during post-processing. I strongly believe that the growing number of devices coming to the market will shift the focus to the data quality, and very soon we'll have industry-recognized metrics that can be applied here too.

USABILITY WILL BROADEN THE MARKET

The core activity of scanning buildings and factories with indoor mobile devices continues to flourish and, in so doing, establishes the foundations for a digital twin – or virtual replica – of the entire built environment. A 2019 survey by Gartner Research provides ample evidence that digital twins for enterprises have entered mainstream use. With regards to applications, the use cases for indoor mobile mapping have even exceeded my own expectations this past year. We've seen the mapping of power stations in Germany, metro stations in France and a university campus in Sweden, and even the creation of a digital twin of an expeditionary research ship to advance our understanding of the Arctic. It's thrilling to see end uses for the technology which hadn't been initially envisaged, but which in hindsight make perfect sense.
Looking ahead to the coming year, I predict that another key trend will be an emphasis on usability. With vast quantities of data being generated, the continuing success of indoor mobile mapping has as much to do with speed and accuracy as it does with ease of use. Online services will be able to handle everything from post-processing to publishing in an efficient yet dependable workflow. When it comes to accuracy, the point cloud needs to be of a sufficiently high quality that it can be used for traditional use cases, such as BIM modelling. At the same time, keeping the end user in mind – such as by providing intuitive deliverables that every building stakeholder can access with confidence or making remote collaboration as effortless as though everyone were in the same room – is a surefire recipe for success. ◀

▲ *Felix Reinshagen.*

▲ *Based on point clouds, NavVis IndoorViewer software generates fully immersive digital twins of indoor environments such as factories.*

ABOUT THE AUTHOR

Felix Reinshagen is co-founder and CEO of NavVis, a company specializing in indoor mapping. He has a PhD in Information System Research and is active as a speaker and writer on digitalization, AI, 3D mapping and location-based services.

HOW MAJOR CITIES MAY BENEFIT FROM A HYBRID SENSOR SYSTEM

Capturing Lidar and Imagery Simultaneously

People continue to migrate from rural areas to major cities, driving sustained urban growth and increasing the demand for accurate, detailed and up-to-date 3D city models. The creation of such models is still a cumbersome endeavour but new advancements, such as the combination of three sensor types – nadir camera, oblique cameras and a Lidar unit – in one and the same geodata acquisition system, may bring relief. Aerial surveys conducted in major cities in the UK and Ireland demonstrate the potential of this solution.

Cities will continue to grow as long as the world's population keeps flocking to urban areas. In western countries, migration from rural to urban areas started in the early 1800s, and by the early 1900s 15% of the global population was living in cities. This will have increased to 60% by 2030, thanks in part to the large-scale shift towards urban living in Africa and Asia which began in the mid-1990s. This population concentration has created dozens of urban agglomerations with over 10 million inhabitants, called megacities. According to a study of the world's demography by Euromonitor International, in the decade between 2020 and 2030 six new megacities will emerge: Chicago, Bogota, Luanda, Chennai, Baghdad and Dar es Salaam. By 2030 there will be 39 megacities, which between them will be home to nearly 10% of the population and produce 15% of the world's gross domestic product (GDP). The liveability and sustainability of megacities rely on well-functioning roads, subways, railways, bridges, schools, hospitals and other public services.

3D CITY MODELS

Most modern cities and megacities have become complex, multifaceted 3D landscapes. Those responsible for the management, security and development of these major cities require detailed 3D models of buildings and infrastructure to support them in their tasks. 3D models are usually produced manually from stereo photogrammetry. Accurate and detailed 3D city models are in high demand, but expensive to produce. Realistic views require rendering with images, which is a labour-intensive activity. Often 3D city models consist of rendered polygon meshes that are common in computer graphics, gaming and animation. For 3D city modelling, mesh models are used for visualization, line-of-sight analysis, risk assessment, noise modelling, flood modelling, master planning and much more. They are also indispensable for creating smart cities.

MESH MODELS

A mesh is a group of edges, lines and faces that define the surface shape of a 3D object. The faces often consist of a network of triangles usually referred to as a triangular irregular network (TIN). The higher the point density is, the denser the mesh and the more detailed the representation of the 3D object will be. If the points constituting the triangles are represented in the same reference system as images, photorealistic 3D objects can be combined to create an entire city highly automatically. Airborne Lidar and vertical and oblique aerial images are well suited to the creation of 3D city models. Mesh models are often regarded as purely visual 3D models. However, limiting their use to visualization purposes alone would do an injustice to their full potential. Particularly when georeferenced at decimetre accuracy or even higher, such 3D data can be used for measuring distances, heights, surfaces and volumes. In addition it allows line of sight and other types of analysis, shading and flood modelling. Once it is known that a collection of adjacent meshes form a building or other coherent object, it is

ACCURATE AND DETAILED 3D CITY MODELS ARE IN HIGH DEMAND, BUT EXPENSIVE TO PRODUCE

▲ *Figure 1: View of the CityMapper, which combines – in a single pod – a nadir-looking multispectral camera (RGB + NIR), four oblique RGB cameras and a Lidar unit. (Courtesy: Leica Geosystems)* possible to assign an address, market value, BIM information or other information to the conglomerate of meshes. Attributing semantic information allows queries and intelligent analysis to be conducted.

BOTTLENECKS

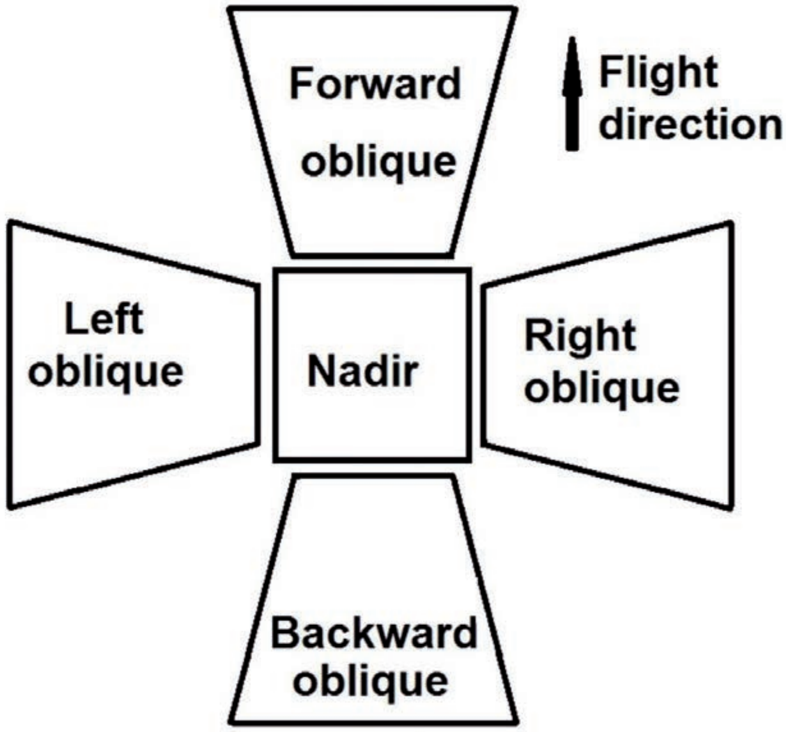
There are several bottlenecks in the creation of 3D mesh models of cities. One of the bottlenecks concerns the acquisition of homogeneous data over the entire survey area. Point clouds generated from images show impediments, even if the images are acquired with high overlaps and using dense image matching techniques, resulting in the extraction of no – or unreliable – points for some areas. Reasons for these shortcomings include:

- Occlusion: in narrow streets or urban canyons, some objects may block the view of other objects such as building facades. To extract 3D points from images, it is a fundamental requirement that objects are visible in at least two images.
- Presence of shadows: although dense image matching based on semi-global matching is highly robust against the absence of edges and texture, it may still cause unreliable matches.

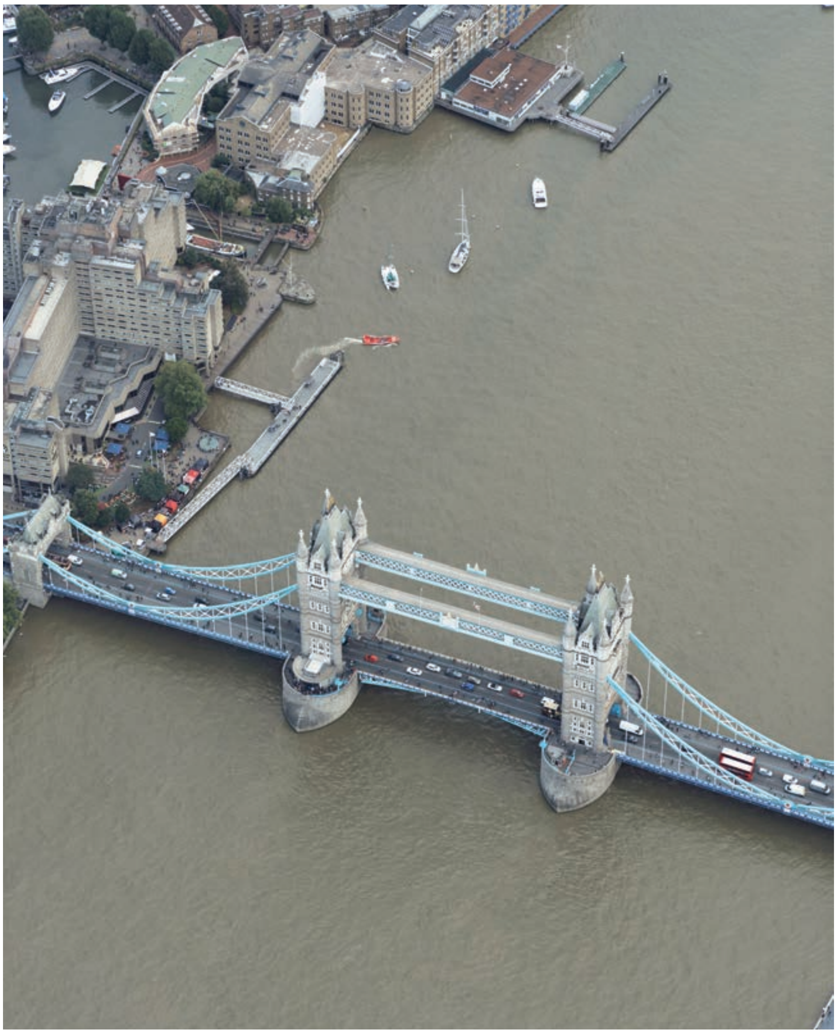
Today's airborne Lidar systems are able to create point clouds with high point density. However, the points have only one spectral value, which is the intensity of the return pulse. Nevertheless, the returns are not affected by the presence of shadows caused by sunlight, which is a clear advantage compared to photogrammetry. Since objects only have to be visible from one viewpoint, airborne Lidar is less affected by occlusion than photogrammetry.

CITYMAPPER

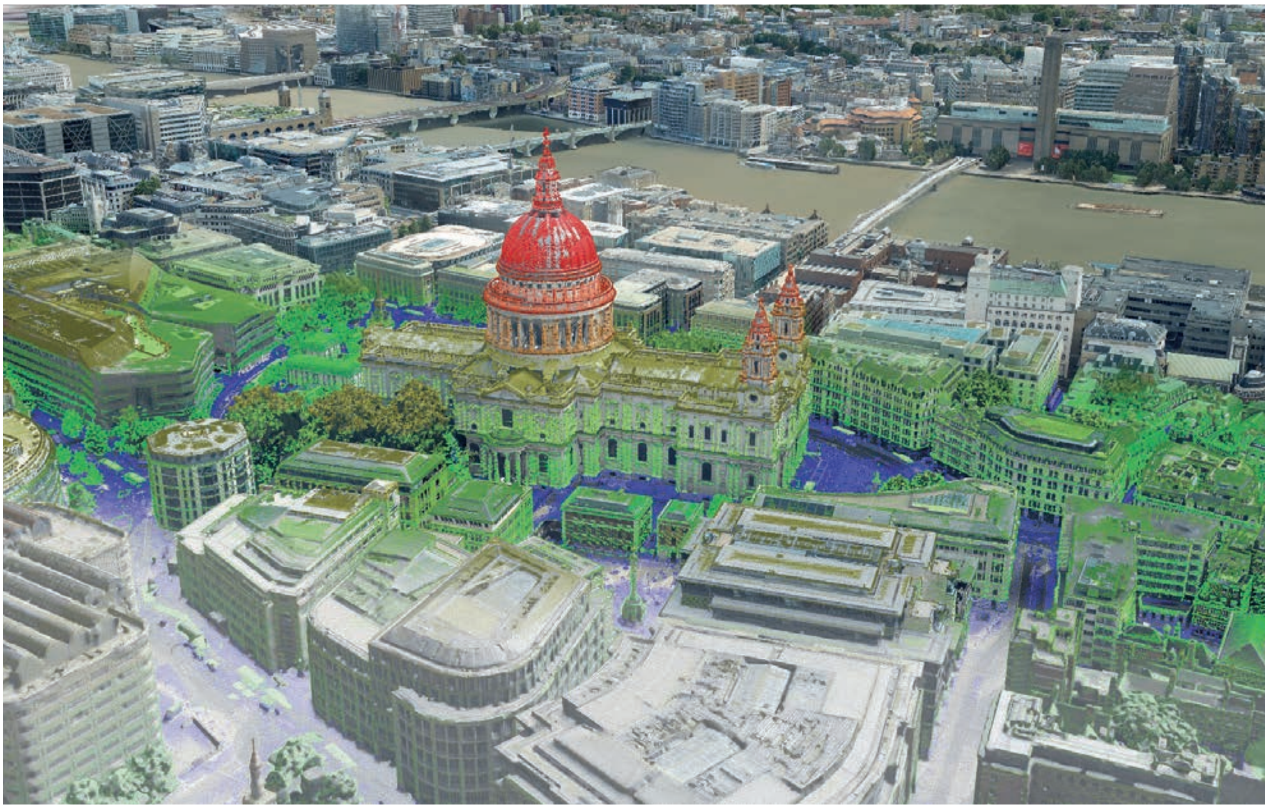
To tackle the above-mentioned bottlenecks of photogrammetry on the one hand and airborne Lidar on the other, Leica Geosystems has combined three sensor types in the world's first hybrid airborne geodata acquisition system. Called CityMapper, this system combines – in a single pod – one RCD30 CH82 multispectral camera for capturing nadir imagery, four RCD30 CH81m cameras for capturing oblique imagery and one Lidar unit (Figure 1). The nadir and oblique-looking heads are arranged according to the Maltese cross concept (Figure 2). The images of nadir camera captures RGB and the near-infrared (NIR) at 0.78 to 0.88µm. The four oblique cameras capture RGB imagery at 45 degrees forwards, backwards, left and



▲ *Figure 2: Principle of the Maltese cross concept. (Courtesy: M. Lemmens)*



▲ *Figure 3: Oblique RGB image of the Tower Bridge, London. (Courtesy: Bluesky)*



▲ *Figure 4: Partially rendered 3D mesh model of St Paul's Cathedral, London. (Courtesy: Bluesky)*

right. The nadir imagery can be captured at a ground sample distance (GSD) of three centimetres with a potential accuracy of 6cm root mean square error (RMSE). At the centre of the image, the GSD of oblique images is approximately 75% of the nadir GSD due to a combination of looking angle and focal length. When the nadir imagery has a GSD of 5cm, the GSD of the oblique imagery at the centre will be 3.7cm. The Lidar unit emits laser pulses with a wavelength of 1,064µm and a pulse repetition frequency of up to 700kHz. The accuracy is 6cm and the point density is 15 points per square metre at a flying height of 750m. None of these three sensor types nor their specifications are new. The workflows of generating outputs from the three data types are well established and operational in many photogrammetric companies. What is new is that incorporation in a single pod and using a single control unit enables the imagery and Lidar point clouds to be acquired simultaneously. This simultaneous data acquisition offers many advantages for the creation of 3D city models. For example, Lidar pulses are able to penetrate street canyons where there may be shadows due to obscured sunlight, and in narrow streets – where occlusion might prevent cameras from obtaining two views – Lidar can double the chance of successful data capture.

▲ *Figure 5: Oblique RGB image of the Aviva sports stadium, Dublin, Ireland. (Courtesy: Bluesky)*

USE CASES

CityMapper has been extensively deployed in Asia for accurate and detailed 3D mapping of new megacities with huge skyscrapers, which have been constructed at a breathtaking rate since 2000, and interest is now growing in Europe too. In 2018 and 2019, UK-based aerial mapping company Bluesky captured parts of London, Manchester, Birmingham, Cambridge, Oxford and several other UK cities. Figure 3 shows an oblique image of the Tower Bridge and Figure 4 shows a 3D mesh model of the area around St Paul's Cathedral, both in London, and Dublin, Ireland, was also surveyed (Figure 5). The nadir and oblique images as well as the Lidar point clouds are processed using HxMap, which contains tools for data download and raw quality control. Additional tools for aerial triangulation, radiometric adjustments and point cloud registration and georeferencing are available. Subsequently, the data is further processed to digital surface models, digital terrain models, orthoimages and other products derived from CityMapper imagery and Lidar point clouds which Bluesky calls 'MetroVista'. As part of a major transport infrastructure project, a photorealistic MetroVista 3D mesh model was used to gain insight into the impact of proposed construction by adding the object to the accurate 3D mesh model at the exact location and orientation. The model of the existing real world combined with the proposed development allowed the nature and scale of the development to be communicated to stakeholders and the general public.

PHOTOGRAMMETRIC DATA VOLUMES REQUIRE PARALLEL PROCESSING AND HENCE SIGNIFICANT INVESTMENT IN HARDWARE AND SOFTWARE

CHALLENGES

Needless to say, the creation of sophisticated, high-accuracy products which benefit city governments, managers and planners alike is not without its challenges. An aerial photogrammetric survey produces large data volumes that require parallel processing and hence significant investment in hardware and software in order to process, disseminate and share them efficiently and reliably. Other challenges include the weather in the UK, which is often not ideal for conducting aerial surveys. The flying height – between 1,000m and 1,800m – is lower than standard aerial surveys, which can be beneficial since it is often below cloud cover. However, the lower flying height can also draw increased attention from air traffic control in the crowded airspace above cities and megacities, leading to delays. Moreover, the flying speed – which at around 220km/h is slightly slower than for traditional survey flights – increases the data capture time, which may cause issues with permissions or weather windows.

ACKNOWLEDGEMENTS

This feature article is partly based on the results of aerial surveys conducted by Bluesky in the UK, using Leica's CityMapper. Particular thanks are due to Penny Boviatsou (Hexagon) and Laura Eddy (Bluesky).

ABOUT THE AUTHOR

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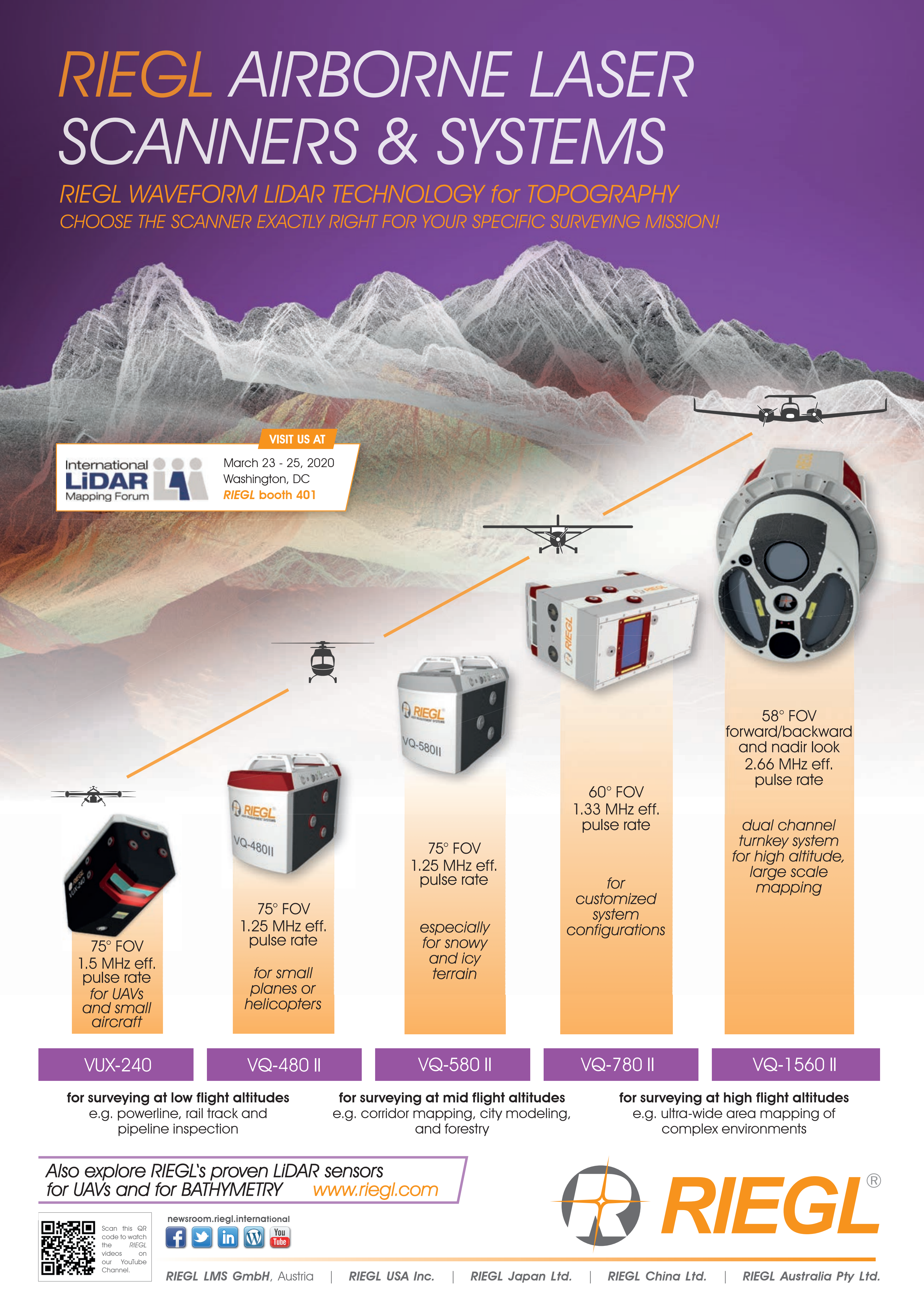
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FROM TEST-BED TO OPERATIONAL SYSTEM

Establishing an Operational SBAS Down Under

A satellite-based augmentation system (SBAS) is a system of differential corrections to GNSS positioning delivered from a geostationary satellite. The Australasian region took a major step towards gaining its first-ever SBAS in early 2017 when the governments of Australia and New Zealand agreed to fund a two-year test-bed to evaluate the benefits of SBAS technology across a number of industry sectors in the region. The highly successful test-bed ran from 2017 to 2019 and built the case for the governments of both countries to fund an operational SBAS.

SBAS is inherently an aviation technology, originally designed to help aircraft with vertical guidance during landing approaches. It was first developed in the USA (WAAS), followed by the European Union (EGNOS), Japan (MSAS) and India (GAGAN). Apart from the improvements in accuracy, SBAS also delivers an integrity component, which is specifically aimed at keeping aviation users informed of the system status, such that they can be alerted of any potential issues with their approach in real time. However, since its inception, non-aviation-based use cases of SBAS have become widespread, especially in GIS, mapping and forestry. In the USA, WAAS remains the most widely used augmentation service in non-aviation segments.
Australia first investigated the merits of an SBAS in 2011 and New Zealand followed suit in 2014. Both studies had an explicit focus on aviation use. Later, in 2016, Australia made another concerted effort, this time covering multiple industry sectors representing a much wider segment of the economy. As a result, a two-year SBAS test-bed was funded with the goal of demonstrating the economic benefits that an SBAS could bring to both countries.

THE INNOVATION

In total, six organizations were involved in the implementation of the Australian-New Zealand (Aus-NZ) SBAS test-bed infrastructure, with Geoscience Australia (GA) and Land Information New Zealand (LINZ) being the government organizations in each country responsible for the SBAS service. Three private companies established the test-bed service: GMV was tasked with generating SBAS corrections from the GA and LINZ data, Lockheed Martin provided and operated the signal generator and uplink antenna which delivered the corrections to the communications satellite, and Inmarsat provided the geostationary communications satellite which distributed the corrected positioning signal to the receivers. FrontierSI is a not-for-profit research organization that was responsible for managing industry-based SBAS demonstrator projects and working

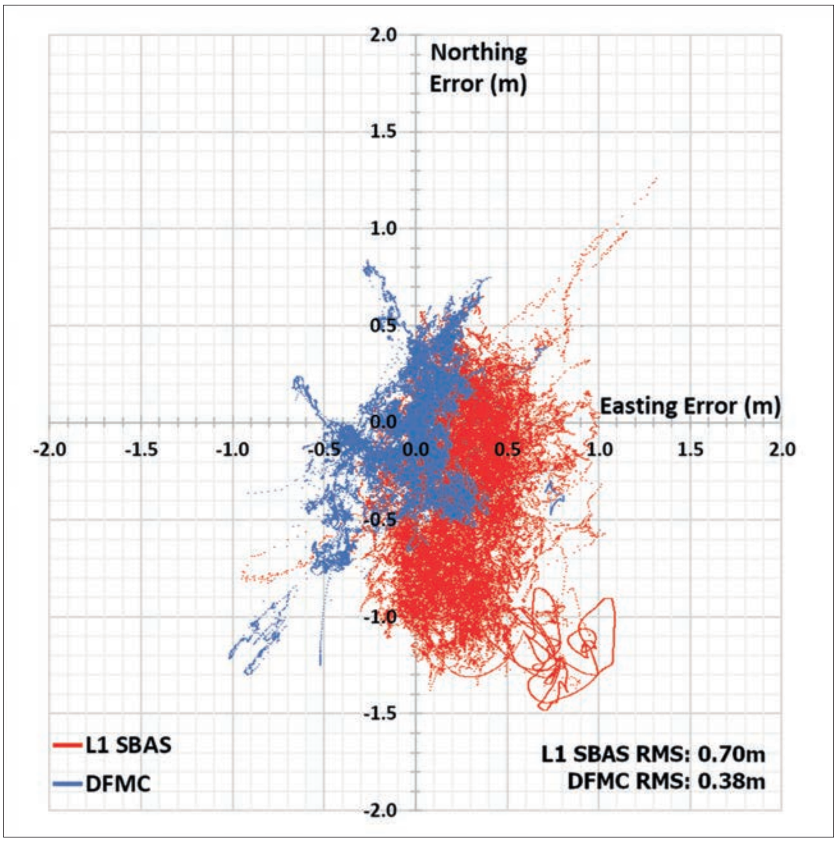


Figure 1: Results of L1 SBAS vs DFMC.

▲ *Figure 2: Autonomous tractor during an SBAS trial.*

▲ *Figure 3: Aircraft used in the aviation testing of SBAS in Australia.*

with an economic consultant to produce an economic benefits report.

The Aus-NZ test-bed was different from established SBAS systems in a number of ways. All the currently operational SBASs provide only one service: a single-frequency L1 augmentation service to GPS. The Aus-NZ test-bed had three services:

- L1 SBAS
- Dual-frequency multi-constellation (DFMC) SBAS
- Precise point positioning (PPP)

DFMC is a second-generation SBAS based on L1 and L5 frequencies and both GPS and Galileo constellations. Suddenly, the region that had never had SBAS before was leap-frogging the other regions in terms of the services offered. DFMC, for example, was a brand-new service. Although the standard had not even been released, it was broadcast and evaluated during the test-bed (see Figure 1). The test-bed programme progressed at a phenomenal speed following the kick-off meeting in Canberra in March 2017. The L1 SBAS signal in space was being broadcast by June 2017, with DFMC and PPP following just three months later.

INDUSTRY ENGAGEMENT

An open call for projects generated in excess of 80 expressions of interest from a variety of industry sectors including road, rail, agriculture, construction, utilities, resources, aviation, maritime and consumer (see Figures 2 and 3). Eventually, 27 of those projects were funded across the breadth of industry sectors. This was not without its challenges, since each industry has totally different requirements with regards to accuracy, integrity, cost, receiver hardware and so on. In aviation, for example, it is not the accuracy but the integrity – which is presented in the form of protection levels – that is of primary importance. Integrity is also important for other sectors such as maritime, road and rail, but the standards are either not available or are still being developed. However, for the majority of non-aviation sectors, the primary use of SBAS is to leverage the enhanced positioning accuracy, which is typically in the sub-metre range. Receiver quality, operating environment and the choice of antenna each play a key role in the system's positioning performance. For high-value rail and maritime applications, the use of professional-grade receivers costing thousands of dollars can be completely justifiable, but for widespread consumer applications the receiver must be small, light and very low cost.

COMPATIBLE HARDWARE

One of the keys to the success of the test-bed was ensuring compatible receivers that could pick up all the signals that were being broadcast. Almost all commercial off-the-shelf (COTS) receivers are compatible with the L1 SBAS service, although firmware upgrades were needed in most cases. For DFMC and PPP, however, no COTS receiver was compatible with the new services. Therefore, a complex array of equipment was designed and assembled which included a GNSS receiver and an RF front end connected to a single antenna via a signal splitter. The front end was used to decode the DFMC and PPP messages, while special software running on a rugged tablet was used to compute the positioning.

The whole array had to be carried in a backpack, closely resembling the early days of DGPS positioning. Around halfway through the test-bed programme, GMV developed a prototype handheld device (Figure 4) which was able to track and decode all three signals, which made the testing much easier.

ECONOMIC BENEFITS REPORT

The test-bed culminated with an economic benefits report completed with Ernst & Young. This comprehensive report covered all the aspects of the test-bed and included a chapter on each of the industry sectors with a breakdown of the benefits. The final conclusion from the report was that use of the SBAS in both countries will unlock AUD $7.6 billion worth of benefits over the next 30-year period, with $6.2 billion of those benefits attributed to Australia and $1.4 billion to New Zealand (Figure 5). The agriculture sector is predicted to have the biggest single benefit ($2.2 billion) followed by the resources, construction and road sectors with over $1 billion each. The full breakdown across both countries by sector is shown in Table 1.

Sector	Benefits (AUD)
Agriculture	$2.2b
Resources	$1.6b
Construction	$1.2b
Road	$1.1b
Maritime	$590m
Aviation	$404m
Water utilities	$280m
Rail	$190m
Consumer	$34m
Total	$7.6b

▲ *Table 1: Economic benefits by sector.*

Just some of the demonstrated benefits attributed directly to the SBAS include feed and fertilizer savings for farmers, reduction in fatalities and serious injuries on roads, reduction in falls from height on construction sites due to geofencing, and provision of more efficient rail management systems.

TRANSITIONARY PERIOD

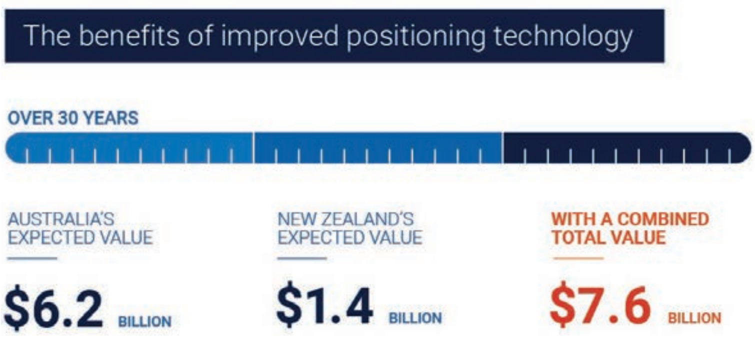
After the test-bed was completed in June 2019, the project entered a transitionary period. All three services are still being broadcast until at least the end of July 2020, and FrontierSI is working hard on behalf of GA and LINZ to engage the industry to use the various SBAS and PPP services. Although the test-bed has been completed, it continues to attract expressions of interest from numerous organizations, including some of the largest oil & gas and mining companies, small and medium enterprises (SMEs), start-ups and even individuals.

Alongside supporting the industry by providing testing equipment and advice, FrontierSI continues to conduct internal testing of the various SBAS services and receivers. The key focus now is on the consumer market. The latest results have shown that sub-metre positioning using the SBAS is achievable with a $6 GNSS chip and a $30 antenna, which in itself is quite a remarkable outcome that opens the door for many new low-cost applications. Further research and development is ongoing in conjunction with industry partners, and the aim is to bring sub-metre SBAS positioning to mobile phones in the near future.

OPERATIONAL SBAS

In 2020, GA and LINZ will collaborate to establish the required infrastructure for the operational SBAS. This process includes setting up SBAS ground stations, establishing secure uplink stations and the procurement of at least two geostationary satellites. The goal is to have an operational SBAS certified by the International Civil Aviation Authority (ICAO) by 2023. ◂

▲ *Figure 4: The GMV SBAS and PPP receiver.*



▲ *Figure 5: Economic benefits of SBAS in Australia and New Zealand.*

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ABOUT THE AUTHORS

Eldar Rubinov received a PhD in High-precision GNSS from the University of Melbourne, Australia, and is currently working as the SBAS technical manager at FrontierSI. He has a keen interest in all things positioning and geodesy, and is involved in a number of other projects at FrontierSI outside of SBAS.
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Chris Marshall is an SBAS engineer at FrontierSI, who has spent the last two years contributing to the Aus-NZ SBAS following the completion of his master's degree from the University of Melbourne. Chris has leveraged his keen interest in spatial information and positioning technologies to help evaluate the performance of the systems and promote the uptake of the forthcoming satellite infrastructure.
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CHALLENGING AERIAL ACQUISITION MISSION IN GREENLAND

Using Lidar North of the Arctic Circle

The acquisition of precise geodata is a high priority in Greenland, the world's biggest island and a place of great diversity. There, geodata is considered vital to support almost all aspects of community activities and also for the future development of the autonomous territory within the kingdom of Denmark. This article provides insight into an aerial acquisition mission made all the more challenging by Greenland's unique Arctic location.

In the summer of 2019, ASIAQ Greenland Survey commissioned the engineering company Niras to acquire Lidar data and photographic imagery of the five largest cities in Greenland: Nuuk, Sisimiut, Ilulissat, Qaqortoq and Aasiaat. The northernmost of the five – the city of Ilulissat – is situated 350km north of the Arctic Circle. The Danish company called Airborne LiDAR Mapping A/S was assigned the task of data acquisition.

MISSION REQUIREMENTS

For the mission to be a success, certain requirements needed to be meet. These included completing data acquisition over a city within the same day with a maximum allowable snow cover of 20%. Additionally, the angle of the sun had to be at least 30 degrees to the horizon during all collection operations, atmospheric and meteorological conditions between the aircraft and ground had to be free of cloud, fog and precipitation, the point density had to be at least six points per square metre in order to produce high-density point clouds, the vertical accuracy had to be better than 3cm and the ground sample distance (GSD) had to be 5cm.

PREPARATION

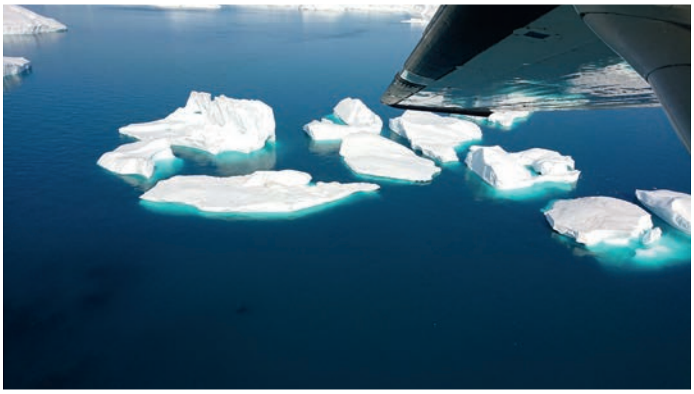
The actual areas to be scanned were relatively small: 80km^2 at Nuuk, 21km^2 at Sisimiut, 10km^2 at Aasiaat, 24km^2 at Ilulissat and 11km^2 at Qaqortoq, amounting to 146km^2 in total. Nevertheless, the mission requirements combined with the Arctic climate, the remote location and the sheer size of Greenland necessitated careful planning – in terms of both the data acquisition method and the logistics of transporting the aircraft used. For the acquisition of data, the equipment chosen was the RIEGL 480i airborne scanner, an Applanix 510 IMU and two Hasselblad a6 100c cameras.

▲ *The Cessna 337 was equipped with a RIEGL 480i airborne scanner, an Applanix 510 IMU and two Hasselblad a6 100c cameras.*

The stability of the airborne platform was also important, which ultimately resulted in the Cessna C337 Skymaster being chosen. The Cessna 337 is a multi-engine aircraft built in a push-pull configuration which offers different handling from conventional multi-engine aircraft. The aircraft is inherently stable and the centreline thrust configuration means it does not experience yaw if an engine should fail. In line with the current regulations for operating an aircraft in Greenland, it was necessary to obtain and carry a large amount of safety-related items, including flares, red signal cartridges, flag/sheet, mirror, emergency locator transmitter, compass, knife, matches, string, cooking stove, waterproof sleeping bags and a roofed dinghy for every person on board. The C337 chosen for the mission also featured de-icing/anti-icing equipment and long-range fuel tanks, which further increased safety.

MOBILIZATION AND START OF THE MISSION

On 23 July 2019, the Cessna 337 departed for Greenland from the Swedish airport of Sturup, making rest and fuel stops at Sumburgh in the Shetland Islands and Reykjavik in Iceland. The team arrived in Greenland on 24 July, landing at Kulusuk International Airport on the east coast. Kulusuk Airport, which shares its name with the nearby hamlet of Kulusuk with roughly 300 inhabitants, was built by the USA



Located on the west coast of Greenland, 250km north of the Arctic Circle, Greenland's Ilulissat Icefjord is the sea mouth of one of the few glaciers through which the Greenland ice cap is connected with the sea.

Having surveyed Aasiaat without complications, the team had completed the data acquisition part of the mission.

in 1956 as part of the Distant Early Warning Line.

From Kulusuk, the team proceeded to the first city to be scanned: Qaqortoq. However, because Qaqortoq (like many cities in Greenland) only has a helipad rather than a runway, the airport of Narsarsuaq – approximately 30 nautical miles away – was a suitable base for the first phase of the mission. After performing the scan with no complications, the team proceeded north to Nuuk on 25 July. Unfortunately the weather had changed by then, with low cloud, scattered rain showers and isolated fog making airborne Lidar data acquisition impossible. Therefore, the mission was put on hold and the team were forced to wait until conditions became more favourable again a week later. The mission could finally be resumed on 2 August, and data was acquired of the city of Nuuk – one of the largest areas of the mission – in a scan which took approximately three hours to finish. After Nuuk, the next scan was performed in Sisimiut and the team then flew on to Ilulissat – home to the Ilulissat Icefjord which was added to the Unesco World Heritage List in 2004.

MORE DELAYS

Upon arrival in Ilulissat, the progress was yet again delayed by cloudy, wet and foggy weather conditions, and the survey of the city could not be flown until 5 August. Then, entering the final stage of the mission, the team relocated from Ilulissat to the final city of the survey: Aasiaat. Despite an initially unfavourable forecast, the weather suddenly cleared in the afternoon of 9 August. The team swiftly mobilized and the C337 successfully became airborne with everyone and everything on board just before the local airport closed at 3 p.m. Having surveyed Aasiaat without any further complications, the team had completed the data acquisition part of the mission, resulting in 3TB of raw data in total.

Since the airport at Aasiaat was closed, the team flew south to Kangerlussuaq Airport for an overnight stay before heading back to Denmark. On 10 August, having spent the better part of three weeks in Greenland, it was time to depart from Kangerlussuaq and make the approximately 1,400km trip to Reykjavik in Iceland.

DATA PROCESSING

The global navigation satellite system (GNSS) and inertial measurement unit (IMU) data was processed using the Applanix MMS software. For this, the base data was derived through local and existing base stations. The trajectory of the Lidar data was merged in RiProcess and RiPrecision which was used to calibrate the data. The captured raw images were first processed in Photoshop to assure uniform intensity, lighting and colour. The picture triangulation was subsequently done in Agisoft Metashape and Trimble Match AT, whereas the further processing continued in uSmart suite. The photographic data was used for orthophoto production and photogrammetric updating of ASIAQ's base map, and the Lidar data was used for creating new digital surface models (DSMs) and updating existing ones.

CONCLUSION

Information is quickly becoming one of the most important commodities in the 21st century, and ongoing technological advancement is bringing new ways of handling and sharing geographic information. Gathering Lidar data and photographic imagery in Greenland was a challenging, exciting and important mission. For the island of Greenland to continue to evolve at the same pace as the increasingly digitalized modern world, well-defined and accurate geodata is crucial. In this carefully planned project, the right equipment and specialists were instrumental in producing the data that will help to support effective decision-making about Greenland's future development.

The acquisition of precise geodata is a high priority in Greenland and considered vital to support almost all aspects of community activities.

ABOUT THE AUTHOR

Janus List is chief commercial officer of Airborne LiDAR Mapping A/S in Denmark. He has a business degree, a commercial pilot's licence and over ten years' experience of operating survey flights.

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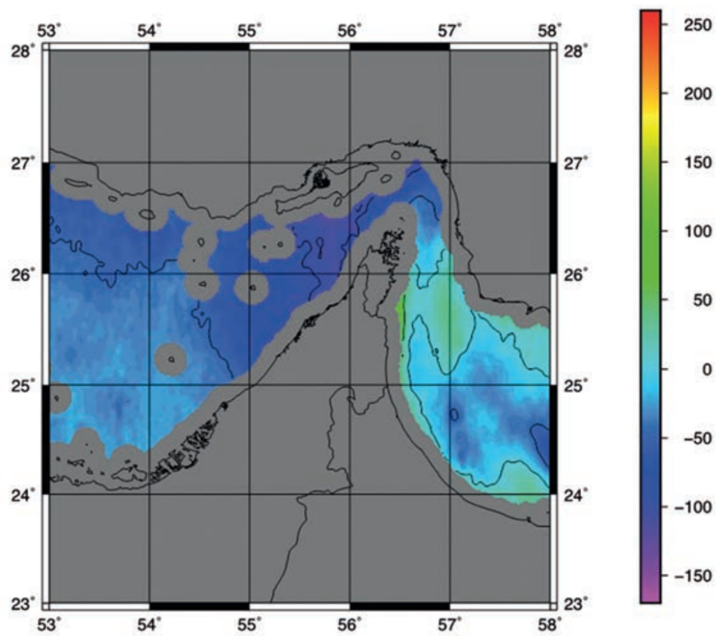
INTRODUCING STATE-OF-THE-ART GEOID MODELLING AND RELATED HEIGHTS

Analysing Mean Sea Level Variations across the Strait of Hormuz

When using GNSS as a geodetic and topographic height survey technique, the GNSS-based ellipsoidal heights must be transformed into orthometric ('levelling') heights using the geoid-ellipsoid separation ('geoid heights'), but these are not accurately known in all countries. Emirates Defence Industries Company (EDIC) and Fugro recently embarked on modernizing the geodetic and hydrographic infrastructure of the Emirate of Sharjah in the United Arab Emirates (UAE). Using GNSS, levelling and gravimetry, an accurate local geoid model was developed. This allowed analysis of the fine mean sea level (MSL) variations along and between the Arabo-Persian Gulf and the Oman Sea on both sides of the Strait of Hormuz.

For demanding applications, global gravitational models (GGMs) do not suffice; hybrid gravimetric geoids, based on gravimetric geoids and GNSS-levelling benchmarks with (theoretically) known rigorous orthometric heights, are required. Nearshore, the topography of the sea surface (TSS) is computed using tide gauge observations referenced to the geoid. Offshore (in the open sea), its equivalent is the mean dynamic ocean topography (MDT), which is computed using the mean sea surface (MSS), measured primarily from satellite altimetry, referenced to the ellipsoid and the geoid. However, the MDT/TSS is reputedly unreliable nearshore. This project in the UAE researched the possible range of its inaccuracy across the Strait of Hormuz. EDIC and Fugro set up the geodetic and hydrographic baseline for the Emirate of Sharjah, including a continuously operating reference station (CORS) network, first-order geodetic control points and levelling benchmarks, radar tide gauges and associated tidal benchmarks, absolute gravity marks and a relative gravity grid, all to determine a hybrid gravimetric geoid.



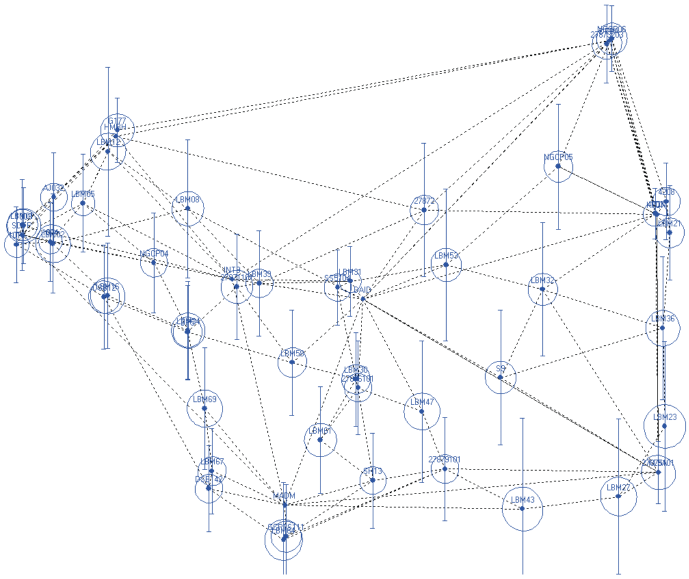
▲ *Figure 1: 15km masked satellite altimetry-derived gravity data in the study area. All values are in mGal.*

GNSS-DERIVED ELLIPSOIDAL HEIGHTS

The geodetic infrastructure consists of 31 first-order reference points, with 23 first-order geodetic control points (GCPs) complemented with eight active CORS. The geodetic GNSS survey was extended to 67 first-order levelling benchmarks (LBMs).

The data from the eight CORS was collected for 17 days. The local eight-station CORS network was tied into the International Terrestrial Reference Frame (ITRF) using 30 additional regional IGS CORS. Data processing was then performed using Gamit-

▲ *Figure 2a: CORS network.*



▲ *Figure 2b: First-order and LBM subset geodetic network.*

Globk software from MIT and crosschecked using Bernese software (University of Bern). This step yielded uncertainties of 2mm in Easting and Northing and 5mm in Ellipsoidal height for the CORS.

The first-order GCPs were observed using geodetic GNSS. A final least squares adjustment was constrained to the eight initially computed CORS coordinates, which provided uncertainties of 5mm in Easting and Northing and 15mm in Ellipsoidal height for the GCPs. Transformation of the geographical GCP coordinates to the UAE local coordinate reference system (epoch 2000.0) was performed using the ITRF2014 and GEODVEL tectonic plate motion models (MORVEL56 was tested but not used).

ACCURATE GRAVITY GRID

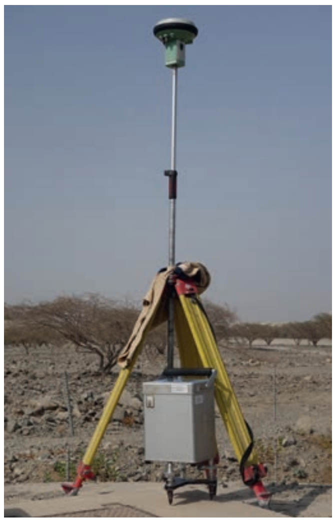
To determine the gravity derived geoid, relative gravity data was measured at a 2km grid spacing in the Sharjah Emirate and at a 5km spacing in the surrounding emirates to complement the existing gravity database (terrestrial and coastal airborne gravity data). Measurements were carried out according to state-of-the-art methodologies. Three absolute stations were established for tying-in the relative measurements to the International Gravity Standardization Network (IGSN71), scaling the network and limiting the error propagation. Processing of the absolute measurements was performed by the University of Montpellier with Micro-g Lacoste g9 software with a final 5µGal uncertainty. The relative gravity measurements were reduced to second-order free-air anomalies. The final least squares adjustment was constrained to the absolute stations values, providing grid point uncertainties of 32µGal.

ACCURATE MEAN SEA LEVELS

The nearshore water level was observed for two years using radar level tide gauges installed at four coastal tidal stations (Figure 4). Harmonic analysis to determine the 37 main tidal constituents was performed using a least square adjustment. Statistical analysis of the differences between the observed and the predicted tides validated the computation process. With the complete datasets, the differences between the yearly harmonic components averaged over two years allowed estimating mean sea level (MSL) and lowest astronomical tide (LAT) uncertainties ▸

▲ *Figure 3a: FG5 absolute gravimeter.*

▲ *Figure 3b and c: CG6 measurements of vertical gradient.*



▲ *Figure 3d: Combined GNSS and relative gravimetry.*

with an uncertainty of between 2 and 4cm depending on the station.

ACCURATE RIGOROUS ORTHOMETRIC HEIGHTS

A 400km first-order, first-class levelling network made of three loops with 67 levelling benchmarks was established and observed forward and backward to define the vertical datum (Figure 5). Both loops closed to within 1 to 3mm√Km with the difference between forward and backward runs within 4 to 9mm. Gravity observations were carried out at each levelling benchmark. The levelling network was least squares adjusted in geopotential numbers to account for gravity variations along the levelling paths. Helmert orthometric heights were computed approximating integral mean value of gravity with Poincaré-Prey reduction. The difference between geometric heights (stand-alone levelling without accounting for local gravity variations) and the gravity-reduced Helmert orthometric heights was 7.1cm at the extreme of the network. Finally, rigorous orthometric height corrections (terrain, density and geoid effects) were applied using the method by the University of New Brunswick (UNB). Depending on the benchmarks, these rigorous corrections ranged up to 1.5cm – which is quite significant, considering the challenging level of accuracy required for reliably tying the four tide gauges with each other and achieving an accurate hybrid gravimetric geoid in the Al-Hajar mountain range.

ACCURATE GRAVIMETRIC AND HYBRID GRAVIMETRIC GEOID MODELS

A gravimetric geoid was computed for the entire Sharjah Emirate using Stokes-Helmert approach implemented in UNB/Fugro's SHGeo package. With this method, the topographic masses are numerically condensed into a layer of infinitesimal thickness on the geoid prior to implementing a Stokes integration. The latest release (2019) of the software takes into account the topographic masses' lateral density variations for maximal accuracy.

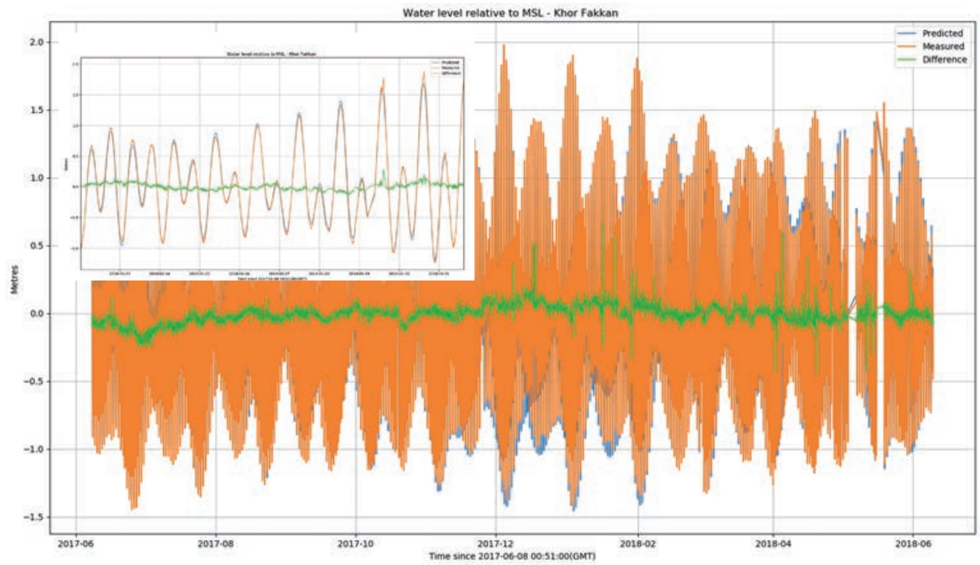
The process started with the compilation and assessment of all newly acquired and existing datasets available for the region (UAE and neighbouring countries), and included land, airborne (including lines flown nearshore), shipborne and satellite altimetry-derived marine gravity. A least square downward continuation was computed on the entire datasets to detect outliers. The optimal combined/satellite-only reference fields over the area of interest (AOI) were found to be the GECO/GOCO05s models. The SRTM-1" DTM was used to compute the topographical effect. The 3-space/no-topography method was implemented due to its capability to recover short wavelengths of smooth input data when adding condensed effect after downward continuation.

The accuracy of the gravimetric geoid was evaluated using the 67 levelling benchmarks. The residual standard deviation was 3.9cm, showing a remarkable improvement with respect to the global GECO gravity model for which this value was only 11.1cm. The gravimetric geoid was then fitted onto the benchmarks by least squares collocation. In addition to making the geoid consistent with the vertical datum realization, such a fitting is essential whenever there are areas with strong gravity anomalies where gravity data is scarce, inaccurate or just not publicly available (typically beyond the borders, in this case in Oman), which prevent capturing some medium to long wavelengths of the gravity field in the AOI. The hybrid gravimetric geoid was evaluated implementing blind tests, giving an accuracy of better than 2.5cm (pessimistic estimation).

STUDYING MSL DIFFERENCES ALONG ARABO-PERSIAN GULF AND OMAN SEA

Once the levelling network was shifted onto the Al-Hamriyyah MSL (Gulf), comparisons yielded differences of -13.0cm at Khalid (Gulf), and -0.063cm at Khor-Fakkan and -0.001m at Kalba, (both in Oman Sea). According to literature, the MSS varies significantly in the Gulf and the Oman Sea (exceeding 15m, mostly due to geoid variations), but the four tide gauges of interest happen to be in areas where TSS should be quite similar in height.

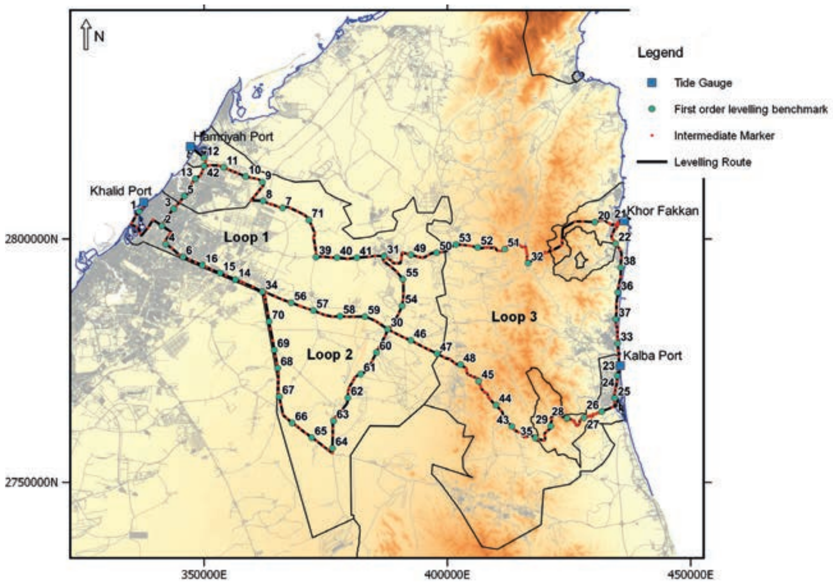
At local scale, MDT models agree as to the TSS along the Gulf coastline, very slightly decreasing westward. This trend is confirmed by the measured variation of the MSL between Al-Hamriyyah and Khalid (-13.0cm), whose uncertainty due to some possible – albeit limited – local effect was estimated below 2cm. The MSL gradient along the Oman Sea coastline looks more questionable; the TSS is slightly but clearly decreasing northward (-0.062cm from Kalba to Khor-Fakkan, with the uncertainty estimated to be below 3cm), but this trend cannot be ascertained by any model due to the variability of the TSS slope magnitude and direction in the Oman sea. Likewise, between the Gulf and the Oman Sea, whereas the TSS appears in the same range in the AOI (virtually the same MSL at Al-Hamriyyah and Kalba), no model seems capable of ascertaining the extent to which



▲ *Figure 4a and b: Observed and predicted water level over first year and enlargement – Khor-Fakkan.*

Geoid model	Mean residual [m]	Residual standard deviation [m]	Minimum residual [m]	Maximum residual [m]
Best fitted GGM (GECO)	+0.081	0.111	-0.164	+0.450
Raw gravimetric geoid	+0.981	0.039	-0.095	+0.064
Hybrid gravimetric geoid	0.000	0.010	-0.026	+0.019

▲ *Table 1: Geoid model evaluation using 67 GNSS-levelling benchmarks.*



▲ *Figure 5: First-order levelling network and tide gauge locations (four).*

they are the same. Indeed, when compared to the TSS resulting from the study's tidal measurements and the rigorous orthometric heights, the latest MDT publicly available (CNES-CLS18 MDT, based on GOCO05s GGM, consistent with this geoid at low degree/order) showed TSS slope biases of 2 to 7mm/km in both seas and virtually no difference in the SST shift between the two seas (Figure 7). The slope inaccuracy was anticipated while analysing estimated errors from satellite altimetry at the geoid computation stage (Figure 6). All data within 15km of the shoreline was masked out. This represented an acceptable compromise for keeping as much data as possible while using data with errors similar to those of marine ship-track gravity (3.5 to 5mGal). Whereas this choice resulted in typical errors of between 0.5 and 5mGal, one may notice that they reach almost 12mGal offshore Khor-Fakkan (and 7mGal offshore Kalba), and much higher nearshore.

All studies agree that extracting accurate MSL from satellite altimetry in coastal areas is hardly feasible due to amongst other things corrupted waveforms and errors in most of the corrections. However, this geoid study suggests that the resulting inaccuracy depends on the area and can be anticipated using the error model provided with the satellite data. In any case, a network of tide gauges remains the only way to accurately measure coastal MSL variations.

Although slightly underestimating TSS slopes in these coastal areas, CNES-CLS18 MDT has proved fairly accurate in the AOI, certainly due to its related MSS relying on Jason-1/2 and Cryosat-2 and its inclusion of data from the Drifters surface velocity program (SVP) in the Oman Sea. Once shifted onto a reference MSL

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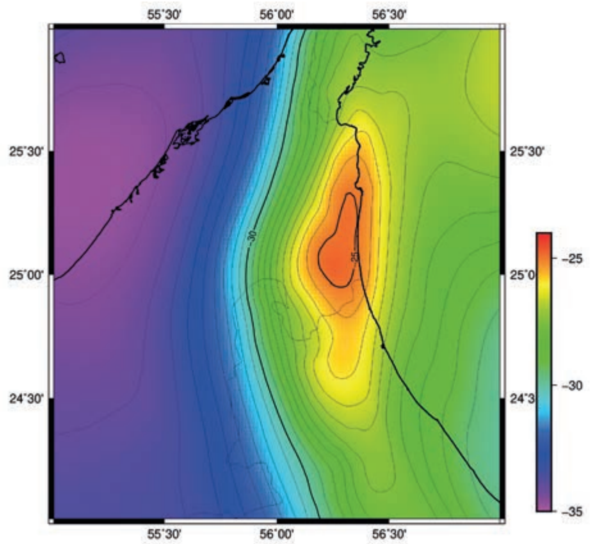
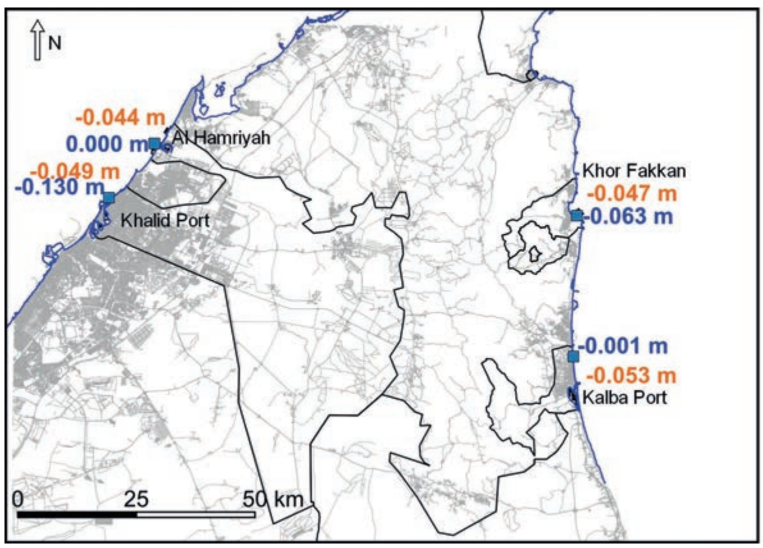


▲ *Figure 6: Emirate of Sharjah's gravimetric geoid. Values are in m.*



▲ *Figure 7: Comparison between Sharjah hydrographic levels/geoid 2019 TSS (in orange font) and CNES-CLS18MDT interpolated and shifted to minimize the differences to the four tide gauges (in blue font).*

at a reference port, the model can be used to estimate the MSL in first approximation up to a few dozen kilometres from the reference port. Even better, the model can be calibrated using two tide gauges in each sea and the SST extrapolated much further if the TSS slope is somewhat regular.

CONCLUSION

The combination of state-of-the-art GNSS data for 17-day observation sessions, water level data from four tide gauges over a two-year observation period, precise geodetic levelling, and absolute and precise relative gravimetry allows the computation of rigorous orthometric heights and a high-accuracy hybrid gravimetric geoid. This has given the Emirate of Sharjah a reliable geodetic and hydrographic infrastructure whose robustness has allowed refining of the TSS slopes nearshore along the Gulf and the Oman Sea as well as the TSS difference between both seas. The latter is hard to accurately measure from satellite altimetry alone. This study also suggests that gravity-estimated errors from satellite altimetry can be an indicator of the need for increased coastal water level measurements. ◂

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MOVING BEYOND THE FIELD OF DATA CAPTURE FOR DIGITAL PRESERVATION

3D BIM Models for Heritage Asset Management

Research undertaken under a collaborative doctoral partnership between Historic England and the University of Reading, UK, is moving beyond the field of 3D data capture for digital preservation. It considers how critical information for the conservation, repair and maintenance of historic buildings can be visualized in 3D BIM models and how BIM processes can be used for the management of structured datasets that inform conservation and repair programmes. A pilot study has been conducted using the work of the UK Antarctic Heritage Trust and historic British research base 'E' on Stonington Island, Antarctica, to consider this potential.

Building information modelling (BIM) is a process of information production, management and delivery among project stakeholders. It facilitates collaborative working practices through defined processes and technology, and offers the potential for improved performance and efficiencies and, thus, huge benefits to the construction industry. In view of the government agenda to meet BIM level 2 compliance and the increasing use of BIM in design and construction, the use of BIM technology with existing and historic buildings has been researched for the past decade. It clearly offers benefits for conservation management.

BIM APPLICATION IN THE HERITAGE SECTOR

To date, BIM application in the heritage sector has had a heavy focus on digital documentation of heritage assets, fuelled by technological developments in 3D data capture such as photogrammetry and laser scanning. There are numerous examples of heritage assets being documented in this way, and the range of benefits in visualization, structural and condition monitoring, education and research for conservation practice are becoming well understood. Research has considered the practical issues of data capture, subsequent 3D parametric modelling from point cloud data, automated data processing, pattern recognition and the creation of object libraries. However, an important aspect of recent research that deserves further exploration is the potential of BIM as a centralized data hub, facilitating the production, integration and management of required building information such as survey data, material, constructional and performance analysis, drawings, photographs, historical information and archival data. When data and information is produced or collated in relation to a project or asset, it can build up rapidly. Traditional methods to produce paper-based files or digital PDF documents can be difficult to manage and can get misplaced or missed by individual project stakeholders. Furthermore, information and documentation in this format does not facilitate efficient analysis, planning and decision-making. Key BIM concepts such as component-based parametric modelling and associated data parameters, inventory and database development and the extraction and transfer of structured data to asset information models (AIM), allow for the development of a comprehensive knowledge base. This could be extremely beneficial in the operational phase of a building's lifecycle, particularly for repair and maintenance.

▲ *Orthographic projection of the generator shed.*

AN ANTARCTIC CASE STUDY

Established in 1993, the UK Antarctic Heritage Trust (UKAHT) is tasked with the almost impossible mission of preserving the remains of over 70 years of British scientific exploration and research on the Antarctic Peninsula. Faced with the hostile conditions of the Antarctic climate such as katabatic winds, freezing temperatures and sea ice, even getting the necessary equipment (amounting to more than five tonnes) to the remote bases is an accomplishment. In the face of such adversities, UKAHT has taken on the challenge of managing six historic sites and monuments and embarked on a comprehensive survey, conservation and maintenance programme of the buildings and artefacts.

UKAHT's portfolio had been managed prior to this with what can be best described as ad hoc maintenance work. Basic historic reports were used as guiding documents for conservation decisions and repair philosophy, and conservation work was recorded in annual worklists and end-of-season reports. However, with the appointment of a new CEO in 2014, it was decided that a more informed and managed approach to the conservation of the sites within the portfolio, and the way the trust executed its responsibilities, must be established. Most importantly was UKAHT's ambition to collate a comprehensive set of base data about the historic sites, including measured survey, condition survey, material sampling, digital recording and artefact audits. Central to achieving these aims would be the development of a new digital data management system.

▲ *Base E, Stonington Island.*

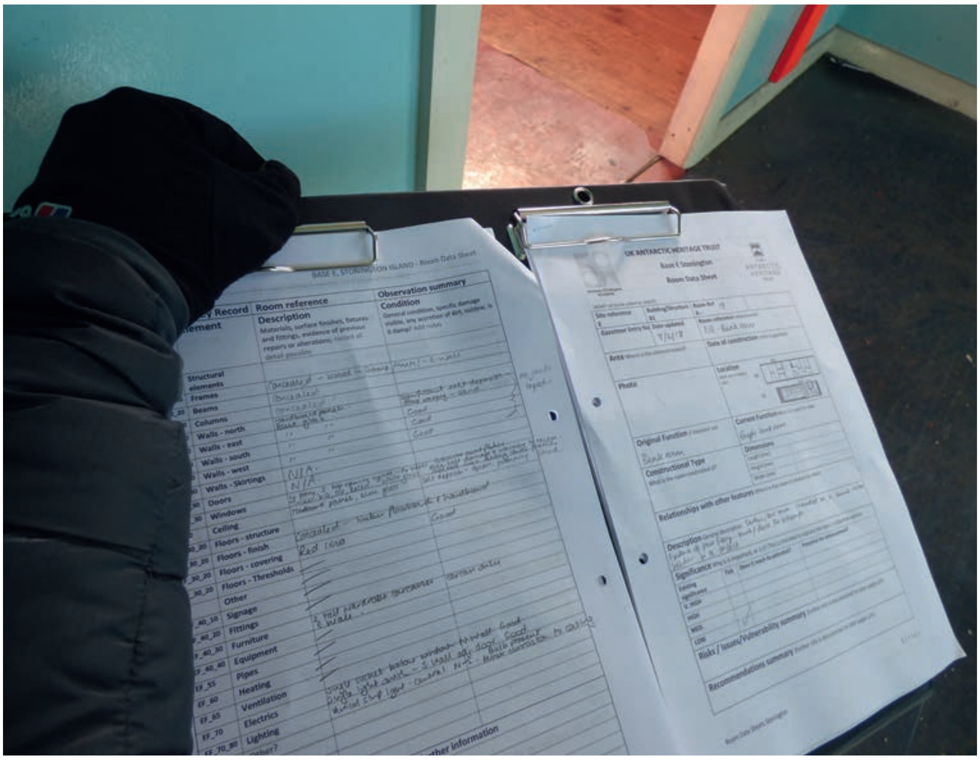
▲ *Base E Interior, output from photogrammetry. (Courtesy: UK Antarctic Heritage Trust, by Nathan Fenney.)*

The pilot study considers the BIM concept of component-based parametric modelling and the application of data parameters to produce structured datasets for heritage asset management. The addition of bespoke 'conservation' data parameters, such as element condition, significance and urgency of repair/maintenance, can be used as a visual planning tool within the model and is particularly useful for analysing and interrogating data for the planning of conservation/repair programmes. Furthermore, this data can be extracted in a structured format to be added to the digital AIM and imported into existing property management systems, offering a single source of validated data to support asset management activities.

3D DATA CAPTURE AND MODELLING

An assessment of logistical difficulties, freezing temperatures and unpredictable weather conditions preceded the decision to use photogrammetry to capture 3D data of the historic huts on the Antarctic Peninsula. A three-week period, an ingenious homemade telescopic pole and the use of coloured tape and food cans as survey points was the sum total required to complete the data capture. Agisoft Photoscan was used to process the digital images and generate 3D spatial data in the form of a point cloud. SketchUp was used to create the initial 3D model from the point cloud. 3D data capture and modelling were arguably the most straightforward steps in the overall process. Technological developments and research in this field mean that these processes are now well understood.

The process of adding data parameters to a BIM model of an existing building required more thought. With a view to adding component data retrospectively, it was first important to consider the critical information requirements for heritage asset management and, thus, a framework of 'conservation' data parameters. Arranging data in a component-structured asset data capture spreadsheet (similar to a COBie information and data exchange template) was the next important task. The project team decided to break the built assets down into building components and use Uniclass 2015 to classify and structure the data. The 'asset data capture spreadsheet' was then developed which would act as the overall 'database' in which data from visual condition surveys (conservation data parameters) and the supporting reports would be entered against the building components.



▲ *Collecting survey data in a structured format.*

CHALLENGES AND SURPRISES

During the Stonington Island field season, a number of challenges and surprises were encountered associated with the introduction of new processes and data capture objectives. The first surprise was people's focus on the 3D data capture and modelling aspects of BIM as opposed to the potential of BIM as a way of structuring and managing building data. This highlights the need for education in BIM as an information management tool and has contributed to the development of the new Historic England guidance document – *Heritage BIM: Developing an Asset Information Model*. This document will assist other heritage industry professionals consider their future digital asset management strategies.

Secondly, field seasons in Antarctica are relatively short given the extreme weather conditions and, as such, time is precious. All individuals have a role to play and tasks to complete. The conservation carpenter's energy was spent carrying out urgent repairs whilst the weather was good, leaving little time for survey and data capture. In terms of a BIM information management process, this challenge identifies the need to determine roles and responsibilities and highlights the importance of the information manager. Finally, the impact that inanimate objects such as jerry cans can have on a BIM process was both surprising and critical (two days into the crossing of Drake's Passage, the realization dawned that the team's fuel supply was missing). This, along with the effect the cold temperature has on laptop batteries and the impact of incompatibility between different laptops and hard drives, illustrates an actor-network effect that must be considered for future research that considers BIM implementation.

OUTPUTS AND NEXT STEPS

The pilot study has a number of extremely useful outputs. Base E, Stonington Island has now been digitally documented to benefit future generations. 3D data capture allows for a number of further outputs such as 3D virtual tours of the site, thus enhancing public awareness. Moreover, highly accurate CAD drawings, 3D models and orthographic projections have been developed that can be used for the planning of conservation, repair and maintenance, and for the pre-fabrication of replacement building components such as window shutters. The study has contributed to the development of framework 'conservation' data parameters for use by heritage organizations when developing BIM models and where there is an intent to manage condition survey data and asset management within a BIM environment. Future research will look to add developed 'conservation' data parameters to a parametric model and consider the benefits of using this visual method for the planning of future conservation/repair. ◀

ACKNOWLEDGEMENTS

Thank you to the UK Antarctic Heritage Trust which has supported this pilot study along with the British Antarctic Survey, Mapping and Geographic Information Centre (MAGIC) for providing expert advice and assistance in digital data capture and processing. Last but not least, thanks to Historic England and the University of Reading for supervising the Collaborative Doctoral Award.

ABOUT THE AUTHOR

Joanna Hull has a first-class honours degree in Building Surveying and a master's degree in the Conservation of Historic Buildings. She has worked in a variety of conservation management roles, including asset management, surveying, facilities and project management, for English Heritage and the UK Antarctic Heritage Trust, and in consultancy roles for Historic England and the National Trust. Joanna is currently working as Head of Projects for Serco Defence at the UK Defence Academy. In this role, she is trialling the results of her research in the development of the organization's asset management processes.

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MUNICH AS INNOVATION LEADER IN VISUALIZING THE FUTURE

3D City Model and Augmented Reality

The city of Munich launched an innovation competition and provided developmental support to the winner, Holo-Light. This ultimately resulted in the development of an award-winning augmented reality-based 3D city model of the Bavarian capital in conjunction with GeodatenService München (Geodata Service Munich). This underlines the pioneering work of this German city in using state-of-the-art technology to visualize the future.

▲ *Markus Mohl from GeodatenService München with HoloLens. (Courtesy: GeodatenService München)*

The city of Munich launched an innovation competition in March 2018 and the winners were announced in July of that year. Participants in the innovation competition were tasked with visualizing and virtually modelling the future development in Munich's new district of Freiham using GeodatenService München's digital 3D data. The first winner in the augmented reality category was the company Holo-Light. That solution was subsequently developed under the leadership of GeodatenService München, together with Holo-Light itself and the city of Munich's IT Department and the Department of Urban Planning and Building Regulations. It was presented to the public at the end of February 2019.

ROOMSCALE – VISUALIZATION FOR MEETINGS

The Holo-Light solution currently includes two different modes: RoomScale and WorldScale. In RoomScale mode, the photorealistic 3D city model is displayed virtually and supplemented by the future development based on the legally binding development plan. RoomScale mode is used, for instance, in the context of committee and city council meetings or public events. The virtual version of Munich can be viewed simultaneously by up to 12 people. Wearing Microsoft's mixed-reality headsets, they can see further information such as street names or floor numbers of the individual buildings. Furthermore, viewers can interactively adapt virtual objects and, among other things, change the height of a selected building by altering the number of floors. During the meetings, the participants can also discuss the extent to which the planned buildings fit into the cityscape. Changes and variations are visualized immediately. This supports better coordination of development plans.

WORLDSCALE – ON-SITE VISUALIZATION

WorldScale mode enables virtual 3D data to be added to the real world on site. This takes stakeholders away from the drawing board and the meeting room and out into the city itself. By standing on a viewing platform, for instance, users can get an impression of the actual dimensions of the planned buildings.

In WorldScale mode, it is also possible for several people to look at the virtual buildings at the same time. Additional information is displayed, and interactive adjustments can be made. Munich is believed to be the first city in the world to take this approach.

USE IN PRACTICE

Use of the solution in practice has shown that extending the reality with virtual information works and is accepted by users. After successful implementation of the solution, numerous people in Munich – ranging from politicians and urban planners to citizens – were able to get a first impression. In this context, the technology was not of the utmost relevance. Instead, the users directly started discussing the information they could see. This was a very positive result for the usability of augmented reality.

▲ *Augmented reality and RoomScale. (Courtesy: Holo-Light and GeodatenService München)*

▲ *Augmented reality in WorldScale. (Courtesy: Holo-Light)*

LEADING INNOVATION IN AUGMENTED REALITY

Holo-Light received the German Innovation Award in May 2019, providing official recognition of the highly innovative approach of this augmented reality solution for 3D city modelling. It provides very transparent planning support for city councils, urban planners as well as decision-makers within the authorities. In addition, the solution offers new possibilities in terms of the communication of urban planning projects to the citizens of Munich.

GeodatenService München continues to pursue the use of augmented reality for the purposes of the Bavarian capital. This is currently implemented as part of the funding project for the creation of a digital twin of the city of Munich, which was launched on 1 January 2019 and is funded by the Federal Ministry of Transport and Digital Infrastructure. The aim of this project is to create a complete digital 3D city model of Munich which also contains extensive information and real-time data. The goal is to improve the foundation for urban planning, for example by modelling what-if scenarios. Last but not least, augmented reality will play a vital role in visualization. ◀

ABOUT THE AUTHOR

Markus Mohl started his professional career in 2000 after gaining his degree in geodesy and geoinformation from the Technical University of Munich, Germany. He initially worked for the company AED-SICAD and moved to the city of Munich in 2010. At GeodatenService München, he is among other things a project manager for the development of a digital twin of Munich.

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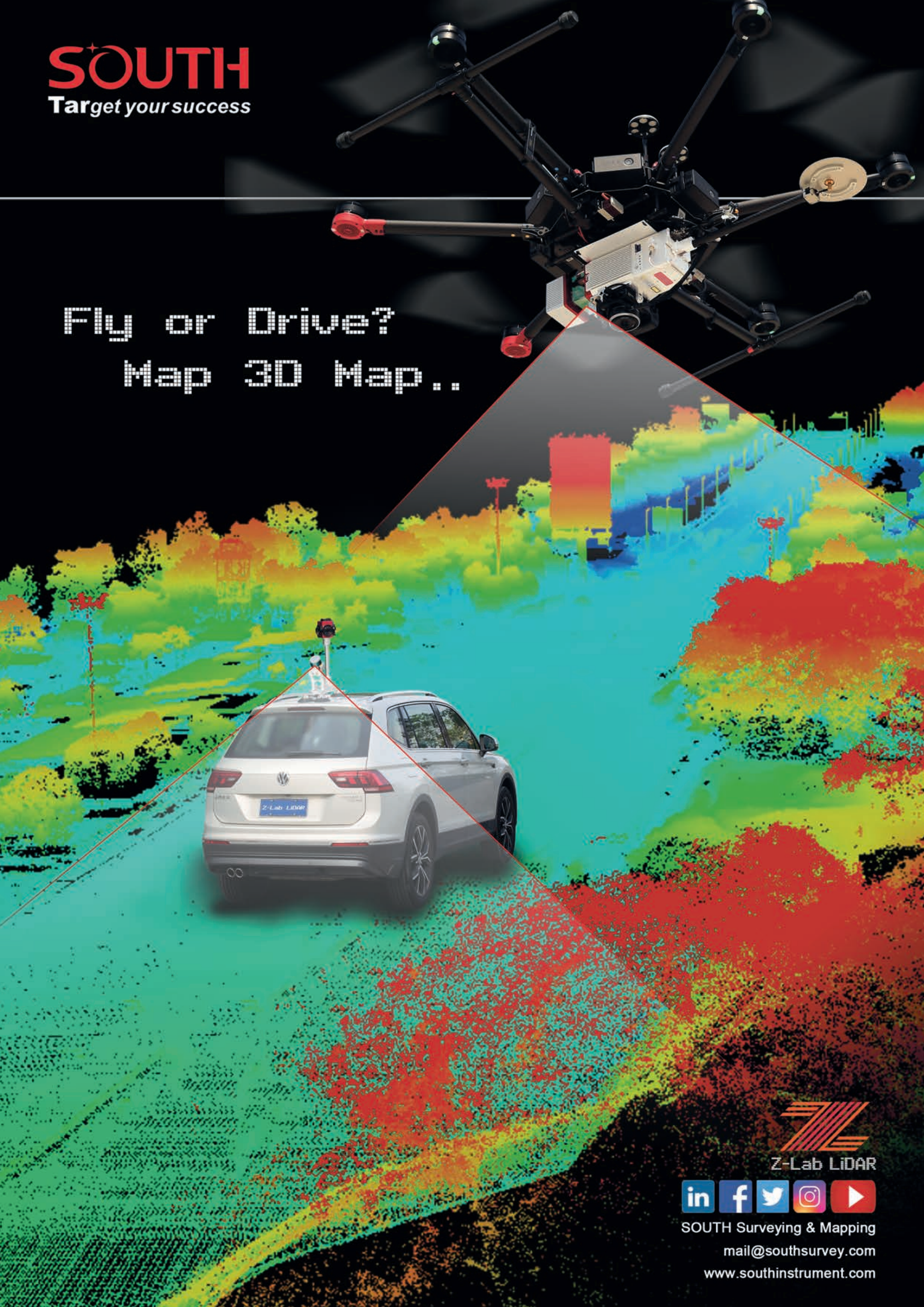
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Map 3D Map..
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FIG Young Surveyors Regional Events

The International Federation of Surveyors - Young Surveyors Network (FIG YSN) is a large group of dedicated young surveyors working towards common goals as identified in the Work Plan.

Five regional networks form the foundation of FIG YSN:

- Africa
- Asia and the Pacific
- Europe
- North America
- South America

These regional networks help us better communicate and engage with young surveyors from around the world by having a regional and country level focus.

In the second half of 2019, the 2nd African Regional Meeting and the 6th European Regional Meeting were held in collaboration with national meetings and regional meetings of FIG.

6TH FIG YOUNG SURVEYORS EUROPEAN MEETING, 11-12 OCTOBER 2019, PORTO, PORTUGAL

The success of previous FIG Young Surveyors events paved the way for yet another collaboration between young surveying students and young professionals. The 6th Young Surveyors European Meeting was held in the beautiful city of Porto, Portugal, from 11-12 October 2019. About 40 keen young professionals and students from 15 countries gathered together to share and explore new ideas, address pressing issues and focus on the future development of the European FIG YSN. The focus of this meeting was the future of young surveyors, as professionals as well as individuals, in mapping the path to sustainability. To continue the charitable nature of these events, we organized a charity walking tour to raise money for FIG Foundation and Forestis, a local non-profit.

2ND FIG YOUNG SURVEYORS AFRICA MEETING, 25-26 NOVEMBER 2019, DAKAR, SENEGAL

Following the successful 6th FIG Young Surveyor's European meeting, FIG Young Surveyors Africa held its second meeting together with the newly formed Federation of Francophone Surveyors' (FGF) Young Surveyors Network. The bilingual meeting successfully brought together over 50 young surveyors from about 20 countries in the francophone and anglophone world.

With just ten years left to meet the Sustainable Development Goals (SDGs), the theme of the meeting was 'Connecting the Generations for Our Common Future'. This highlighted the continued link between young surveyors and seasoned professionals, as well as the contribution of young surveyors to meeting the global sustainable development agenda through the SDGs. There were presentations from a cross-section of young surveyors and FIG partners, as well as group activities including brainstorm sessions on the young surveyor's role in the global development agenda – both within the African context and on a global scale. These activities created an environment for young surveyors from different countries and cultures, with different academic and professional backgrounds, to discuss issues facing the region and plan for a more resilient future. All this took place in the warm atmosphere of Dakar, Senegal, where young surveyors enjoyed the legendary Senegalese hospitality: *Teranga*.

Melissa Harrington, chair of FIG Young Surveyors Network, Kwabena Asiama (YS Africa) and Inês Vilas Boas (YS Europe)

More information
www.fig.net

A New Benchmark for Global Geodesy

The Subcommittee on Geodesy has reached a new milestone on the road towards a sustainable global geodetic reference frame (GGRF). At the 9th Session of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), the GGRF accounted for the most interventions, which signalled a strong interest in advancing the subcommittee's work programme. Of the Member States intervening on GGRF, 67% strongly supported the establishment of a Global Geodetic Centre of Excellence (GGCE). This gives the subcommittee a strong mandate on the way forward. In addition, three Member States – the Russian Federation, Germany and India – announced their interest in hosting or supporting the activities of the future GGCE. The GGCE will be an operational hub with the intention of strengthening the capacity to implement the UN General Assembly resolution: 'A global geodetic reference frame for sustainable development'. It is proposed that the GGCE will support the objectives of UN-GGIM and the Subcommittee on Geodesy, provide technical assistance and capacity building, and encourage and facilitate open geodetic data sharing. By also providing advocacy and outreach, the GGCE will enhance the subcommittee's capacity to effectively and efficiently manage global cooperation in the area of geodesy.

The Subcommittee on Geodesy is planning

to undertake consultation on the practical implementation of the GGCE, namely to decide on modalities, function, financial arrangements and a programme of work. Consultation will be coordinated with the Committee of Experts and relevant geodetic stakeholders, including the International Association of Geodesy (IAG), International Federation of Surveyors (FIG) and the regional geodetic committees of the UN-GGIM. The plan is to present the initial GGCE work programme to the UN-GGIM Bureau in April 2020, with ongoing progress and status to be reported at the 10th UN-GGIM session in August 2020.

More information
http://ggim.un.org/meetings/GGIM-committee/9th-Session/documents/GGRF_Position_Paper2019_24July_web.pdf

Meeting of the UN Committee of Experts on Global Geospatial Information Management, August 2019. (Courtesy: Anne Jorgensen)

First Meeting of New ICA Executive Committee and Commission Chairs

During the last International Cartographic Conference in Tokyo, Japan, in August 2019, the entire Executive Committee was newly elected for the next term 2019-2023. The assembly of national delegates also approved the applications for 28 ICA commissions and voted in the new commission chairs. On 22 November, the newly elected Executive Committee met for the first physical meeting during the new term in Ghent (Belgium). A full day of intense discussions and a huge list of work items set out the agenda for the International Cartographic Association for the next four years. Following ICA's Strategic Plan and the president's motto ("Maps make a difference" and "Cartography is more relevant than ever today in an increasingly complex world"), the committee discussed next steps and necessary actions in order to achieve these goals and make our important discipline and society even more visible and heard by decision-makers and a larger audience beyond the geospatial community.

Reaching the goals of the next term is of course a collaborative project that the Executive Committee, national members, affiliate members and ICA commissions need to undertake together. Every member of the Executive Committee has an important role to play in this context as a coordinator, enabler and facilitator. Hence, all vice-presidents were assigned the role of liaison with commissions and working groups.

FOUR NEW WORKING GROUPS FOR THE 2019-2023 TERM

As some of the strategic tasks that the new Executive Committee wants to tackle during the next term are very specific or transversal in character and not fully covered by existing commissions, four new working groups were set up during the meeting in Ghent:

- Cartography and Sustainable Development (Philippe De Maeyer)
- Cartographic Body of Knowledge (Terje Midtbø)
- History of ICA (László Zentai)
- New Research Agenda in Cartography (Liqiu Meng)

The respective members of the Executive Committee (in brackets) will help with startup and organization, find interested members and supporters, and lay out the work schedule for the next four years.

NOMINATIONS OF HEADS OF COMMITTEES AND ICA OFFICERS

Furthermore, the Executive Committee nominated the new heads of ICA committees and officers to the ICA Secretariat who will help to keep the society running and inform members and the public in the best possible way through the various channels. Congratulations to the nominees for the 2019-2023 term!

FIRST JOINT MEETING WITH NEW COMMISSIONS

Directly following the meeting of the Executive Committee, on 23-24 November the entire Executive Committee met for the first joint working meeting with the newly elected commission chairs. Altogether, 22 out of 28 ICA commissions were present during the meeting, either represented by their chair or vice-chair. On two exciting, busy working days, the commission representatives and ICA officials got to know each other better, learned about administrative guidelines and procedures for a smooth cooperation and dedicated themselves to common strategic tasks for the next four years. The president pointed out once more the important role that commissions play in our international society. Commissions are where the actual thematic work of ICA is being done that ultimately drives forward our discipline, advances cartography as a science and sets the standards for the quality and usage of our work.

More information
https://icaci.org/executive-committee
https://icaci.org/commissions
https://icaci.org/mission
https://icaci.org/committees

The ISPRS Summer Schools: Building the Youth's Capacities and Fostering Collaboration

The ISPRS Student Consortium (ISPRS SC) is the official representation of students and young professionals within ISPRS in the areas of photogrammetry, remote sensing and spatial information science. The ISPRS SC connects them with outstanding experts and visionaries across the globe to foster collaboration and contributions to the global research, development and application of geospatial technologies for effective decision-making in pursuit of sustainable development.

The summer school is one of the major activities of the ISPRS SC. Since its inception in 2008, a total of 26 summer schools have been hosted in countries across Asia, Africa, Europe, North America and Latin America. The selected participants are given a great deal of exposure to current trends relating to technologies and applications by leading speakers on selected themes. These events also offer unique experiences and perspectives of local culture and traditions.

The summer schools have helped build friendships among the young students and have brought ISPRS experts into contact with the younger generation.

In 2018, the first summer school + hackathon was organized under one of the ISPRS education and capacity-building initiatives led by the ISPRS SC entitled 'MOTIVATE Learning: Making Opportunities to Initiate Valuable Alliance through Experiential Learning'. It was held in collaboration with the Geo-informatics and Space Technology Development Agency (GISTDA), Thailand's public organization leading the country's activities in space technology and geoinformatics applications, and the ASEAN Research and Training Center for Space Technology and Applications (ARTSA). A two-day hackathon was added to the summer school as a challenging activity after the lectures, practical sessions and breakout sessions, which resulted in four innovative ideas using geospatial information: in tourism, public health, infrastructure & transportation, and emergency response.

▲ *The Summer School + Hackathon, under one of the 2018 ISPRS education and capacity-building initiatives entitled 'MOTIVATE Learning', was held at the Space Krenovation Park, Chon Buri, Thailand.*

Through ISPRS SC activities, the ISPRS has strengthened its international linkages in many fora. Since 2010, in partnership with the Asian Association on Remote Sensing (AARS), the summer schools have been organized after the annual Asian Conference on Remote Sensing (ACRS) and have been hosted at renowned organizations and universities in Asia including the University of the Philippines, the Indian Institute of Remote Sensing, Universiti Teknologi Malaysia and Korea University. In Brazil, the summer schools are organized in partnership with the IEEE GRSS Young Professionals (IEEE GRSS YP). This 2019, the ISPRS SC and IEEE GRSS YP summer school is in its fifth year and has reached another milestone by being hosted during the Remote Sensing Applications for Defense Symposium organized by the Institute for the Advanced Studies in Brazil.

The ISPRS SC summer schools will continue this legacy in providing opportunities for young people and promoting remote sensing, photogrammetry and spatial information science.

More information
www.gsw2019.org
www.isprs-ann-photogramm-remote-sens-spatial-inf-sci.net/IV-5/53/2018/
https://bit.ly/2SQ4ARy


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