GIM INTERNATIONAL

THE GLOBAL MAGAZINE FOR GEOMATICS
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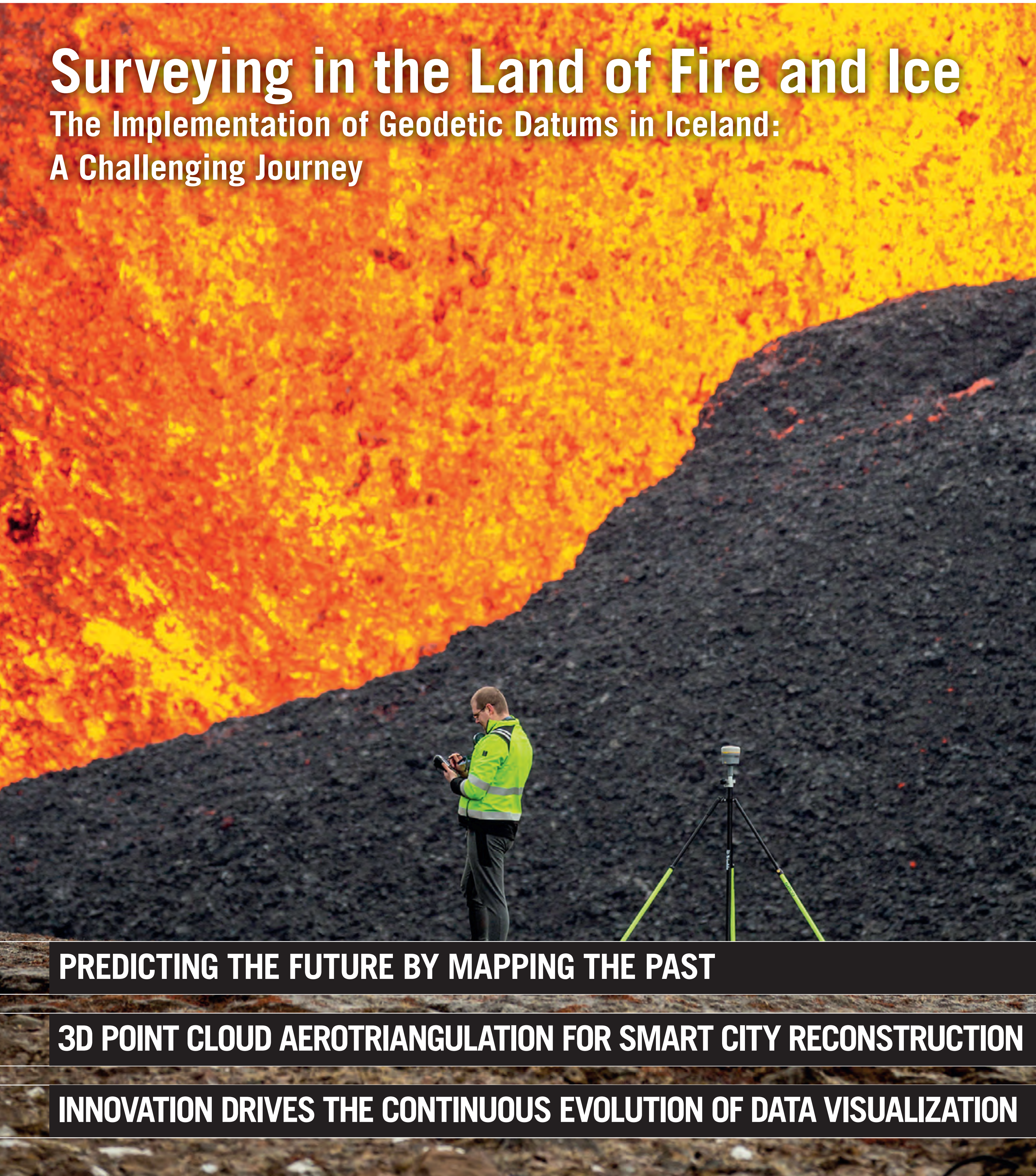
geomares

ISSUE 7 2021 • VOLUME 35



Surveying in the Land of Fire and Ice

The Implementation of Geodetic Datums in Iceland: A Challenging Journey

PREDICTING THE FUTURE BY MAPPING THE PAST

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GIM International, the global magazine for geomatics, is published bimonthly by Geomares. The magazine and related e-newsletter provide topical overviews and accurately presents the latest news in geomatics, all around the world.
GIM International is orientated towards a professional and managerial readership, those leading decision making, and has a worldwide circulation.

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 ISSN 1566-9076

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COVER STORY

On the front cover of this issue of *GIM International*, a surveyor can be seen measuring a ground control point close to a crater in Geldingadalir, Iceland. Iceland's dynamic geodetic situation can be challenging for surveyors, but it also presents opportunities for interesting and exciting projects. Maintaining the geodetic networks in Iceland is a never-ending task. To learn more, read the article titled 'Surveying in the Land of Fire and Ice' starting on page 18.


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Geospatial astronauts

As all surveyors know, photogrammetry is a 3D coordinate measuring technique that relies on photographs as the data source. The fundamental principle used in photogrammetry is triangulation, which is almost as old as photography itself (which was invented over 150 years ago). Just like photography, it has evolved from an analogue technique into a digital one and is today based on digital imagery and computer vision. Elsewhere in this edition, John Welter, president of geospatial content solutions at Hexagon, provides an interesting recap of airborne photogrammetry's past, present and future.

The journey from the old analogue days to our modern digitized times has transformed almost every aspect of the world around us. For me personally, the advancements in space exploration are a great illustration of technological progress; just look at how far we've come since the early 1960s, when Soviet cosmonaut Yuri Gagarin became the first human to journey into outer space! His adventures sparked the imagination of countless youngsters around the world, who all dreamed of becoming an astronaut when they grew up. Yet 60 years later, at the start of this year, just 569 people had actually been in space – so it's not exactly a realistic career choice.

As the geospatial sector, we can offer inquisitive youngsters a more viable alternative. After all, many budding astronauts are attracted by the mystery of exploring new frontiers, combined with pushing the boundaries of what can be achieved using state-of-the-art technology. Photogrammetry is just one example of a technique that has been catapulted by digitization: revived and reinvigorated by the major leaps in computing power, the dazzling performance of today's imaging sensors and advanced Structure-from-Motion (SfM) techniques, not to mention the growing use of unmanned aerial vehicles (UAVs or 'drones') to capture the spatial environment over the past decade. And let's face it, now that drones are becoming a standard part of the surveying toolbox, it's perfectly feasible that kids of today could end up earning a living as a drone pilot! Technological advancements such as these are rapidly changing the face of our whole industry – and there is still no end in sight. The profession is becoming more vibrant and dynamic than ever thanks to digitization, automation and even robotization – with the robot dog 'Spot' just one example of an exciting and attention-grabbing innovation with real-life applications.

And there is no doubt that skilled and qualified personnel will be vital for the geospatial industry in the years ahead. What once was a surveying engineer is now a spatial data manager or a geodata manager, according to Ulrich Hermanski, executive vice president of geopositioning at Topcon, in a recent interview in *GIM International*. Whether in photogrammetry or other areas, digitalization means that we now need technology-minded professionals with the right skills and interests to work with the resulting data. Perhaps it's time to start referring to them as 'geospatial astronauts' instead?

Wim van Wegen,
Content manager

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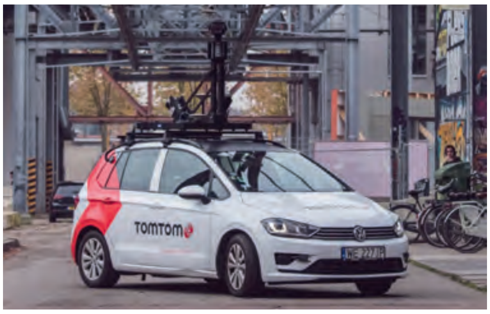
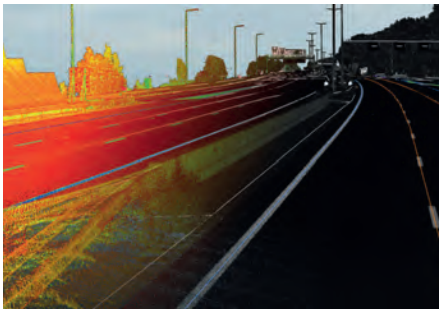
More than 20 Years of Mobile Mapping at TomTom



▲ *Today, TomTom mobile mapping vehicles gather gigabytes of data every day. (Courtesy: TomTom)*

When it comes to mapping the world's roads, TomTom is a pioneer and one of the most experienced firms in the industry. It is now 20 years since its mobile mapping team in Łódź, Poland, started a journey that continues to be a cornerstone of TomTom's business today. To keep its maps as fresh as possible, TomTom uses an array of sources, including government information, survey vehicles and community input. But there's one source that stands unique in its accuracy, reliability and value to the company: mobile mapping vans (MoMas). Thanks to MoMa vans, the company's maps continue to become ever more detailed and refined.

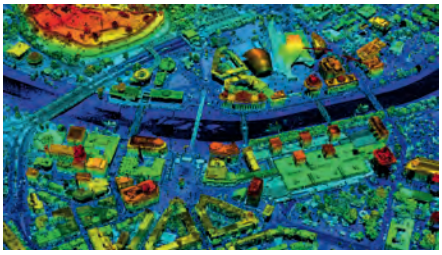
Mobile Mapping of Amsterdam Ring Road



▲ *Geomaat has used its mobile mapping system to scan the entire Amsterdam Ring Road, resulting in billions of points that are processed into a point cloud. (Image courtesy: Geomaat)*

Geomaat has used its mobile mapping system to scan the entire Amsterdam Ring Road, also known as the A10, in the Netherlands. Covering a total distance of 32.3km, the project generated an enormous amount of data, which the company has since processed into usable products for various clients. Constructed over 30 years ago, the A10 is one of the busiest motorways in the Netherlands. The stretch of road between Exit S101 and the Coen Tunnel features in the nation's annual Top 10 of Congestion Hotspots every year. Geomaat has now scanned entire Amsterdam Ring Road, including the Coen Tunnel, for several clients. The company's mobile mapping system – which comprises a vehicle equipped with GPS, IMU, a photographic camera and two laser scanners – enables the road and surrounding area to be scanned while driving in the regular traffic flow. The system captures two million points per second, resulting in billions of points that are processed into a point cloud. Geomaat subsequently converts that point cloud into information-based products for its clients.

New Digital Elevation Models in North Macedonia



▲ *A point cloud from the Lidar scan showing the city centre of Skopje, the capital of North Macedonia. (Courtesy: Kartverket)*

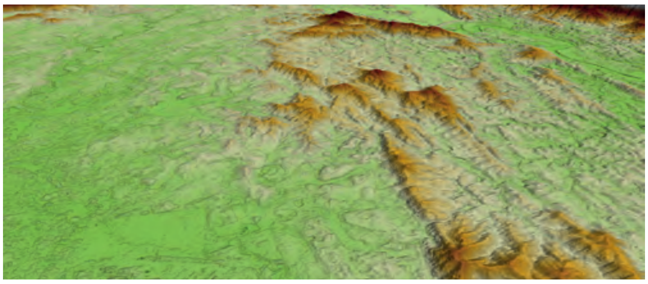
Kartverket, the Norwegian mapping authority, is using airborne Lidar scanning in a project for the territory of North Macedonia. The resulting highly accurate digital elevation models will be distributed to end users through a Lidar portal. Lidar surveying acquires high-accuracy digital elevation model (DEM) data, allowing capture of the bare earth structure that satellites cannot see as well as ground cover in sufficient detail to allow vegetation categorization and change monitoring. The data created will be particularly useful and valuable for a wide range of applications – not only flood risk mitigation, flood monitoring and for actions during flood situations in flood-exposed areas, but also for reducing the cost of infrastructure projects, enhancing environmental protection and monitoring and spatial planning.

Mobile and Aerial Mapping to Protect Bogotá Residents

The Capital District of Bogotá, Colombia, is using artificial intelligence to analyse images collected through terrestrial and aerial mapping. By identifying homes and neighbourhoods that need to be improved, the goal is to have families living in better, greener, safer homes before the next disaster strikes. This effort, supported by the World Bank's Global Program for Resilient Housing (GPRH), uses a Trimble MX7 vehicle-mounted mobile-mapping system to capture street-level imagery across neighbourhoods and combine it with aerial imagery collected by unmanned aerial vehicles (UAVs or 'drones'). Bogota then uses machine learning algorithms to identify buildings and urban areas that could benefit from upgrading and an inspection by an engineer. As Nadya Rangel, Secretary of Habitat of Bogota, points out: "This technology will help the city plan and implement future housing and urban upgrading investments in the most vulnerable areas."

▲ *An aerial view of Bogotá, the capital of Colombia.*

Airbus Unveils New Global Digital Elevation Model

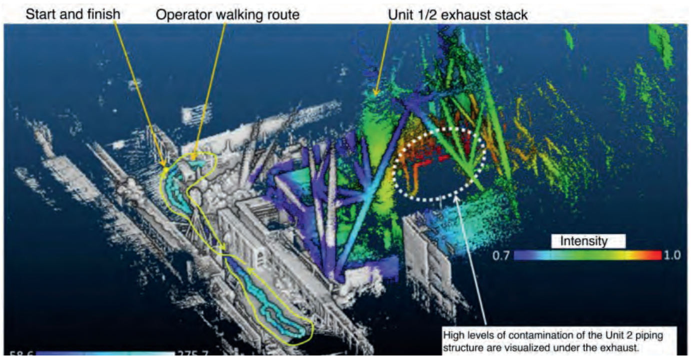


▲ *Imagery of Vietnam WorldDEM Neo. (Courtesy: DLR and Airbus Defence and Space)*

Airbus Defence and Space has launched WorldDEM Neo, its new global digital elevation model (DEM), offering an updated and more precise 3D dataset of the entire Earth's land mass to serve a wide range of applications, from mapping to flight simulation. As the Earth's surface is a dynamic system where changes continuously occur, whether due to natural processes or human actions, it is essential to regularly update the existing DEMs. Produced from new data acquired between 2017 and 2021, WorldDEM Neo provides seamless pole-to-pole coverage and a standardized global DEM with no regional or national border divides. According to Airbus, the data is also more accurate, as it now offers 5m pixel spacing instead of 12m previously, and guarantees a 2.5m absolute vertical accuracy. This WorldDEM Neo's homogeneous coverage, combined with higher accuracy, is very suitable for commercial aviation flight systems as well as for military applications (fighter aircraft, helicopter and UAVs), mission planning and operations. The 3D dataset also offers many potential uses in oil, gas and mineral exploration, as well as for civil engineering, network planning and infrastructure construction. Moreover, WorldDEM Neo is valuable for creating maps of less than 1:10,000 scale and serves as high-quality base data in the field of orthorectification of aerial or satellite imagery.

Creating a 3D Contamination Map of Fukushima Nuclear Disaster Site

The Japan Atomic Energy Agency (JAEA) successfully developed a way to 3D scan and visualize the radiation data from the 2011 Fukushima nuclear disaster by combining a Compton camera, radiation meter and Kaarta Stencil 2 mobile mapping system. In the decommissioning work, it is critical to understand radiation distribution to effectively reduce radiation exposure and decontaminate the area. Contaminated areas must be identified in three dimensions to accurately understand the distribution. The main problem is that conventional methods such as radiation meters or gamma cameras provide only point or surface measurements. It is very difficult to understand pollution distribution in three dimensions from such discrete measurements due to measurement time required and low data density. To solve this problem, Japan Atomic Energy Agency (JAEA) developed a way to visualize contaminated areas and air dose rates by combining a Compton radiation camera and Kaarta Stencil 2, a three-dimensional portable mapping system. The system, called iRIS, enables rapid creation of 3D radiation maps. JAEA was able to acquire the date for visualizing the contamination distribution near the Unit 1/2 exhaust stack of the Fukushima Daiichi Nuclear Power Station as well as the dose rate distribution on the trajectory – the walking route – in a very short time (less than 5 minutes) without approaching the contaminated area.



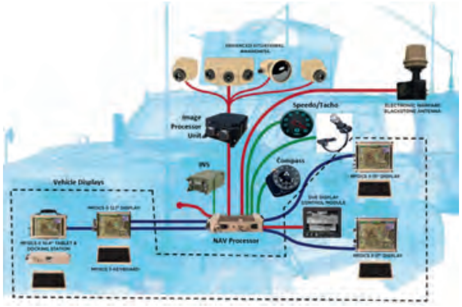
▲ *A 3D map visualizing the air dose rate and high-concentration contaminated areas near the Unit 1/2 exhaust stack of the Fukushima Daiichi Nuclear Power Station.*

Autonomous Robotic Scanning Solution

▲ *Spot robot equipped with the X7 3D laser scanner.*

Trimble has released the X7 3D laser scanner and FieldLink software fully integrated with Boston Dynamics' Spot robot. This turnkey solution from Trimble, jointly developed with Boston Dynamics, facilitates autonomous operation on construction sites and takes advantage of the robot's unique capabilities to navigate challenging, dynamic and potentially unsafe environments. Trimble's 3D data capture technology, integrated with Spot, enables a continuous flow of information between the field and the office for consistent, ongoing documentation of jobsite progress. "The relationship between Trimble and Boston Dynamics is really special. Users don't have to figure out the integration of the scanner. It also enables us to work with only one vendor," said Thai Nguyen, director of virtual design and construction at Hensel Phelps. "Using the X7 laser scanner integrated with Spot lets us document changes on the jobsite and make important decisions in the field, rather than waiting hours or potentially days for the information to be relayed to our project staff. This allows us to make the best decisions as quickly as possible with the best information."

UCF Researchers to Develop Non-GPS Location Finder

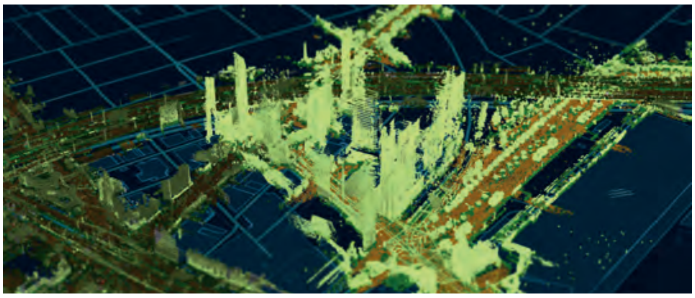


▲ *This image shows the concept of a smart, computer vision-based navigation system using multi-sensor inputs and geospatial databases to determine vehicle position. (Image courtesy: University of Central Florida)*

The University of Central Florida has been awarded a US$4.5 million grant to develop a smart, computer vision-based navigation system for when GPS is unavailable or jammed. The grant comes from the US Army's corporate research laboratory. The system will be like a cyber co-pilot that supports navigation of ground vehicles by using artificial intelligence and machine learning to assess computer imaging of terrain captured by the vehicle and by unmanned aerial vehicles (UAVs). It will help drivers determine where they are and how to get to where they are going in complex terrain. The system will use geospatial databases to identify landmarks for correlation to imagery and will track object movements through video to estimate motion. "For the US Army, this is all about navigating in GPS-denied environments wherein adversaries can jam or spoof GPS signals, and it's also about supporting ground vehicles with off-board sensors on UAVs that can provide additional perspectives for awareness and threat detection in complex, typically urban, scenarios," said Kyle Renshaw, the project's principal investigator and an assistant professor in UCF's College of Optics and Photonics (also known as CREOL).

Woolpert Acquires Australasian Geospatial Leader AAM

Woolpert has acquired AAM, a global geospatial services company that specializes in aerial mapping, surveying, GIS and the development of innovative geospatial processes and technologies. AAM is headquartered in Australia and has offices across New Zealand, Asia, Africa and the Middle East. Woolpert is a US-based architecture, engineering, geospatial (AEG) and strategic consulting firm with 44 offices in three countries. "With AAM, we gain offices across the South Pacific and the Middle East, and almost double our presence in Africa," Woolpert president and CEO Scott Cattran said. "Combined with our industry leadership in the United States, this merger signifies a major milestone in attaining our vision of becoming the premier global AEG firm." With this merger, AAM, one of the leading Australasian geospatial firms, will gain access to additional aircraft and sensor technologies to increase its overall aerial acquisition capacity, and will support Woolpert's growing mapping activities in the Asia-Pacific region. The companies will combine their cloud-based, artificial intelligence processing pipelines for increasingly automated rapid data processing and product delivery. In South Africa, where Woolpert acquired Southern Mapping in 2019 and where AAM has offices, the firms will collaborate on key technologies to improve operational reach and capacity to the African region. This move makes Woolpert one of the largest geospatial companies in Africa.



▲ *AAM's detailed models of the Earth's surface and buildings captured via Lidar come with high levels of height accuracy.*

New YellowScan Point Visualization Cloud Software Module

▲ *The Colorization module allows users to combine the point cloud data they have generated from a flight and combine it with multiple photos taken simultaneously, thus generating a colourized point cloud.*

YellowScan recently launched its software add-on module: Colorization. This third software module enhances the capability of CloudStation, YellowScan's powerful data processing tool that provides users the ability to create and manipulate point cloud data from their Lidar surveys. YellowScan is one of today's leaders in UAV-Lidar solutions. The Colorization module allows users to combine the point cloud data they have generated from a flight and combine it with multiple photos taken simultaneously, thus generating a colourized point cloud. The colourization process automatically refines the camera alignment with the Lidar on a per-flight basis ensuring the quality of the final colourized product. Understanding the importance of merging image-derived RGB colours with Lidar, YellowScan developed this new module following the same path as the other add-on modules, allowing for ease of use and enabling users to get results in only a few clicks. Made for the latest YellowScan Mapper camera hardware, it is also compatible for owners of a single camera package (Sony A6000 or A7R). The key advantage of this new module is that the colourization process occurs directly inside CloudStation, saving time to generate the final output and making it easier to manipulate geospatial data.

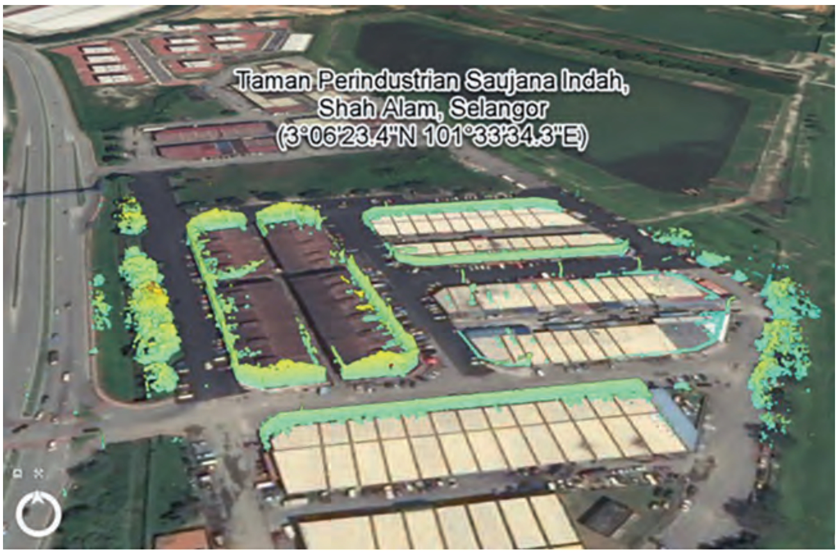
THE SEARCH FOR OPTIMAL SPECIFICATIONS TO PRODUCE APPROPRIATE OUTPUTS

3D Point Cloud Aerotriangulation for Smart City Reconstruction

3D city models are used as the underlying base for smart cities before being combined with other smart technologies such as building sensors, traffic control, street lighting and other advanced tools. 3D city models can be built using various spatial data acquisition techniques. Nevertheless, it is relatively challenging to acquire complete large-scale environment 3D spatial data using a single type of sensor because of limitations such as a single perspective view. Thus, the integration of different types of datasets or sensors is necessary. This article explains how the 3D point clouds produced from sensors are used as data input and processed using Bentley ContextCapture software, while testing the performance capability using various inputs. The study was conducted in three cities in Malaysia: Putrajaya, Shah Alam and Johor Bahru.

AEROTRIANGULATION

Aerotriangulation is a process for performing 3D reconstruction from photographs. In other words, ground control coordinates are determined by photogrammetric means, thereby reducing the terrestrial survey work for photocontrol. The process identifies the accurate photogroup properties for each photogroup input, and computes the position and rotation of every image before the reconstruction process. Every image position and rotation is calculated from the metadata to be used in the reconstruction process. As each image is already in one component, the software automatically groups the images in the main component.

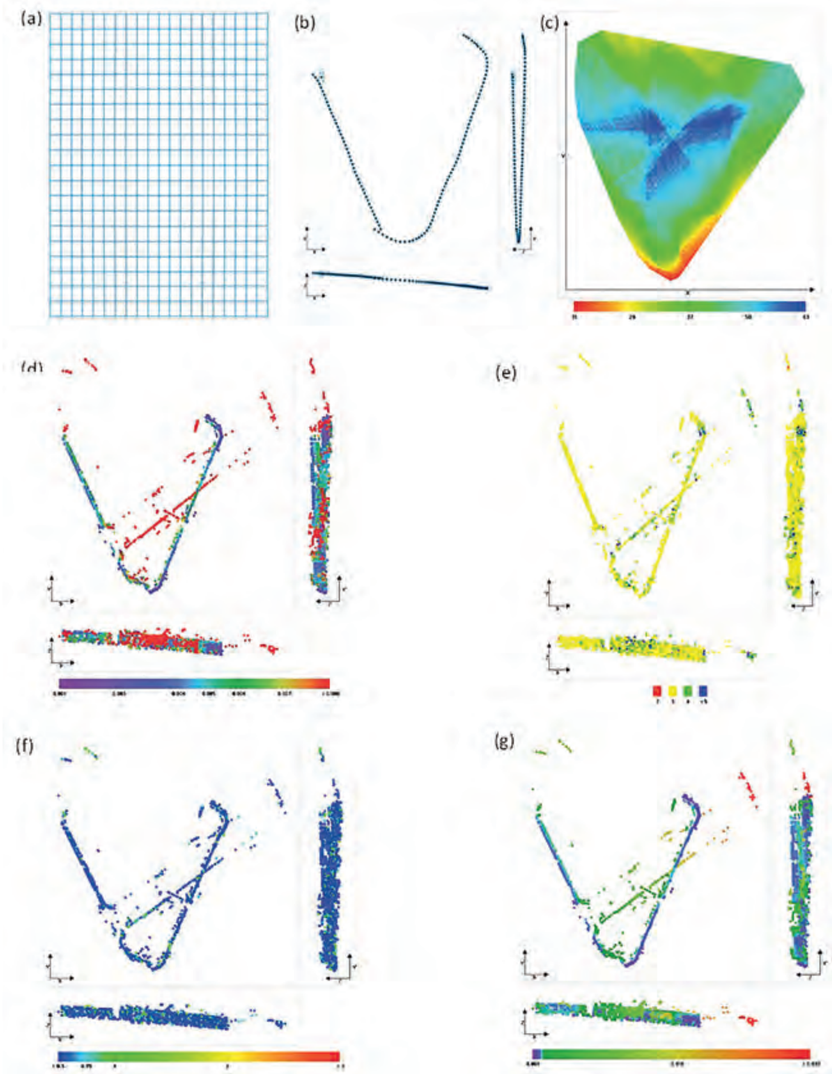


▲ *Figure 1: Taman Perindustrian Saujana Indah.*

The reconstruction is defined by a few properties. First, a spatial framework that defines the spatial reference system, region of interest and tiling. Second, the reconstruction constraints that allow the use of existing 3D data to control the reconstruction and avoid reconstruction errors. Third, the reference 3D model, which acts as the reconstruction sandbox and stores a 3D model in native format, which is progressively completed as 3D model productions progress. Fourth, the processing settings that determine the geometric precision level and other reconstruction settings.

AEROTRIANGULATION RESULTS

Figure 1 shows the area of Taman Perindustrian Saujana with the dataset acquired using mobile Lidar mapping and 360 cameras (Brand Leica, Model Pegasus). Around 337 MMS images were generated and used for this study. The total coverage area is 10,370.51km2 and the data size is 1.24GB. Most of the control points were entered manually, while some were imported from files to support accurate georeferencing and avoid long-range metric distortion images. An image can only be used in the aerotriangulation process if it consists of three or more control points, with each of the control points having two or more image measurements. In the aerotriangulation process in the camera calibration, grid distortion (Figure 2a), photo position uncertainty (Figure 2b), scene coverage (Figure 2c), tie point uncertainties (Figure 2d), number of images observing the tie points (Figure 2e), reprojection error (Figure 2f) and point resolution (Figure 2g) in the survey can be identified.



▲ *Figure 2a-g shows the aerotriangulation process report: (a) Distortion grid, (b) Photo position uncertainties, (c) Scene coverage, (d) Point uncertainties, (e) Number of photos observing tie points, (f) Reprojection error and (g) Tie point resolution.*

It took 37 minutes to complete the process. As the data size was low, no tiling was required to process the data since the expected memory usage to produce the model was 1.4GB and allowed extra precision in the processing mode. Since the data source used was based on MMS and low point cloud density, the best visualization could not be produced. Figure 3 shows the final output of the point cloud triangulation process. The 3D reconstruction results show several blank spots in the upper area of the building that need to be covered using other data, such as orthophoto or UAV images. To produce the best visualization of 3D reconstruction, it is best to combine several types of data from different sources, such as from orthophotos, aerial images and the point cloud.

Another test was run on a different area located in Johor Bahru, this time focusing on a single building block – the building Dewan Muafakat, Taman Kobena. The coverage area is 1,168m2 and there are two types of data input utilized in this test, which are point clouds from TLS and aerial UAV images. The data size of the point clouds is 6.48GB, and the aerial image is 0.64GB. It took 16 hours for the process to produce the 3D reconstruction model. During the reconstruction process, adaptive tiling with extra precision processing was used. Figure 4 shows the final output of aerotriangulation. The result is much better than that for Taman Saujana Indah, as it has no hole and the upper part is mostly covered.

Also tested was the aerotriangulation process on a larger area, in Putrajaya. The aerial image captured an area of 64km2 with a data size of 2.77GB, while the orthomosaic image recorded an area of 358km2 with a data size of 1.24GB. Overall, it took 23 hours to produce the output completely. Figure 5 shows the output of the aerotriangulation process for the Putrajaya area. The whole area is successfully constructed, including the water body. During the reconstruction process, adaptive tiling was used to adaptively subdivide reconstruction into boxes to meet the targeted memory usage. The tiling method is suitable for reconstructing a 3D model with highly non-uniform resolution data, such as aerial images and ground images. In such a case, it is not possible to find a regular grid size that is adequate for all areas. However, the minimum memory required by the software to process the data is 5.9GB. Since the data used in this test was monochrome orthomosaic images, the final output is shown in monochrome colour. To produce the best visualization for the output, a coloured orthophoto is needed with sufficient memory to avoid slowing down the process.

THE CHALLENGES

The main challenge in performing the aerotriangulation process is the hardware, especially when dealing with large datasets. Furthermore, to obtain the best visualization it was needed to combine different types of data sources, such as point clouds and aerial images. To compare hardware performance, the data was processed using the same computer, with a Windows 10 64-bit operating system, Intel i7 processor, 16 GB memory and

▲ *Figure 3: Aerotriangulation output of Taman Saujana Indah.*

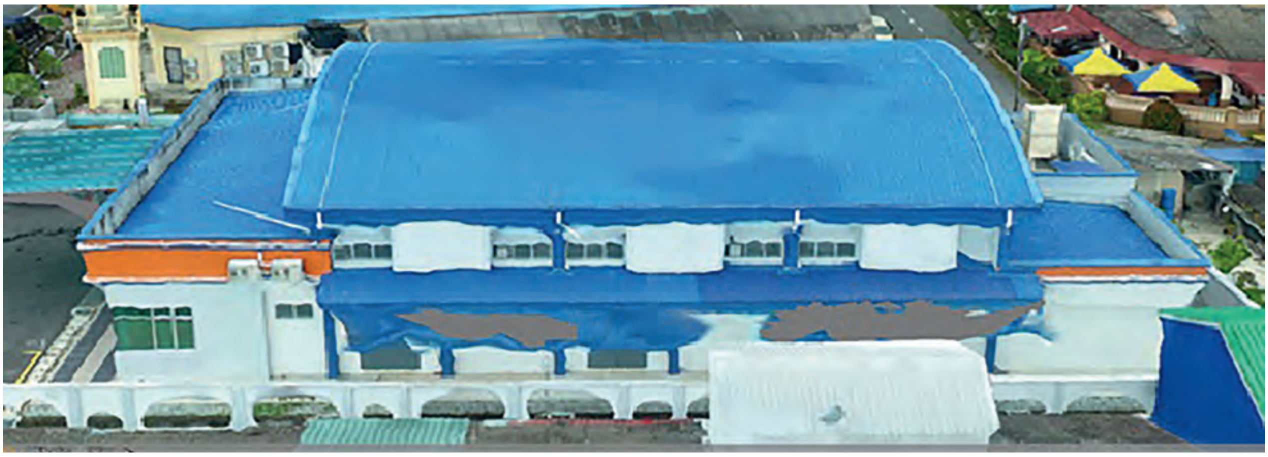


Figure 4: Aerotriangulation output of Dewan Taman Kobena.

NVIDIA GEOFORCE GTX850M graphics card, since the performance was tested in relation to the data size, memory, graphics card, tiling and processing mode.

DATA SIZE

The comparison of the data size is made between the different ground areas and the processing time. An extra precision processing mode was used for all the ground area sizes; however, no tiling was required for a ground area with a small scale. Nevertheless, adaptive tiling can be used for moderate and large ground areas. It took only 15 minutes for 3D reconstruction to finish the process for a small ground area ($0.1346km^2$). Conversely, moderate ($0.2456km^2$) and large ($4.551km^2$) ground areas using adaptive tiling took 2 hours and 25 minutes and 6 hours and 12 minutes respectively to complete the process.

COMPUTATIONAL MEMORY

The processing time was compared between two memories and the amount of time for data processing to finish was recorded. In this test, data from Taman Perindustrian Saujana Indah was employed. This data used an extra precision processing mode since no tiling was needed. The processing time for 4GB memory of RAM and 16GB memory of RAM to finish processing the 3D mesh model was 15 minutes and 19 minutes respectively.

GRAPHICS CARD

Using the same dataset, but this time with two different computers and graphic cards, each computer used an extra precision processing mode and adaptive tiling. The result shows that the processing time for the NVIDIA GEOFORCE GTX 1070 was 2 hours and 25 minutes, while the NVIDIA GEOFORCE GTX 850M took 3 hours and 17 minutes.

TILING

The large tile with an area of 51 metres with adaptive tiling took 4 hours and 46 minutes to process 102 tiles, whereas the moderate tile with a size of 25 metres took 6 hours to process 388 tiles. Conversely, the small tile with a size of 6.6 metres took 31 hours and 25 minutes to process. Both the moderate and small tile sizes used regular volumetric tiling.

Figure 5: Aerotriangulation output of Putrajaya.

ABOUT THE AUTHORS

Suhaibah Azri is currently a senior lecturer in Geoinformation at the Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia (UTM). Prior to her recent appointment at the UTM, she was a postdoctoral researcher at the Technical University of Denmark (DTU). Dr Suhaibah Azri received her PhD in 3D GIS from UTM. She is also an active member of the International Society for Photogrammetry and Remote Sensing (ISPRS). Her research activities are currently twofold: the use of relational databases to organize geospatial data, and 3D GIS and spatial analysis with various applications, in particular urban planning and smart cities.

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PROCESSING MODE

The next step was to process the same dataset with different levels of precision: medium, high, extra and ultra. Since no tiling was required for medium precision, it took just 31 minutes and 50 seconds to complete the process with 69% CPU usage. High precision used regular planar grid tiling to produce 4 tiles with 200 metres of grid size each and 70% CPU usage. This took 34 minutes and 43 seconds of processing time. Furthermore, extra precision also used regular planar grid tiling of 1 tile with a grid size of 400 metres, and ultra precision used 16 tiles with a grid size of 100 metres. Extra precision took 35 minutes and 57 seconds, while ultra precision took 3 hours and 30 minutes. The comparison is presented in Table 1.

Precision mode	Type of tiling	Number of tiles	Grid size (metre)	Processing time
Medium	No tiling	0	-	31Min 50Sec
High	Regular planar grid	4	200	34Min 43Sec
Extra		1	400	35Min 57Sec
Ultra		16	100	3Hr 30Min

▲ *Table 1: Comparison of processing time and precision mode.*

SPECIFICATIONS RECOMMENDATION

The following hardware specifications are suggested to ensure uninterrupted data processing. The Windows 64-bit operating system has a user-friendly environment and is highly compatible with various types of software. As for the processor, the latest Intel Core i9 is known for its capability to handle 3D modelling. However, the price of the Intel Core i7 is more economical, plus it can support complex processing and modelling. As for the memory, Windows 64-bit Intel Core i7 requires a minimum of 32GB to work well and storage that varies depending on the size of data; however, the remaining storage must be double the data size for optimal use. 64GB RAM allows smooth rendering for processing work and many studies have shown that the higher the RAM, the shorter the time to process the data. Lastly, the NVDIA Quadro P2000 graphics card is much slower than the NVDIA GeForce Series with the same functionality, and is suitable for various multipurpose computer workstations and mid-range rendering, CAD work and design.

CONCLUSION

Overall, explicit hardware specifications are required to produce a high-quality visualization for the smart city subsurface. This is to ensure that the data processing can run smoothly with fewer technical issues. Furthermore, the complement of suitable hardware and software is important for 3D reconstruction. Most of the software describes the minimum hardware requirement for installation but does not specify the effect of the hardware configuration during and after the software installation. Therefore, this study was conducted to determine the optimal specifications to produce outputs that are appropriate to current needs concerning the difference between the data size and study area. ◀

RICS GUIDANCE NOTE IMPROVES AERIAL DATA INTEROPERABILITY

New Geospatial Sector Standard for Imagery

Interoperability is a major issue for geospatial professionals and clients. A new RICS guidance note takes a major step forwards on imagery and aerial data interoperability by going back to the basic principles of how understanding accuracy and control can bring several sub-sectors of aerial surveying together.

Recent years have seen an enormous increase in the availability and use of all kinds of geospatial data – from the advent of accessible Earth observation and satellite systems such as Copernicus and the rapid development of Lidar, to the evolution of UAV systems and the revolution of hybrid sensors. Aerial survey capabilities have been further extended by enhanced digital processing, improved navigation and control systems as well as increasingly accurate GNSS use in ground/airborne control. This is an exciting and fast-moving sector of geospatial surveying and is increasingly used in applications such as environmental and land management, topographic mapping, site surveys, construction and infrastructure, coastal management, building condition reports and much more.

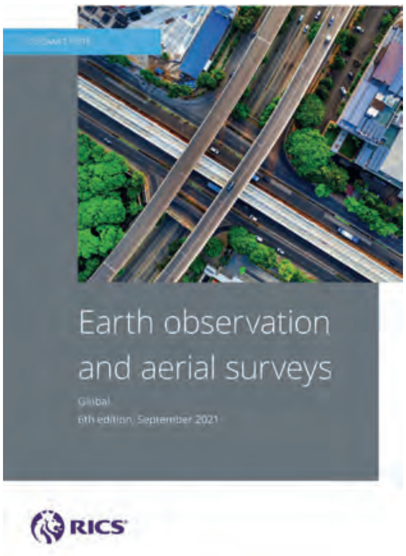
Interoperability is a major issue for geospatial professionals and clients. Different platforms, different capabilities and different outputs can lead to confusion, and the mixing and matching of inappropriate geospatial datasets with often widely differing accuracies and uses can have unforeseen consequences. A new RICS guidance note takes a major step forwards on imagery and aerial data interoperability by not only recognizing these issues, but by actually going back to the basic principles of how understanding accuracy – and, crucially, control – helps to bring several sub-sectors such as unmanned aerial vehicles (UAVs or 'drones'), aerial imagery (from helicopters/aircraft) and Earth observation together. The new edition also focuses on potential restrictions of use and legal compliance with national and international aviation codes and legislation.

The Royal Institution of Chartered Surveyors (RICS) took a lot of time to finalize and get sector consensus on key terms, which can often vary across geographies and even within the sector. The sixth edition highlights the importance of consistent terminology and use. Some of the other important elements of the document are examined below.

DATA CAPTURE PLATFORMS

Choosing an appropriate geospatial data capture platform is a critical part of the process. The choice needs to be based on a deep understanding of client needs, capabilities and achievable output. The use case for the aerial survey will determine the most appropriate type of data:

- Aerial photography is the most common type of data as it aligns most closely with



ABOUT THE RICS GLOBAL GUIDANCE NOTE ON EARTH OBSERVATION AND AERIAL SURVEYS

An RICS guidance note is independent in view and is based on the expert opinion, commentary and advice of expert professional surveyors and sector specialists. In this case, the core expert technical author Allan Jamieson FRICS was aided by a very strong and diverse expert peer review group. A broad international consultation process further honed the document as further commentary and debate on accuracy, UAVs, Lidar, bathymetry and interoperability continued. The final document has been endorsed by EAASI, The Survey Association, Chartered Institution of Civil Engineering Surveyors, RSPsoc and Historic England with extensive input from ARPAS, the Environment Agency, HS2 Ltd, Network Rail, Ordnance Survey, Technical University Dublin (TUD) and Universiti Teknologi MARA (UiTM). The final best practice guidance note is now available for use by surveyors, sector specialists, clients and other professionals. It can be downloaded at https://www.rics.org/uk/upholding-professional-standards/sector-standards/land/earth-observation-and-aerial-surveys-6th-edition-global-guidance-note/.

the client's view of reality, albeit from a different perspective. Most modern sensor systems have the capability to collect four-band red, green and blue (RGB), and near-infrared (NIR) imagery.

- Lidar is a good source of height information and has found numerous applications in modelling the built and natural environments, including the depth of shallow water in coastal and riverine areas and forest canopy detail.
- Multispectral, hyperspectral and thermal data, sensing outside the visible part of the electromagnetic spectrum, can be particularly useful in detecting the health of different plant species.
- Synthetic Aperture Radar (SAR) data is captured using an active microwave sensor, creating high-resolution imagery of the Earth's surface independently of the availability of daylight or in the case of poor visibility due to bad weather.

Frequently, more than one data type is commissioned for a particular use case. For example, aerial photography and Lidar are frequently commissioned together, with the photography providing a view of reality and the Lidar data the third dimension.

Issues of accuracy and area of interest (AOI) also have a bearing on the data platform, as do potential restrictions and aviation code compliance. Table 1 shows examples of how data types can be matched to data capture platforms in eight common use cases. In practice, there are many other successful combinations.

Use case	Project extent	Data type	Accuracy	Data capture platform
National mapping	Large	Aerial photography	High	Manned fixed wing
City Modelling	Large	Aerial Photography (nadir and oblique) Lidar	High	Manned fixed wing
Heritage recording	Small	Aerial photography	High	UAV, manned helicopter
Forestry	Large	Lidar	Medium	Manned fixed wing
Intertidal mapping, near-shore and river	Large	Bathymetric Lidar	Medium	Manned fixed wing
Infrastructure, civil engineering	Small / medium	Aerial photography / Lidar	High	UAV / Manned Helicopter
Land classification	Large	Multispectral imagery	Low	Satellite
Precision agriculture	Small	Multispectral imagery	High	UAV

▲ *Table 1: The relationship between use case, project extent, data type, accuracy, resolution and data capture platform.*

Platform	Height AGL		Achievable accuracy (m)		Achievable resolution – GSD (m)
	m	Ft	Plan X,Y	Height Z	
UAV	30	100	+/- 0.01	+/- 0.015	0.005
UAV	122	400	+/- 0.04	+/- 0.06	0.02
Helicopter	319	1,047	+/- 0.03	+/- 0.04	0.02
Helicopter	638	2,093	+/- 0.06	+/- 0.08	0.04
Fixed wing	1,200	3,937	+/- 0.06	+/- 0.08	0.04
Fixed wing	2,250	7,382	+/- 0.11	+/- 0.15	0.08
Fixed wing	4,500	14,764	+/- 0.23	+/- 0.30	0.15
Fixed wing	7,500	24,606	+/- 0.38	+/- 0.50	0.25

▲ *Table 2: Achievable accuracy and resolution values for aerial photography.*

PROJECT PLANNING

The section of the guidance note on aerial survey project planning underlines the need to collate and verify information on the project, from the basics of time/date to other types of necessary information (such as time of year and – for bathymetry – tidal information). The sixth edition states that "The starting point for any survey should always be a georeferenced digital file supplied by the client showing their area of interest. This should be accompanied by a specification document providing details of the target imagery GSD, point density (in the case of Lidar), accuracy requirements and the deliverable products to be created."

IF THERE IS ONE THING THAT PROFESSIONAL SURVEYORS BRING TO IMAGERY AND AERIAL DATA, IT IS AN INNATE UNDERSTANDING OF GEOSPATIAL 'CONTROL'

The important issue of control is dealt with in Section 3.4 and is a 'must read' for all involved in aerial survey: "Independent GCPs are required to support the data processing and verify the accuracy of the final product. If onboard survey-grade global navigation satellite system (GNSS) and inertial measurement unit (IMU) airborne control is used, there may be no need for full ground control; however, ground verification points should still be established." If there is one thing that professional surveyors bring to imagery and aerial data (especially UAV surveys), it is an innate understanding of geospatial 'control'.

AERIAL PHOTOGRAPHY

Another section of the guidance note explores aerial photography in depth and delves into technical aspects of flight lines, image footprints, ground sample distance (GSD), focal length, instrument calibration and an understanding of achievable accuracies. "Imagery acquired using a UAV and intended for SfM processing will normally require the higher figure of 80% forward overlap and a 60% side-lap and may benefit from additional oblique imagery. In coastal areas where a run crosses the shoreline, the forward overlap can be increased to 90%. The increase in overlap should include at least three photo centres over land."

Flying and coverage is dealt with extensively. Understanding coverage (and much else besides) is critical to understanding the economics and costing of aerial survey projects. The section also contains an updated accuracy table as a new and important 'rule of thumb' for professionals in this sector.

THE RISE OF LIDAR

Lidar technologies have established themselves as the predominant method of obtaining accurate 3D data from aerial surveys. Lidar offers advantages over photogrammetric methods, such as the ability to capture data at night, during the winter, under trees and irrespective of solar angle. The Lidar section in the guidance note brings together land and bathymetric data capture into one chapter. It continues to recognize the fundamental differences between the two techniques, but also emphasizes the similarities: "Lidar data is scanned line by line as opposed to being captured in a single frame. The scanner head position should be accurately and directly georeferenced. All Lidar instruments should have an integrated GNSS/IMU navigation system." Flying, coverage, achievable accuracies and resolutions are outlined, together with a suggested set of acceptance quality limits (AQLs) from which to judge the captured data quality.

The section finishes by outlining Lidar deliverables and proposed metadata: "The basic deliverable is the Lidar point cloud, which is made up of individual laser data points that are fully georeferenced in 3D in the client's choice of coordinate system and usually cut into 1km squares. LAS (or the compressed version, LAZ) is the most frequently used format for Lidar data."

THERMAL, MULTISPECTRAL AND HYPERSPECTRAL

Aerial survey sensors operating in the non-visible parts of the electromagnetic spectrum offer a rich source of data from which to extract information through sophisticated spectral analysis. In recent years, the use of UAVs for precision agriculture has been an important factor in driving the development of small-format multispectral and hyperspectral cameras. The new guidance note explores each of the techniques and focuses on ground sample distance (GSD), calibration, georeferencing, flight times and acceptable quality limits: "When using hyperspectral, multispectral and thermal imaging sensors, improving the spatial and spectral resolution can increase the amount of noise in the signal. It is therefore not uncommon for GSDs of 0.5m or even 1m to be used, with the emphasis on feature identification and condition."

EARTH OBSERVATION

The RICS has included Earth observation (EO) in a guidance document together with aerial surveys for the first time. EO geospatial data is much more accessible than before and is often cited by clients as potentially usable or even preferable in a project. Visible, radar and multispectral sensors are the most common sensors used on satellite platforms. Radar imaging relies on an active sensor emitting electromagnetic radio waves. Unlike optical methods that measure the wave amplitude, radar sensors measure the phase of the backscattered active radio waves and can therefore operate in the dark and in all weather conditions.

Modern satellite sensors offer spatial resolutions of between 0.35m and 1.5m GSD for panchromatic sensors, and from 1m to 6m GSD in the multispectral bands. Active radar sensors can offer imagery resolutions of between 1m and 5m. The guidance note includes a detailed discussion of coverage, accuracy and resolution, and a review of EO products.

The final section of the sixth edition looks at future developments such as sensor

Platform	Height AGL		Achievable accuracy RMSE (m)		Achievable resolution (ppm²)
	m	Ft	Plan X,Y	Height Z	
UAV	30	100	+/- 0.02	+/- 0.02	208
UAV	122	400	+/- 0.06	+/- 0.05	51
Helicopter	260	853	+/- 0.03	+/- 0.03	100
Helicopter	400	1,312	+/- 0.04	+/- 0.03	48
Fixed wing	500	1,640	+/- 0.04	+/- 0.03	30
Fixed wing	725	2,379	+/- 0.06	+/- 0.04	20
Fixed wing	1,300	4,265	+/- 0.10	+/- 0.05	8
Fixed wing	2,600	8,530	+/- 0.20	+/- 0.10	2
Fixed wing	5,000	16,404	+/- 0.39	+/- 0.15	1

▲ *Table 3: Achievable accuracy and resolution values for Lidar sensors.*

Platform	Height		Achievable accuracy (m)		Example survey types/uses
	m	Ft	Plan X,Y	Height Z	
UAV	30	100	0.01	0.02	• imagery and Lidar for heritage recording and construction monitoring • multispectral imagery for precision agriculture.
Helicopter	319	1,047	0.03	0.04	High-accuracy imagery and Lidar for engineering design: • road • rail • power networks.
Helicopter	638	2,093	0.06	0.08	Imagery and Lidar • engineering asset management • mapping telecommunications networks.
Fixed wing	1,300	4,265	0.06	0.08	• BIM for infrastructure • imagery for cadastral mapping • Lidar for forestry • multispectral for biomass mapping and monitoring the health of plants and crops • hyperspectral for tree species mapping and tracking soil moisture content.
Fixed wing	2,600	8,530	0.14	0.18	• imagery for urban mapping and 3D city models • imagery and Lidar for coastal management • thermal mapping for energy efficiency surveys and detection of pollution.
Fixed wing	4,500	14,764	0.23	0.30	• imagery for rural mapping • imagery and Lidar for river catchment flood risk management.
Fixed wing	7,500	24,606	0.38	0.50	• imagery for upland area mapping • environmental impact assessments.
Satellite	450–770 km	279–478 mi	3–4m (CE90)	3–4m (LE90)	• satellite imagery for land cover classification • multispectral satellite imagery for environmental monitoring and vegetation index mapping.

▲ *Table 4: Combined platform, altitude, data type and achievable accuracy table.*

miniaturization and fusion, beyond visual line-of-sight (BVLOS) UAV operation, Lidar developments, high-altitude pseudo satellites and developments in satellite technology: "True BVLOS flights should occur once UAVs are able to communicate autonomously with other airspace users and automatically sense and avoid other flying objects. The benefits of BVLOS will be fully realized once the flight times of UAVs are increased with improved battery technologies."

The appendices of the guidance note contain an extensive list of further reading and resources, an expanded glossary, several basic sample specifications and an accuracy table that brings all of the aerial survey platforms into one combined format based on achievable accuracy. In the accuracy table, the achievable accuracies are quoted in RMSE figures relative to ground control, apart from for satellite imagery. These are quoted as circular and linear errors (CE and LE) at a 90% confidence level.

It is envisaged that this groundbreaking table will be integrated with an updated accuracy table for measured surveys (topographic, building, utility) within the forthcoming revision of the RICS guidance note on measured surveys of land, buildings and utilities.

CONCLUSION

The new guidance note is intended for use by land, sea, engineering and environmental professionals who are acting in an advisory capacity, and by survey-knowledgeable clients who specify their own surveys. It is also intended to be used by Earth observation and aerial survey specialists. It will help clients communicate their goals and what they expect to receive in terms of the types of data, accuracy and resolution, the level of survey detail and the final deliverables required. It will also help both parties clarify issues such as the major project constraints, related costs and timescales. ◂

ABOUT THE AUTHORS

James Kavanagh is director of the RICS Land Group and chair of the ILMS Coalition. He is a chartered land surveyor and chartered geographer with over 25 years of experience in civil engineering, land issues and surveying. He has worked on some of the largest civil engineering projects in Europe and spent several years mapping Palestinian refugee camps in the Middle East while working for the United Nations.

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THE IMPLEMENTATION OF GEODETIC DATUMS IN ICELAND: A CHALLENGING JOURNEY

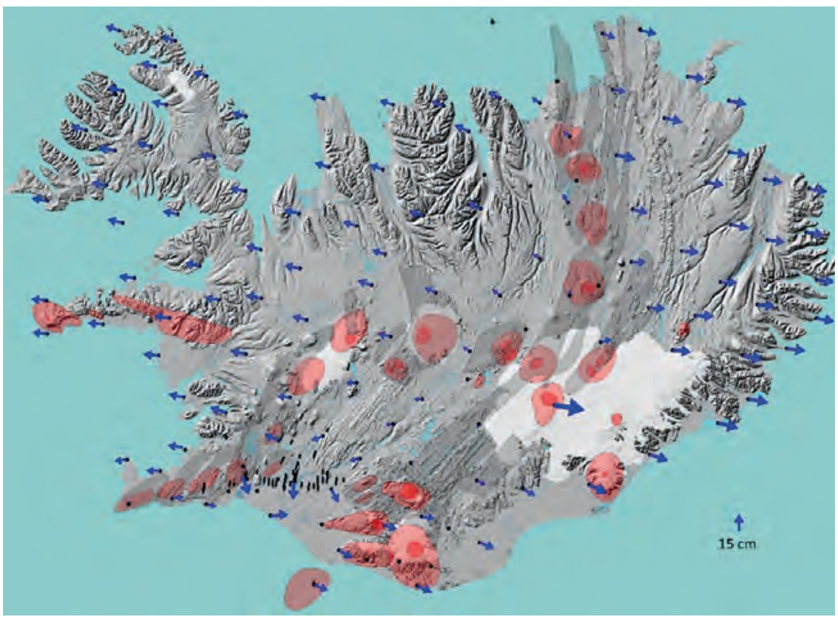
Surveying in the Land of Fire and Ice

Geodesists and surveyors in Iceland face considerable challenges due to the deformation effects of earthquakes, volcanic eruptions and glaciers on the geodetic networks. This article provides insight into the impact of this dynamic situation on the country's geodetic datums over the past decades.

Iceland is situated at the boundaries of the Eurasian and North American tectonic plates, which are drifting apart at a rate of around 10mm/year. The plate boundaries interact with a deep-seated mantle plume currently situated under the Vatnajökull glacier. This creates a complicated pattern of rift and transform fault zones which is every geophysicist's and geologist's dream, but quite a challenge for geodesists and surveyors. Due to the plate tectonics, the geodetic networks are constantly deforming at a similar speed as human nails grow. Earthquakes and volcanic eruptions can cause sudden and serious deformation, in some cases by up to several metres. This usually occurs locally but can sometimes affect larger areas, depending on the nature and the magnitude of the event. The current changes in the climate are also affecting the geodetic networks; Iceland's glaciers have been melting considerably over the last decades, not only causing the land to rise and therefore vertical deformation, but also some horizontal deformation. Additionally, there are some signs of local man-made deformation, mainly land subsidence due to utilization of geothermal power.

ISN93

The first modern GPS-based geodetic network in Iceland, ISNET93, was measured in 1993 and a new coordinate system/datum called ISN93 was published in 1997. It replaced the obsolete Hjörsey55 datum. In the subsequent years, several GPS surveys were carried out to densify the network and to connect it with the old Hjörsey55 and other local systems. When working in areas at and close to the plate boundaries, it soon became evident that crustal deformations due to plate tectonics were causing problems. It was not possible to achieve a satisfactory network adjustment result when keeping ISN93 points fixed on both sides of the plate boundaries. Additionally, two earthquakes of magnitude 6.5 occurred in south Iceland in the summer of 2000. Since this was not unexpected, it was incorporated in the ISN93 regulations that the geodetic network should be measured – and a new coordinate system/datum should be published – at least every ten years.



▲ *Figure 1: Horizontal deformation of the ISNET network between 1993 and 2004. The grey polygons show the rift zones in Iceland, and red/pink indicates central volcanoes and calderas. The black dots indicate repressing fracture zones.*

ISN2004 AND PROBLEMS WITH IMPLEMENTING A NEW DATUM

The geodetic network was measured for the second time in 2004. The results clearly showed the deformation at the plate boundaries. It also showed the effect of the earthquakes in 2000 and the vertical deformations caused by the melting of the glaciers. It is worth noting that according to the International Terrestrial Reference Frame (ITRF), Iceland is moving northwards at around 2cm/year, with the North American plate moving at a slightly higher rate. This movement is usually subtracted when analysing the deformation.

Adoption of the new datum ISN2004 failed. Many users had only just adopted ISN93 and were very reluctant to change over to ISN2004. Most GIS data did not accurately reflect the deformation between ISN93 and ISN2004. Developing grid transformations and getting them into GIS software also took some time. Moreover, some users argued that by the time they had adopted the new datum the NLSI would be set to publish another new one, so they preferred to wait for that one. Therefore, the ISN2004 datum is hardly ever used, even though it is the official datum of Iceland. But this does not change the fact that ISN93 is deforming – usually slowly and sometimes suddenly. As a result, survey results in the deformed areas are dependent on the benchmarks that are used as a reference. It is also complex to run a modern nationwide RTK-correction service in a constantly deforming but static coordinate system.

Therefore, it was clear that the next datum would have to address the deformation in order to extend its lifetime and ensure it was not obsolete by the time it was finally adopted by everyone. Experts from the National Land Survey of Iceland (NLSI) discussed this problem with colleagues from New Zealand who are dealing with a similar problem in terms of crustal deformation. One colleague told them: “The users want to have accurate coordinates, but they don’t want them to change”. To solve this predicament, NZGD2000 has been introduced in New Zealand as a semi-dynamic datum. The datum definition is kept frozen at a certain epoch in the ITRF. A velocity model is used to account for secular motions and patches are used to correct for earthquake deformation. The main benefit of this approach is that it can be treated as a static datum in many cases and applications, but the deformation can also be taken into account when needed. Another option would be to have fully dynamic datum in a global reference frame assigning velocities to every coordinate.

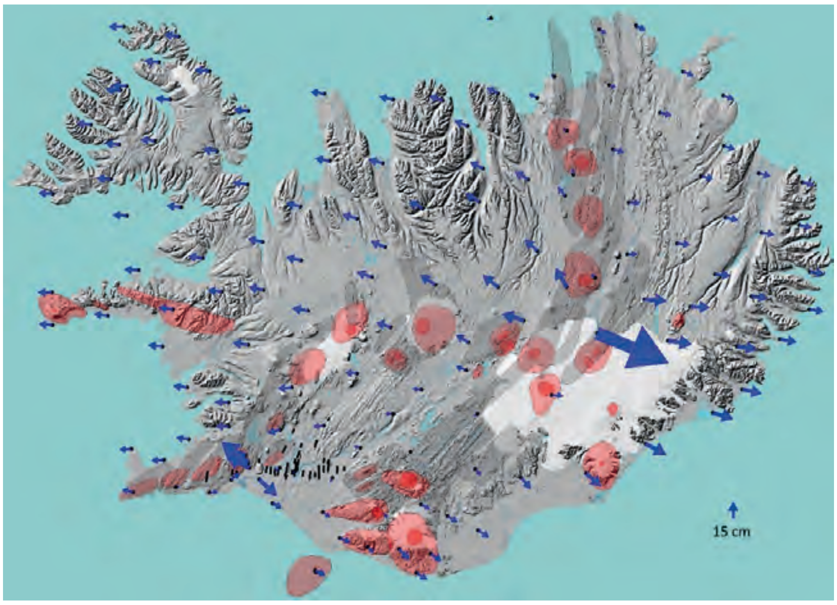


Figure 2: Horizontal deformation of the ISNET network between 2004 and 2016.

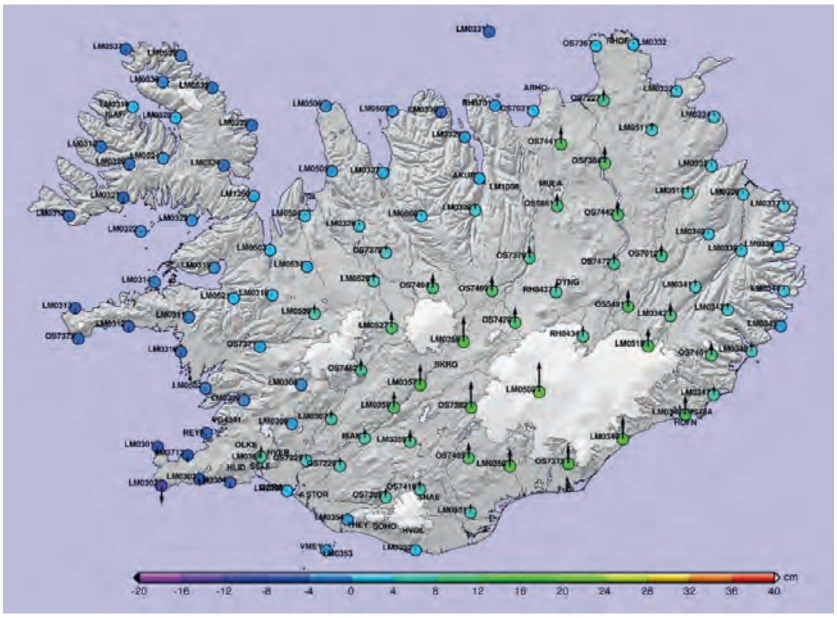


Figure 3: Vertical deformation of the ISNET network between 1993 and 2004.

ISN2016: A DYNAMIC APPROACH

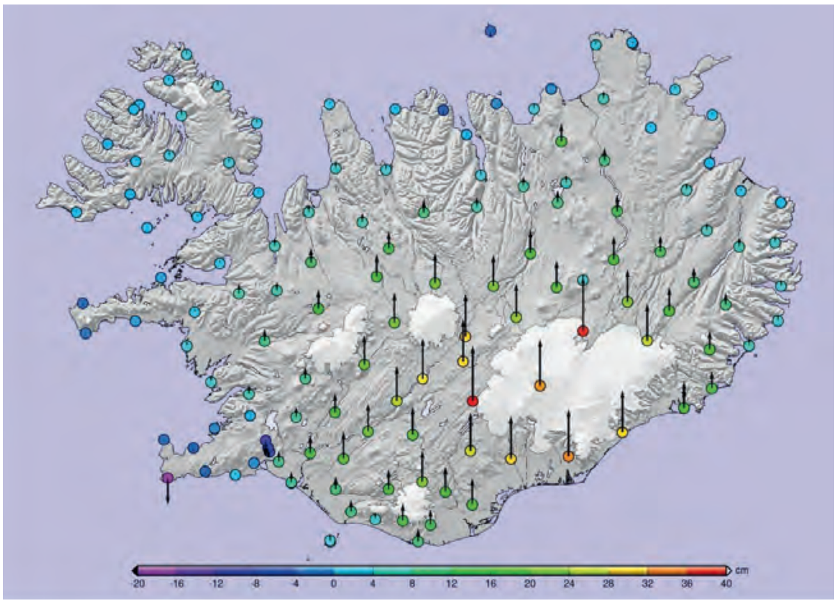
This was taken into consideration when planning the third measurement of the geodetic network, which was performed in 2016, and introducing the next coordinate system for Iceland. As expected, comparison with previous ISNET campaigns showed deformations due to plate tectonics and effects from the main geophysical events in the period from 2004-2016. An earthquake in south Iceland in 2008 caused more than 0.45cm deformation between the towns of Hveragerði and Selfoss, which are just 15km away from one another. The effect of the eruption in Holuhraun, north of the Vatnajökull glacier, in 2014-2015 was also very clear – not only in Kverkfjöll, where the eastward movement was 0.654m compared to 0.079m in the period from 1993-2004, but also in all the surrounding points. Jumps are visible in GNSS time series more than 150km away from the eruption site.

The most interesting results were the vertical changes. There were some indications from cGNSS time series in central Iceland of acceleration in the land uplift after 2004, and the comparison confirmed this both in central Iceland and along the southeastern coast. In the area south of Vatnajökull, the observed land uplift was around 30cm from 2004-2016 compared with only around 10cm between 1993 and 2004.

The new ISN2016 datum for Iceland is a semi-dynamic datum. Its counterpart, ISN_DRF, is a local realization of the current global reference frame at any time, based on the coordinates and station velocities of the IceCORS cGNSS network. This approach enables a surveyor to choose the appropriate method depending on the particular area and the required accuracy. Along with this, the NLSI has published transformation grids, the first version of secular velocity model and a new geoid to account for the vertical changes from 2004 to 2016 since the vertical reference system of Iceland (ISH2004) is connected to the same epoch as ISN2004. EPSG codes are available for ISN2016 and its transformation to older ISN systems. The online transformation service called cocodati has been updated and a nationwide RTK correction service which is free of charge for all users will be finalized before the end of 2021.

Some external factors have been favourable. The increased use and development in PPP-RTK for surveying and precise navigation has created a greater need for precise velocity and transformation models since the results are always in the current global reference frame at the epoch of the observation. This means that more nations are working on these issues. For example, the Nordic Geodetic Commission recently launched a study project called DRF Iceland providing a fruitful forum to study various issues related to dynamic datums and time-dependent coordinates.

One of the key factors in the adoption of ISN2016 is to get transformations, velocity and deformation grids into mainstream geospatial software. The recent development of the Proj transformation software and GDAL that are running in the background of many geospatial software solutions has made it easier for the NLSI to distribute and implement its models. This offers the possibility of more advanced coordinate transformations and other coordinate manipulation than its predecessor. Even though it is not possible to use velocity models in mainstream software at the moment, this can be done directly in GDAL with simple command lines. Moreover, the velocity model and the transformation grids are also available in the latest versions of the Trimble Access and Trimble Business Center.



▲ *Figure 4: Vertical deformation of the ISNET network between 2004 and 2016.*

▲ *Figure 5: Measuring one of the GCPs close to the crater.*

▲ *Iceland's geography can make surveying a challenging job; pictured here is Jökulsárgljúfur canyon. The canyon was formed over a very long period of time by catastrophic glacial bursts, once 10,000 years ago and again 3,000 years ago. (Image courtesy: Bernd Thaller)*

The ISN2016 is still not widely used in Iceland, but with most pieces in place it should be easier to adopt than ISN2004. Since NLSI is not going to introduce a new datum in 2026, the adoption is less time-sensitive. Surveyors and others working in the geospatial industry are generally positive towards ISN2016, but they need a nudge to get started. But overall, solving the geodetic issues that that follow a semi-dynamic datum is less challenging than adopting a new datum.

VOLCANIC ERUPTIONS ON THE REYKJANES PENINSULA

The maintenance of ISN2016 is an ongoing project and the recent events on the Reykjanes peninsula – the most southwestern part of Iceland – are posing some interesting challenges. There are seven towns on the peninsula and the capital city of Reykajvik is in its backyard. The international airport of Keflavík is located in the northern part of the Reykjanes peninsula, plus there are two geothermal powerplants. The plate boundaries run through the peninsula, making it an active area. Small earthquakes are rather frequent and larger ones occur every now and then. The last volcanic activity on Reykjanes was between 800-1240 BC, but there are signs that we might be entering a new period.

The unrest started in January 2020 with land uplift around the mountain of Þorbjörn close to the town of Grindavik and the Blue Lagoon. This was followed by two earthquakes of magnitude 5 in March and October 2020, then several smaller ones. On 24 February 2021 an earthquake of magnitude 5.7 occurred. Around 60,000 earthquakes followed in the subsequent weeks and INSAR and GNSS data showed clear signs of magma intrusion. On 19 March an eruption started in Geldingadalir, just east of Fagradalsfjall and 9km northeast of the town of Grindavík. The location of the eruption did not pose an imminent threat to the general population or infrastructure. However, since it was so close to inhabited areas and infrastructure, it was necessary to closely monitor the effusion rate, volume and area of the new lava in order to predict the threat if the eruption would continue for some time. This was done by frequently carrying out aerial surveys over the eruption to generate a DSM and orthophotos. This work involved close cooperation between the NLSI, the Iceland Institute of Natural History and the University of Iceland's Institute of Earth Sciences.

One of the tasks of the NLSI was to establish a network of ground control points (GCPs) in the area and ensure a common reference system for all parties involved in the aerial surveys, both for response and research. The obvious choice was to use ISN_DRF and it was decided to use the epoch 2021.4. Coordinates of cGNSS stations installed by the Institute of Earth Sciences (IES) and the Icelandic Met Office (IMO) close to the eruption site were computed and the stations were monitored. If any large movements occurred, the coordinates would be revised. Although there have been no significant movements, one of the cGNSS stations was lost under the lava in July 2021. Over 20 flights missions were carried out during the eruptions, providing vital information on the progress.

CONCLUSIONS

Iceland's dynamic geodetic situation can be challenging for surveyors, but it also presents opportunities for interesting and exciting projects. Maintaining the geodetic networks in Iceland is a never-ending task. It is necessary to implement a datum with time-dependent coordinates, velocity and deformation models in order to keep pace with the latest developments in the geospatial word. Perhaps the biggest task is to make this as easy as possible for the users, and this is being supported by recent developments in open software like PROJ and GDAL. ◀

FURTHER READING

More information about the results of the aerial surveys can be found at the websites of NLSI, IES and INH.
www.lmi.is
earthice.hi.is
en.ni.is

ERUPTION UPDATE

There has been no volcanic activity on the peninsular since 24 September 2021, but the end of the eruption has still not been declared since there are frequent earthquakes just a few kilometres north of Fagridalur, close to the mountain of Keilir. The new lava already covers 4.85km^2 with an estimated volume of 150 million cubic metres. But now that the unrest seems to have come to an end for a while, NLSI can start working on a deformation model of the event to be included as a patch in ISN2016.

ABOUT THE AUTHOR

Guðmundur Valsson is a coordinator of geodesy and surveying at the National Land Survey of Iceland (NLSI). He gained a master's degree in Geomatics from the Norwegian University of Life Science and has been working for the NLSI since 2000. He also teaches surveying at Reykjavik University.
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PUSHING THE LIMITS ON LIDAR CHANGE DETECTION AT REGIONAL SCALES

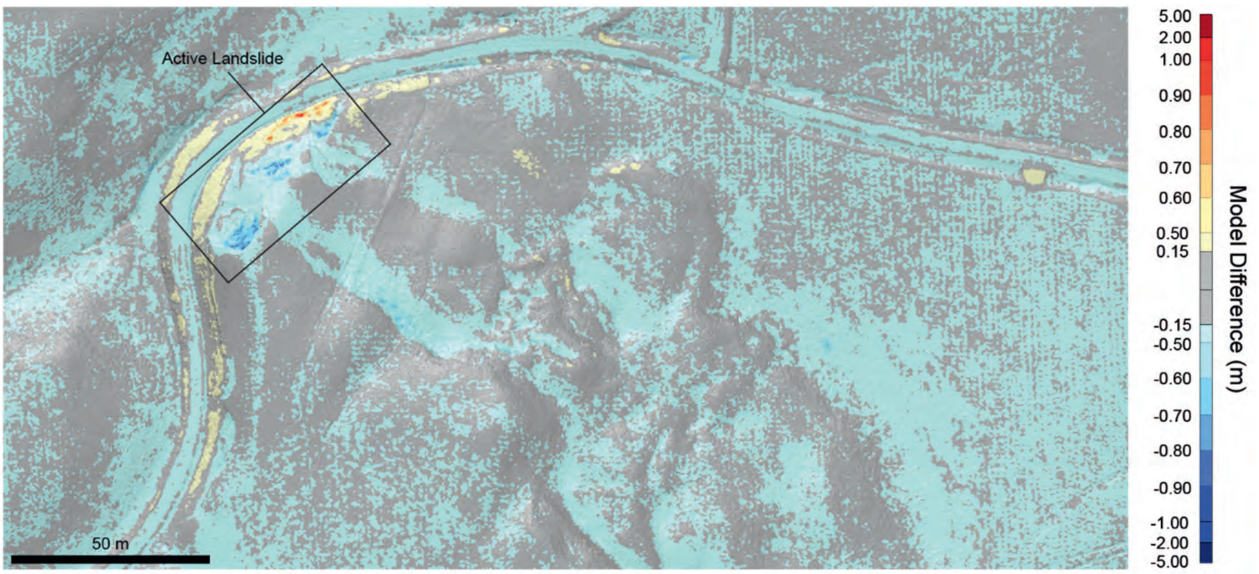
Predicting the Future by Mapping the Past

Lidar change detection (LCD) is one of the most capable techniques for mapping changing terrain through time. It can be applied in billion-dollar decisions to design, build and operate tunnels, bridges, highways, railways, pipelines or subdivisions, which require engineers to evaluate how the earth will behave for decades to come. Predicting morphological change involves a deep understanding and appreciation of geology, geological processes, climate change and knowledge as to what physical changes have happened in the past or may occur in the future. This article presents how utilizing a graphics processing unit (GPU) and digital delivery of results can improve the LCD process by a factor of a thousand, opening up previously unthinkable applications.

LCD is the numerical process of comparing multiple Lidar datasets with overlapping coverage from different points in time. Airborne Lidar scanning (ALS) LCD is used by engineers and geoprofessionals to identify and track changing ground conditions commonly associated with geohazards such as landslides, flooding, bank erosion, debris slides, subsidence and rockfalls/avalanches, as well as assets such as embankments, highway pavement, bridges, open pits and dams. Conducting LCD analysis is typically completed using one of three general approaches:

1) Digital elevation model (DEM) differencing. DEM differencing calculates the vertical change between two DEMs at each raster cell, typically at a resolution of 1m. This LCD method is the most efficient and simplest to run, facilitating its use on geographically expansive datasets. However, the results of this approach are generally an order of magnitude less accurate than a fully optimized 3D solution (see point 3 below).

2) 3D point-based normal or shortest distance-based differencing (M3C2). 3D point-based LCD calculates the difference between two bare earth point cloud datasets along vectors representing the local normal of each individual point in the dataset, or the shortest distance between multiple datasets.



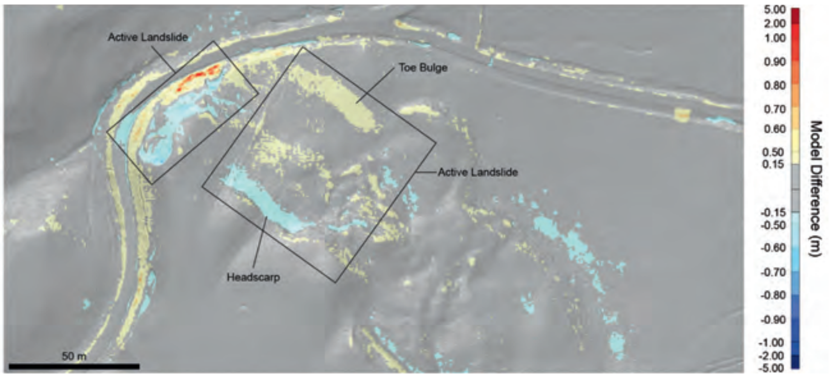
▲ *Figure 1: Change detection results for a slope without any ICP alignment, at a +/-15cm limit of detection.*

This method is computationally expensive and requires ALS datasets to be subdivided into smaller zones (typically less than 30 million points per dataset) for processing. This method produces enhanced results over DEM differencing (see point 1 above) as the results represent a true 3D change based on the full resolution of the point-cloud data.

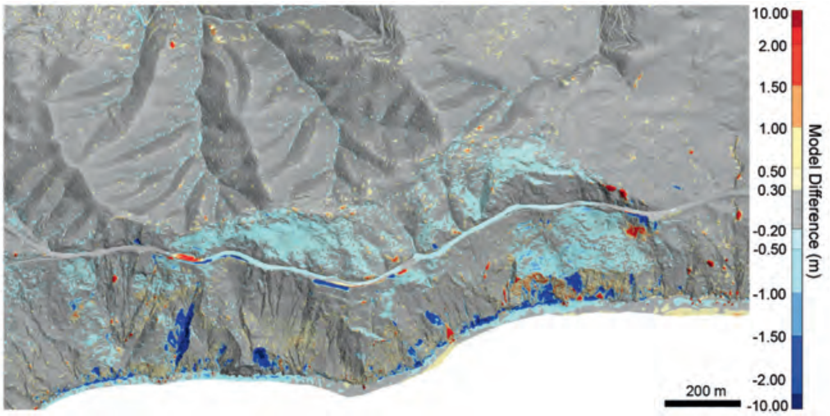
3) ICP pre-aligned 3D point-based normal or shortest distance-based. Iterative Closest Point (ICP) pre-alignment with 3D change measurement is a modification of point 2 above that utilizes advanced 3D error reduction algorithms to reduce the spatial noise between the ALS datasets prior to conducting the LCD. This spatial noise often presents itself as a systematic difference between the two datasets due to ground control and georeferencing at the time of data collection. The ICP process adds considerable computational expense and the use of advanced algorithms to the processing chain to spatially adjust the data while not introducing further errors. This is the most accurate approach to conducting LCD.

In the case of applied earth science applications, a 3D point-based approach with ICP pre-alignment captures the mechanics of the changing ground in the most accurate way, given that purely vertical changes resulting from the DEM differencing approach rarely represent the true mechanism of ground movement, and errors from the georeferencing misalignments are significantly reduced.

The example in Figure 1 and Figure 2 highlights a case in which computing a 3D point cloud-based change detection without ICP (Figure 1) would not have allowed the detection of an active landslide that is immediately evident in the results of the change detection using ICP 3D point-based LCD (Figure 2).



▲ *Figure 2: Change detection results for the same slope as in Figure 1, but with ICP processing, at a +/-15cm limit of detection.*



▲ *Figure 3: Lidar change detection for Last Chance Grade utilizing a ICP pre-aligned point cloud normal-based change detection.*

US HIGHWAY 101

To demonstrate the various LCD methods and power of advanced LCD processing, ALS data procured by the California Department of Transportation (CalTrans) in Northern California along US Highway 101, in an area known as Last Chance Grade, is presented below. At this location, the highway traverses steep slopes and ocean bluffs which are actively eroding and engaged in landslide processes.

LCD results comparing ALS data collected in 2016 and 2020 are presented in Figure 3. LCD results are typically presented as colour-contoured datasets overlain on the bare earth topography model. Model differences greater than the limit of detection (LoD) are typically filtered out of the results. The LoD is calculated based on a 95% confidence interval and is dependent on the quality of the spatial alignment between the two Lidar datasets. Blue colours represent zones of negative change (material loss or subsidence) and red colours represent zones of positive change (material accumulation, bulging or aggradation).

Switching from the DEM-based approach to a 3D point cloud-based approach at Last Chance Grade resulted in a reduction of the limit of detection by 3 to 4cm, and using the ICP combined with 3D point cloud-based approach resulted in a further reduction of the limit of detection by 4 to 8cm. This is an overall reduction in the LoD of 40%. The impact of the error reduction on infrastructure monitoring is significant, and the ability to detect these small changes is extremely valuable. This allows owners and engineers to act sooner and be more proactive in managing assets to reduce overall lifecycle costs.

THE VISION AND THE PROBLEM WITH LCD

Figures 1, 2, and 3 illustrate the advantage of utilizing an ICP pre-alignment, point-based change detection approach for LCD. As ALS data is collected more frequently and at higher densities than ever before, the use case for advanced LCD is increasing. The ability to provide engineers, geoprofessionals and asset owners with a method to assess and communicate 3D spatial change across vast scales is a powerful tool to understand the past, predict future behaviour and manage associated risks. LCD applications span several industries and applications such as monitoring highway, rail and pipeline networks, reservoir slopes and shorelines, and changing coastlines. Until recently, however, the ability to apply advanced numerical methods (specifically method 3 above) for LCD at scales beyond specific project sites has been extremely limited to due computational resources required for data execution, subject matter expertise to conduct the analysis, and digital platforms for visualization and interrogation of results.

To scale up 3D ICP LCD from single sites to regional networks, three R&D projects were undertaken:
1) Custom-built 3D ICP LCD algorithms written using native GPU compute shaders
2) Collaborative multi-user 3D environment for analysis and visualization of cloud-hosted LCD results, ortho images and terrain data
3) Integration with geospatial asset management software for storage, access and interrogation of LCD data with all other geospatial information.

MOVING TO THE GPU AND THE WORLD OF COMPUTE SHADERS

Over the last 20 years, GPUs have evolved from fixed-function systems for 3D rendering to general-purpose computation units. Modern GPUs can execute thousands of calculations in parallel, provided that those operations are independent. This contrasts with CPUs which can only execute dozens of operations in parallel but handle general-purpose code and conditional logic well. As a result, GPUs offer huge speed gains in cases where calculations can be performed in parallel. For example, deep learning and 3D rasterization are hugely accelerated on a GPU because they mostly involve performing independent calculations on each element in large buffers of data.

With point-cloud change detection, it is more difficult to realize these speed gains since a point-cloud change algorithm consists of two types of operation:
1) Calculations, such as:
   a. solving for an alignment transformation
   b. calculating normals
   c. computing change values.
2) Spatial queries, such as determining which points:
   a. are likely correspondences between two clouds
   b. represent the local surface around a point
   c. should be considered during change detection around a point.

Often, GPU implementations of systems are performed by porting existing code using frameworks like nVidia CUDA. Unfortunately, with point cloud processing, this approach results in a GPU implementation that is entirely bound by query performance since data structures commonly used for spatial queries access memory randomly and have lots of conditional logic. In fact, the result can be slower on a GPU than the same code on a CPU!

The suggested implementation performs all GPU calculations using compute shaders – the lowest level of code natively exposed by a GPU, which provides direct control over execution and parallelism which is used to achieve high performance. The authors use a chain of compute shaders for normal calculation, ICP and the change detection itself.

The authors also perform all spatial queries on the GPU, using compute shaders and linear data structures optimized for GPU hardware. Their query algorithms favour speed and returning conservative results over returning a minimal set of points. Additional points returned by the queries during calculation are then rejected. This is still faster overall, because the GPU performs calculations on redundant points faster than it can execute a more precise query.

These compute shaders are driven by a parallelized CPU framework which marshals data to and from the GPU, handles disk access and performs decompression for Lidar formats such as LAZ. The result is a system that is able to process multi-billion-point datasets in orders of magnitude faster than the fastest CPU implementations.

VISUALIZATION AND COLLABORATION

ALS data are 3D by nature, and ICP 3D point-based LCD results are best analysed in a 3D environment. BGC developed a multi-user collaborative 3D environment that allows users to 'fly' around the Lidar data with LCD results or walk across the terrain. The 3D environment, built on Unity-based technology, facilitates the integration of high-resolution ortho imagery, vector data and dynamic controls over the LCD results. A screenshot from a video of three separate users interacting in the collaborative space is presented in Figure 4.

CONCLUSION

The ability to conduct ICP 3D point-based LCD at a regional scale utilizing GPU processing, delivering results in an interactive, collaborate 3D environment, at speeds upwards of three orders of magnitude faster than CPU-based processing, is revolutionizing the usability of ALS data. In the past year, BGC has processed over 40,000 linear kilometres of LCD data, serving up tens of billions of LCD points in digital platforms to clients, globally. Being able to extract additional value from ALS data to better understand the morphological changes and behaviour of assets over time greatly enhances an engineer's ability to make informed decisions and design resilient infrastructure.

ACKNOWLEDGEMENTS

The authors would like to thank Jaime Matteoli and Eric Wilson from CalTrans for agreeing to

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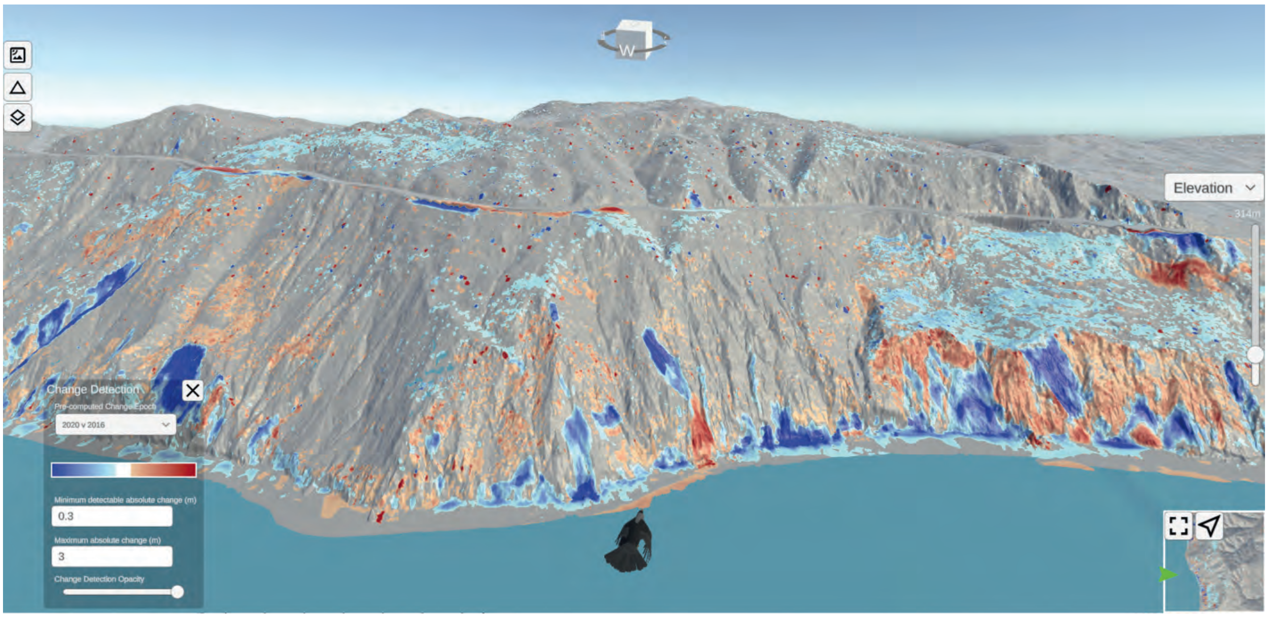
Matt Lato is a senior engineer and the innovation lead at BGC Engineering, Canada. His technical expertise is in the application of 3D remote sensing in geotechnical engineering. Matt is the lead author of the Site Investigation, Analysis, Monitoring and Treatment chapter of the Canadian Technical Guidelines and Best Practices related to Landslides, and an author or co-author of over 150 journal and conference papers. He is an adjunct professor in the Department of Geological Sciences and Geological Engineering at Queen's University, and an affiliate faculty member in the Department of Geology and Geological Engineering at the Colorado School of Mines.

Alex Ferrier is a software developer in BGC Engineering's Vancouver office. His work focuses on algorithms for large-scale point cloud processing using GPUs. Alex has 25 years of experience in real-time 3D graphics and algorithms including 3D medical imaging for Toshiba, leading technology development at Electronic Arts for the videogames Need for Speed and NBA Live, and computer vision and augmented reality development for Microsoft and Disney. He has previously presented work at graphics industry conferences including SIGGRAPH.

Megan van Veen is based in BGC's Ottawa office with experience in remote sensing, geohazards, slope stability monitoring and assessment, and rock mechanics. Her work has primarily focused on remote sensing survey design, field data collection and detailed data processing for geohazard, open-pit and tunnel stability measurements, working with various pipeline, mining, transportation and utility clients. Megan has been involved in the development and deployment of a variety of monitoring programmes which combine remote sensing, instrumentation and field-based observations with geohazard and asset management software, ranging from site-specific to regional-scale applications.

the use of ALS data collected along US Highway 101 and showcase the LCD results which are currently being used by the expert review panel to assist in the redesign of the highways. The authors appreciate the help of Dr Scott Anderson, Alex Graham, Matt Williams, Cole Christiansen and Luke Weidner at BGC for support in processing and interpreting the LCD results. The methods discussed in this article are patent-pending: Application #17/371,337. ◀



▲ *Figure 4: Screenshot from video fly-through of LCD results along US Highway 101.*

EXPLORING THE OPPORTUNITIES AND CHALLENGES

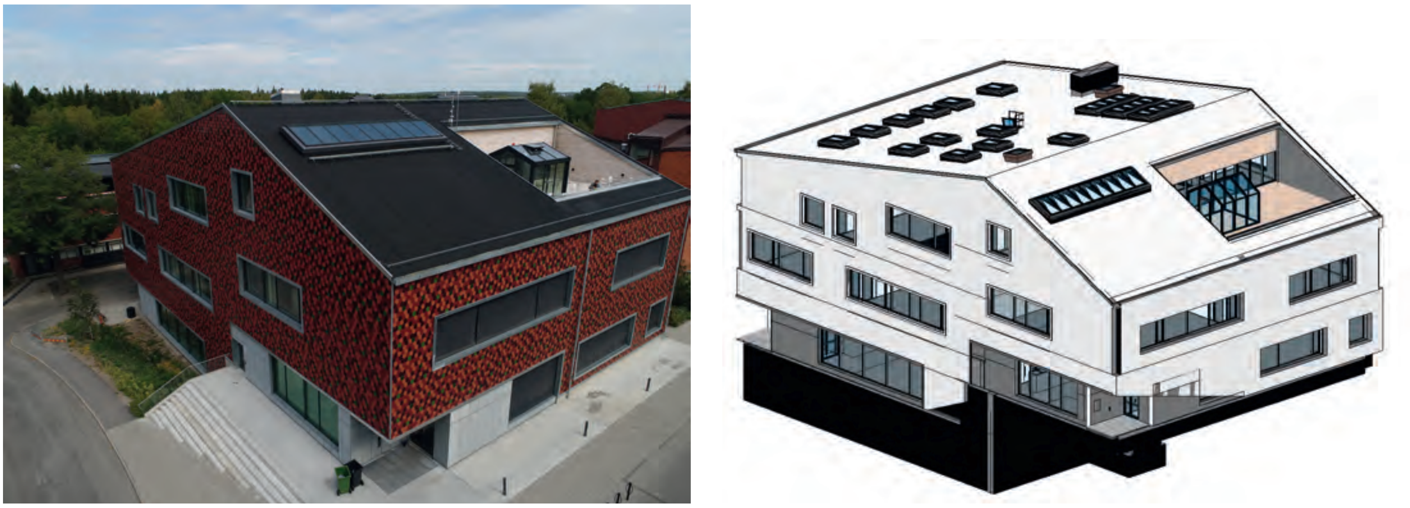
Using BIM Data Together with City Models

An increasing number of cities are creating 3D city models to support visualization and simulations in the urban planning process. The 3D city models are often extended with planned buildings. One way to facilitate this is to add simplified building information modelling (BIM) models of the planned buildings to the 3D city model. This article summarizes some of the recent academic and industrial studies of this topic.

There are several commercial and open-source tools for integrating BIM data into 3D city models (Figure 1). The integration is complicated, as it requires transformation between different information models (ontologies), e.g. between the open BIM format Industry Foundation Classes (IFC) and the open 3D city model format CityGML. The transformation of geometries is also challenging and includes a conversion from solid modelling (used in BIM) to boundary representations (used in city models).

In 2019, a GeoBIM benchmark was launched to study the interoperability in the GeoBIM domain, where GeoBIM stands for an integration between city models and BIM. The benchmark – which was coordinated by the 3D Geoinformation Group at TU Delft, the Netherlands – focused on the interoperability of tools implementing the CityGML and IFC standards, as well as on tools for conversion between the standards. For the latter, some extract, transform & load (ETL) scripts (mainly from Safe Software) were evaluated, and several software tools were tested on four datasets. One conclusion drawn is the problem that IFC files are modelled in different and incompatible manners in terms of the IFC elements that are used and their structure. This makes it challenging to write generic programs to convert IFC data to proper CityGML models. In addition, most IFC elements in the benchmark were translated into generic CityGML objects, which in practice would require manual inspection and modification. To tackle these challenges, the

Figure 1: BIM models simplified by FME scripts and imported into a city model in ArcGIS Online. (Image courtesy: City of Helsingborg)



▲ *Figure 2: KTH educational building (left) and the BIM model (right). (Image courtesy: City of Stockholm and Christensen & Co Architects)*

architecture, engineering and construction (AEC) domain needs to reach consensus on the standards and guidelines concerning how to model IFC models (such work has been conducted at national level in several countries). More efforts are also required to standardize the city models. Note that the latest version of CityGML (3.0, which was approved at conceptual level in September 2021) introduces some concepts to improve its interoperability with IFC.

EXTRACTING BUILDING GEOMETRIES FROM BIM DATA TO UPDATE 3D CITY MODELS

As-built BIM models can be used as an alternative to on-site surveying to update 3D city models. In one case study to evaluate the geometric aspects of this process, the first step was to formulate new measuring guidelines (for several levels of detail) for the building theme in a 3D city model. The guidelines were based on several Swedish guidelines for geometric representations on data exchange, documents from the German SIG3D project, and a number of research papers. Since the guidelines are detailed and lengthy, it was decided to only include one example rule here, stating when to divide a building into building parts or building installations: "The parts of the building that differ due to physical aspect should be modelled as separate building parts or building installations if any side of the parts is longer than 2m or the area of the part is larger than $2m^2$, or the difference in roof height is longer than 2m".

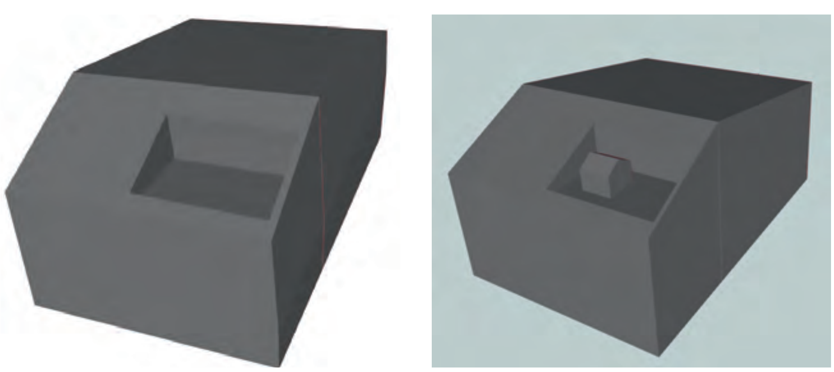
The measuring guidelines were used to extract geometric information of three buildings, including the educational building at KTH, Stockholm (Figure 2). Two people performed the geometric information extraction in parallel. The first person utilized 2D building footprints and airborne laser scanning (ALS) point clouds (point density: 12 points/m2). This input data was modelled using standard ALS methods and ETL tools to generate the geometric models. The second person used BIM as input data to other ETL processes to generate the models.

The resulting building models for the KTH building are shown in Figure 3. The relative geometric differences between the models are marginal, with RMS values in the size of a few decimetres in the horizontal plane and around one decimetre in the vertical dimension. Since the BIM models were not georeferenced, the absolute geometric differences could not be evaluated. One apparent difference between the generated models is that the model created from BIM data includes a greenhouse on the terrace. This greenhouse is not included in the model from ALS/footprint data, as the greenhouse is made of glass which results in a low number of points in the ALS data. Neither of the models represented the roof overhang at the entrance. ALS data is not capable of identifying such an overhang, and the person using BIM data lacked instructions in the measurement guidelines about how to handle roof overhangs.

The study confirmed that BIM models can potentially be used to update city models with new buildings. A main lesson learned is the need for good measurement guidelines that allow multiple data sources to be used.

REQUESTING BIM DATA ON QUERY LEVEL

In the previous study, BIM data was transformed into CityGML and integrated into the 3D city model. An alternative approach is to keep the BIM data and the city models in separate data repositories and create a common query interface instead. In this manner, an application can utilize both data sources. Integration on query level requires that the information models for the 3D city models and BIM data are interlinked. One



▲ *Figure 3: Resulting models of the KTH educational building based on ALS data and the 2D footprint (left) and BIM data (right).*

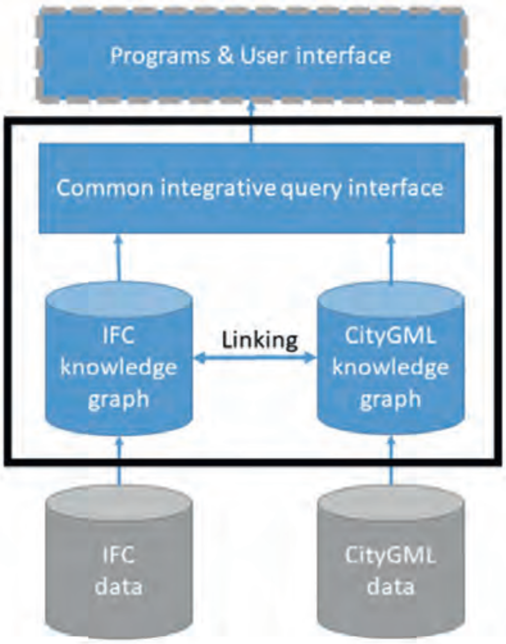
plausible solution to achieve this is to create a knowledge graph (linked data) from the two data sources, where the respective ontologies are aligned. Knowledge graphs are increasingly used to break data silos in various domains, but are only sparsely exploited in GeoBIM, partly due to the difficulties in handling geometries in knowledge graphs. However, work is ongoing to define ontologies for 3D city models, e.g. based on the CityGML data schema, and ontologies in the BIM domain, such as ifcOWL and BOT.

Solar neighbourhood simulation is one application that requires both city models and BIM data. The modelled incoming solar radiation is used to estimate the indoor daylight comfort and also energy savings. Solar neighbourhood simulations require simplified building geometries that can be retrieved from city models, as well as window information, which is seldom presented in city models but can be extracted from BIM models. In order to evaluate the applicability of the knowledge graph approach, a case study was conducted with one building available as IFC model and converted to CityGML. Data from both sources was transformed into knowledge graphs based on their respective ontologies (CityGML and ifcOWL/BOT) and linked to the building instances using a commonly used vocabulary (Figure 4). The knowledge graphs were stored in an RDF store. The query interface partially utilized the OGC standard GeoSPARQL – an extension of the query language SPARQL. The system architecture enabled queries such as finding the total window area of the building and extracting the geometries of all the windows in the building.

Several challenges remain before a common query interface to knowledge graphs can be used in a production environment. The ontologies have to be further developed and they should be interoperable and well aligned. This is one important theme of an ongoing cooperation between OGC (from the geospatial side) and BuildingSMART (from the BIM side). On the data level, there is a coordination challenge of defining responsibilities and practices in setting common IDs and handling them through the life cycle. From a technical perspective, it is challenging to develop efficient RDF stores for querying and storing the geometries of 3D data. Finally, from an end-user perspective, the support of knowledge graph (RDF) data from relevant programs is a prerequisite, i.e. they should ideally implement a SPARQL interface. Despite these challenges, the authors believe that the knowledge graph approach has great potential in GeoBIM.

CONCLUSIONS

This article has discussed the opportunities and challenges associated with utilizing BIM data together with city models. Experience has shown a large potential for utilizing BIM data in several applications to update and enrich city models. However, the technical solutions should be guided by a comprehensive understanding of the target applications.



▲ *Figure 4: System architecture of IFC and CityGML data integration in knowledge graphs.*

FURTHER READING

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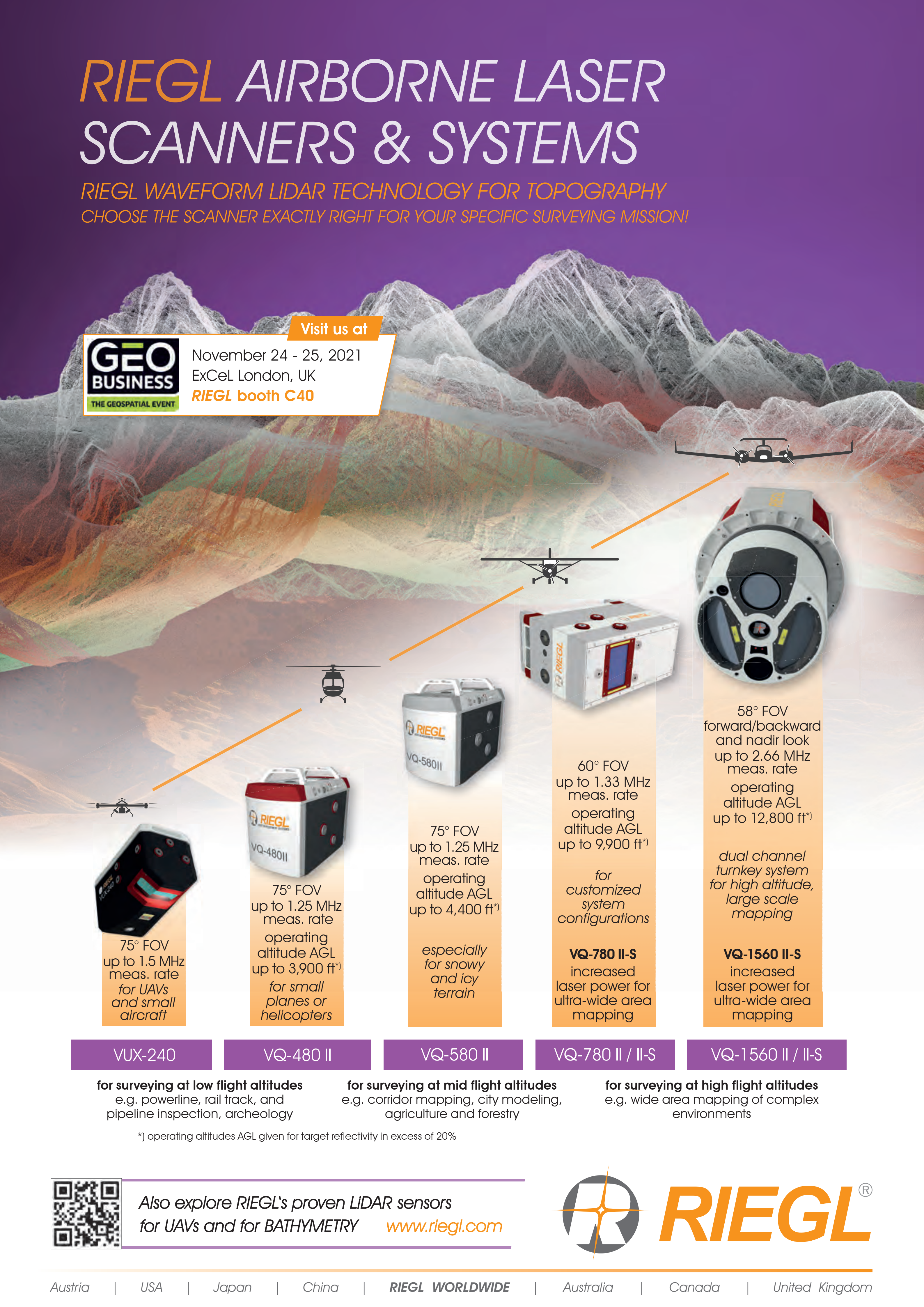
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e.g. corridor mapping, city modeling, agriculture and forestry
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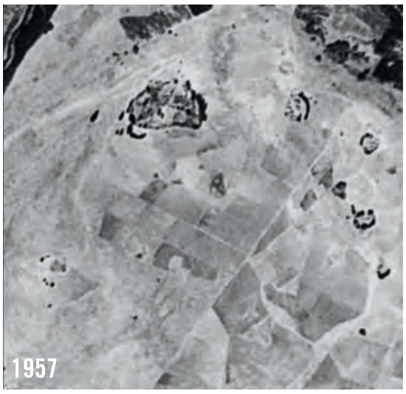
Multi-disciplinary Trend Detection, Analysis and Forecasting from Aerial Film Archives

The What, Where and When of Past Events

Only a small fraction of the information content in aerial films has ever been recorded on paper maps, most of which are inaccessible. The use artificial intelligence (AI) to fully automate the process of information extraction from imagery will soon unleash the true value of this information by enabling the creation of land cover maps of all the world's countries stretching back to the 1930s.

From the 1930s to about the year 2000, much of the world was captured at regular intervals on high-resolution aerial film using aerial mapping and reconnaissance cameras, by national mapping organizations, defence organizations and private mapping companies. During that time, the Earth has been transformed by massive industrialization and urban growth. The Earth's population increased threefold from two to six billion people, tens of millions of kilometres of roads were constructed, billions of houses were built, global GDP increased fourfold, and large areas of forest and grasslands were transformed into agricultural fields and towns.



These changes to the Earth are recorded on millions of rolls of aerial film that mostly lie locked way in archives and remain inaccessible. Unfortunately, due to past technical limitations and laborious manual feature extraction, only a small fraction of the information content in these films has ever been recorded on paper maps, and most of these are no longer accessible and not digitized. Many of the films are deteriorating, or even worse are being disposed of as the storage costs are considered too high. However, these films record the heritage of our changing world and are a highly valuable resource if they can be accessed.

UNLEASHING THE TRUE VALUE

Until now, scanning the films was a very slow and expensive process. For most organizations, the majority of their archive is therefore still inaccessible, except for bespoke and costly scanning of individual frames. The true value of the archive is only achieved when the data becomes easily accessible as

▲ *Sample selection of georeferenced multi-temporal aerial images of Addis Ababa.*

a complete digital archive. Once all the films are scanned and georeferenced, they can form temporal imagery layers that can be quickly viewed to identify changes and trends and to make predictions.

Traditionally, human operators were required to extract information such as the location of buildings, roads, tracks and boundaries. This was a very time-consuming and expensive exercise. Conventional data acquisition concentrated on collecting data as individual objects using a standardized mapping schema. Only specific objects were recorded based on whether they were of specific interest and were of a sufficiently large size. The environment at that time was widely ignored and poorly documented. It is estimated that only about 5% of the information in these films was ever extracted and a fraction of this remains in a digitally accessible form.

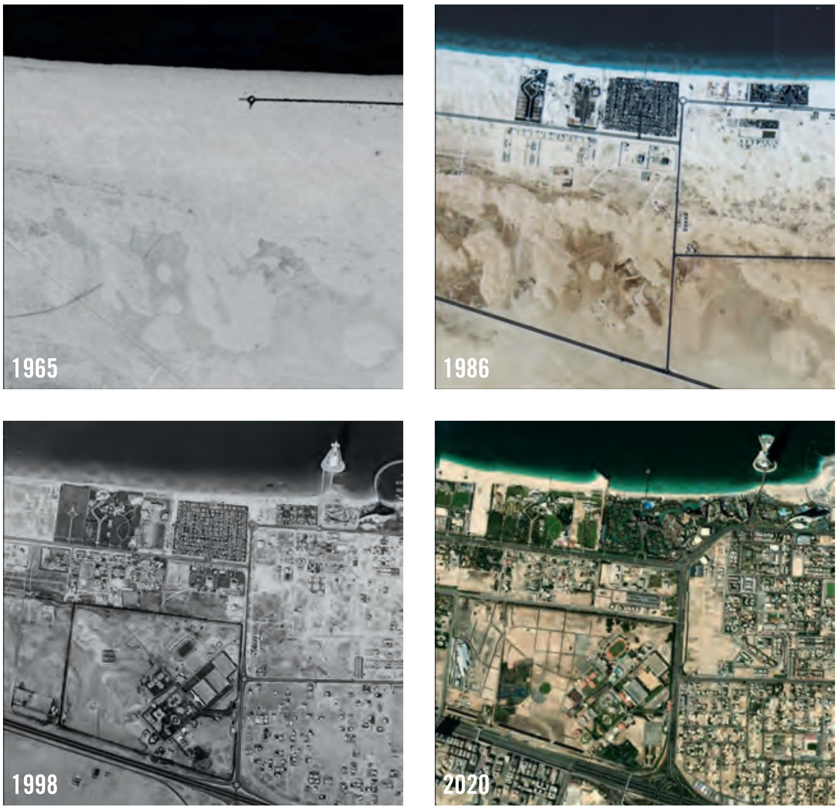
THE USE OF ARTIFICIAL INTELLIGENCE

This has now all changed. It is now possible to use artificial intelligence (AI) to fully automate the process of information extraction from imagery. If a human operator can identify a feature, then AI can do so too as long as it is provided with sufficient training datasets. The deep learning models are advancing rapidly, and techniques such as transfer learning are significantly reducing the number of training datasets required.

In a similar way in which Esri, The Impact Observatory and Microsoft were able to generate 10m land cover maps of the entire world using recent multispectral Sentinel-2 images, it will soon also be possible to create similar land cover maps of each country of the world stretching back to the 1930s based on training and running AI on higher-resolution panchromatic and colour imagery. The spectral depth of the multi-spectral satellite imagery can be replaced with the context obtained from the higher-resolution stereo aerial imagery. The existing aerial photography was nearly all flown with 60/30 overlap, meaning that there are between three and five separate views of each location. This independent measurement redundancy will further increase the obtainable accuracy.

LAND COVER MAPS

These land cover maps will provide real statistics on how the planet has changed. Moreover, creating multiple temporal data points will enable us to determine accurate trends in various domains and hence to better predict the consequences of future development measures. These data points in time can be correlated with other measurements to better understand the cause and effect that humans have on the environment, as well as the changes that must take place to avert a global environmental disaster.



▲ *Sample selection of georeferenced multi-temporal aerial images of Dubai.*

Land cover maps also enable simple change detection and anomaly detection for the identification of features currently lost to more recent human development or natural erosion processes. Further, review of the imagery provides irrefutable evidence that is not available in older paper maps which are based on human interpretation and biases.

SNAPSHOT OF THE WORLD

A single image in time provides a snapshot of the world. That in itself is fascinating. We can identify things that have been lost in time and draw accurate conclusions on aspects such as property boundaries, forest extents, levels of infrastructure, and the location and structure of buildings that may no longer exist. A series of pixel-aligned georeferenced images tell an even greater story. The significance is created by the time-lapse effect, similar to a movie clip composed multiple of images, highlighting gradual movement and changes over time. Therefore, observing temporal orthoimages enables us to instantly identify objects that have changed or been displaced, even when in the displacement has been too slow to be noticed on site in real time. The time-lapse effect allows us to identify developments at an early stage, when we can still identify the cause and consequently have the opportunity to respond to the trend. Waldo Tobler’s first law of geography states that “Everything is related to everything else, but near things are more related than distant things”. The definition of “near” is not only spatial, but also applies to time. Everything affects everything: an axiom!

SATELLITE IMAGERY IMPROVEMENTS

Space-based imagery has been available since the 1970s. With the exception of the Corona Satellite photography imagery (about 1960-1970) that had approx. 3m resolution and was kept highly secret for about 30 years, the only wide-area satellite imagery coverage was from the Landsat programme which at that time had 60m resolution. Most aerial imagery between the 1930s and 2000 was captured at sub-metre resolution, and cities often at decimetre resolution.

The resolution of commercial satellite imagery has improved immensely since then. In 2000s,

▲ *Sample selection of georeferenced multi-temporal aerial images of Munich.*

1m resolution imagery became accessible, and today accurate global 1m resolution imagery is available along with accurate digital terrain models. The massive volumes of high-resolution satellite and digital aerial imagery is providing us with an accurate definition of our world today, but to really understand the trends we need to look back at the changes that have taken place over many decades. The availability of such accurate high-resolution basemap and digital terrain models greatly facilitates the georeferencing and orthorectification of the older aerial imagery to enable suitable simple comparisons.

SOLVING STORAGE CHALLENGES

Whereas storage costs were a challenge in the past, these have been superseded by massive increases in hard disk storage and relatively inexpensive cloud storage costs. A single 15um 8bit panchromatic image can be compressed from about 250MB to about 75MB with minimal quality loss. An aerial film archive of a thousand roles of aerial film will contain approximately a quarter of a million images and require about 18TB of storage, which nowadays would fit on a couple of hard disks or can easily be uploaded to cloud storage. Moreover, the computing cost for AI is low and so what was previously inconceivable is now quite possible.

GeoDyn is revolutionizing the accessibility of aerial film archives by developing highly advanced photogrammetric aerial film scanners capable of transforming these aerial films into quickly accessible, accurate digital images that maintain the full information content. With PromptSCAN, the conversion speed is now 50 times faster and a magnitude cheaper than was previously possible. In addition to scanning, GeoDyn also provides highly efficient workflows for accurately georeferencing these images to create temporal image maps and the extraction of information to enable the identification and quantification of change.

TREASURE TROVE OF INFORMATION

Once accurately scanned and georeferenced, these digital images provide a treasure trove of valuable Information. They enable us to determine the 'what, where and when' of past events. Using new machine learning and data mining technologies, we can now trace how the Earth has transformed, categorize the kinds of changes that have taken place and help to predict future trends.

GeoDyn was founded by a team of photogrammetrists. The vision is to unlock the information recorded in aerial film archives around the world and convert it into temporally sequenced maps so that humanity can fully understand the Earth's geopolitical, climatic and industrial development over time. Between them, GeoDyn's employees have over 200 years of experience in the aerial survey industry. The company provides full-service aerial film conversion, georeferencing and information extraction. In addition to the development of high-speed aerial film scanners, GeoDyn has developed technologies that enable the rapid and accurate conversion, georeferencing, rectification and delivery of aerial imagery.

As an Esri Gold Level business partner, GeoDyn assures full integration with ArcGIS. All images become accessible as both temporal base maps and dynamic image services, enabling the full information content of the imagery to be accessed in a wide range of applications for visual interpretation, automated feature extraction using machine learning, and data analytics. ◀

MORE INFORMATION

A sample selection of georeferenced multi-temporal aerial images can be viewed at www.geodyn.com.

Airborne Photogrammetry: Still Going Strong after 100 Years

Airborne photogrammetry has been around for more than a hundred years. As early as 1851, the French inventor Aimé Laussedat began imagining the possibilities of using the newly invented camera to capture reality through pictures for mapping purposes. Some 50 years later, the technique was successfully employed, and photogrammetry emerged as a long-range landscape measurement technique through analysis of analogue photographs. In the 1920s, Heinrich Wild took professional photogrammetry to the sky with WILD's first aerial camera, the C2. In the following 80 years, the industry progressed from analogue to digital cameras, fulfilling the dream of photogrammetrists to quickly create detailed maps.

PHOTOGRAMMETRY TODAY

Today, after 100 years of continuous innovation in airborne photogrammetry, entire countries can be mapped faster than ever before. The exponential technological advancement since the digital era has led the industry to evolve, grow and excel. Developments in cloud computing and artificial intelligence (AI) on the processing side as well as sensor miniaturization and chip technology on the hardware side have opened up new opportunities. Every IT innovation propels the industry to new heights.

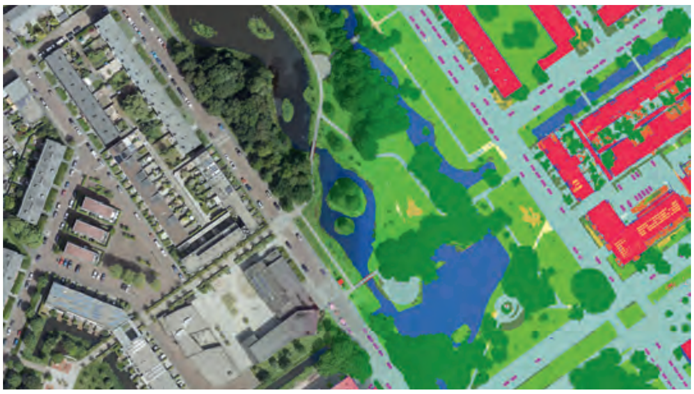
Several industry trends have led to the increasing demand for geospatial imagery in recent years. With our world changing faster, more frequent refresh rates are required and mapping cycles have accelerated. Customers now want to capture larger project areas at increasing measurement density, while budgets decrease. Other considerations are open data policies and growing interest in monetizing the captured data. As geospatial data becomes more important, more and more stakeholders are involved in the procurement process. All these trends drive the need for increased productivity and new, creative business models.

INNOVATIONS IN TECHNOLOGY

The fast evolution of complementary metal oxide semiconductor (CMOS) sensors is delivering higher resolutions. Advancements in cloud technologies and GPUs result in greater processing power and capacity. AI and machine learning (ML) enhance data extraction capabilities. The miniaturization of components means more and more features fit into one instrument. The Leica CityMapper-2 hybrid oblique imaging and Lidar sensor is one example of how miniaturization has enabled what was not possible previously. It contains a Lidar system, data logger, GNSS/INS system and six cameras in one compact package. This enabes it to fit in the same space as past cameras, while its all-in-one package design improves reliability. The same concept applies to software: multiple apps with unique functionality have become part of a unified high-performance multi-sensor workflow platform: Leica HxMap.

Big IT is driving the photogrammetry revolution on the data and processing side. Customers now have the ability to process

▲ *The WILD C2 aerial camera in action.*



▲ *AI-based automatic land classification extracted from an orthophoto.*

data in the cloud using platforms like HxMap, spinning up between 2,000 and 20,000 machines to accelerate processing and scale their capacity as needed. With AI and ML unlocking analytics, automatic feature extraction and object detection, we can put geospatial data to use in different ways. For instance, instead of trying to understand natural disasters after they happen, we can start mining information in advance to create contingency plans. Cloud services enable the hosting and streaming of geospatial data in one central place, providing an easy method for consumption, distribution and access for all.

THE FUTURE

The future of photogrammetry lies in hybrid sensors which capture imagery and Lidar data simultaneously. In fact, at Hexagon we believe in this so strongly that we do not envision imaging-only systems to remain viable as customers' expectations exceed the capabilities of such systems. Instead, hybrid systems enable the capture of more data from every flight, allowing digital twins to become more efficient and affordable for a larger customer base. While the past 100 years of photogrammetry have been exciting, I have no doubt the next 100 years will be even more remarkable. ◀

▲ *Leica CityMapper-2.*

▲ *Imagery and Lidar data simultaneously captured with the Leica CityMapper-2 provides detailed 3D digital twins of cities for more informed decision-making.*

ABOUT THE AUTHOR

John Welter is the president of Geospatial Content Solutions at Hexagon's Geosystems division, based in Washington D.C., USA. With three decades of extensive and demonstrated experience in the information technology and services industry, Welter is an expert on topics including geospatial services, airborne mapping technology, big data concepts and IT strategy.

Innovation Drives the Continuous Evolution of Data Visualization

Data visualization is inherent to humans and continuously evolves, driven by innovation. The term has come into popular usage relatively recently, but the concept actually goes back to the earliest days of humans many thousands of years ago: from the first people scratching out their location in relation to food sources or to one another. Needless to say, the expression of data visualization has changed and evolved many times through the ages, accelerating with each new related technological innovation.

Data visualization is an inherent human trait because our survival depends on it for food, trade and security. We can see this throughout history. The first people sketched the relative locations of food and water sources and other geographic features and phenomena, initially on the ground. As they developed tools and pigments, they illustrated this information on cave walls, some of which are still preserved today around the world. Land boundaries were demarcated with monuments, and physical descriptions were verbally communicated to establish geographic locations for land ownership. Chapters 13-21 in the Book of Joshua in the Old Testament Bible and Jewish Scriptures, from approximately 1400 BCE, contain a detailed description of the boundaries of the 12 tribes in enough detail that they have been placed on maps with a fair level of accuracy. Since then, Arab, Asian, Mediterranean and Polynesian sailors have navigated with instruments to ply trade routes thousands of miles from home.

The invention of papyrus and paper enabled geographic data to be visualized better, faster and cheaper. This important innovation led to the development and use of maps as we know them today, and cartography emerged as the prominent way to visualize location data. Travel for warfare, pilgrimages and trade further drove the development of mapping. Exploration in the 14th and 15th centuries exploded the need for mapping and catapulted the ancient marine navigation techniques onto rhumb lines, or Portolan charts, which evolved into modern-day nautical charts. The invention of the printing press allowed cartographers and printers to meet the growing appetite for maps to visualize the data coming back from the New World with every voyage. Innovations in shipping allowed for circumnavigation of the Earth, and a new kind of data visualization was required with terrestrial globes, celestial globes and armillary spheres to visualize the Earth and stars in 3D. The age of exploration was quickly followed by the 'golden age' of cartography to meet the visualization needs of the ensuing global trade that emerged and location data at these terminals. In the 18th and 19th centuries, many innovations in measurement and surveying led to a higher level of accuracy and larger-scale mapping, which dramatically improved data visualization at new scales.

IMAGERY AND GIS CHANGED EVERYTHING

In the 20th century, visualization of geography changed dramatically with the invention of the aeroplane that was quickly adopted by many nations' militaries. They put cameras on board and intelligence, surveillance and reconnaissance (ISR), and visualization of geographic data and mapping were revolutionized. Imagery joined mapping as one of the key geographic and cultural visualization tools. Mapping itself was changed forever as imagery became the primary source for change detection and feature mapping. This accelerated the need to map more quickly, and innovations in photomechanical reproduction methods began to replace hand-drawn maps.

In the 1960s, technological innovations enabled computer-assisted cartography and geographic information systems (GIS) to revolutionize how data was visualized and

▲ *Early examples of data visualization in history.*

▲ *Figure 1: GIS integrates all types of data for visualization and analysis.*

▲ *Figure 2: GIS leverages technology innovations.*

analysed. Data was no longer compiled and produced for a single point in time, only to quickly degrade. Instead, the results of efforts to capture and produce the map data could now be stored in computers, which allowed the data to be updated and continually reused. As this process was further refined in the 1970s and 1980s, organizations were able to free up resources to leverage the data for many different uses.

I learned this first-hand in 1992, when I started using GIS as a production manager at a Silicon Valley start-up that was on its way to becoming the largest provider of routing map data for in-vehicle navigation systems and eventually the internet. Automotive manufacturers around the globe wanted the data to deliver turn-by-turn instructions to drivers. However, the data itself was not enough. The car companies were not successful until we provided the cartographic attributes in the data model to allow each company to visually render a map to their specifications. In a very short time we enabled many different automotive companies to each visualize the data uniquely to their brand. The map data we created was consumed and visualized by many different organizations and in many different cartographic styles. That same map data was used for cartographic paper maps and digital maps that eventually went into apps and web services.

INNOVATING WITH LOCATION DATA

While we were using GIS on cutting-edge technology in Silicon Valley, the rest of the world was beginning to discover GIS for many different applications. It is a widely accepted fact that 80-90% of the data around the globe has an underutilized location component. GIS leverages that location data attribute and enables the data to be visualized and analysed to derive additional value and uses. Even non-GIS people can take advantage of their data by visualizing it in dashboards and further analysing it to discover new insights using a simple but powerful browser-based GIS app.

Data can now be created, visualized, analysed and utilized in apps in desktop, enterprise, mobile, web and cloud GIS environments. The data can be shared easily, integrated harmoniously and add value to applications across a myriad of government and industry activities, covering thousands of use cases. The different types of data are as diverse as vector, imagery, Lidar/point clouds, terrain, 3D, textured mesh and multidimensional data, voxels, CAD/BIM, tabular and unstructured, big data and real-time (IoT) (see Figure 1).

Increasingly, GIS is being used to make sense of the exploding volume, velocity, veracity and variety of data coming at us every day. GIS allows us to do geoprocessing of big data in the cloud utilizing containerization and microservices. GIS with AI and deep learning, or ‘geoAI’, enables us to data mine this big data to quickly perform change detection and identify, classify and extract information. This gives us the ability to keep up with the blizzard of data coming from imagery and remotely sensed data services streaming from satellite, airborne, terrestrial, marine and drone platforms (see Figure 2).

HOW TO MAKE DATA ACTIONABLE

So the inevitable question is, how do we make all of this data actionable? In his book titled *Information Anxiety*, Richard Saul Wurman (founder of TED Talk and TED Conference) wrote: “To deal with the increasing onslaught of data, it is imperative to distinguish between data and information. Information must be that which leads to understanding.” And as he has famously stated, “Understanding precedes action.”

GIS enables us to visualize our data and turn it into information using geospatial analysis. With human interaction and innovation, that information can be transformed into knowledge, insight and understanding as the basis for more effective actions and decisions. Today’s mapping and geospatial authorities play a key role in this. ◂

FURTHER READING

Innovating with Data, Brent Jones, Esri
Understanding Precedes Action – And Geography Maps the Course (including quotes by Richard Saul Wurman)
Esri.com/maps

ABOUT THE AUTHOR

Mark Cygan has been working in GIS and mapping since 1984. Today, he is director of Esri’s National Mapping Solutions, having been in Esri’s Industry Solutions Group since 2005. Before that, he worked for nearly a decade as a senior consultant and project manager in Esri’s Professional Services. Prior to joining Esri, Cygan was on the management team at NAVTEQ (now HERE), a pioneer in digital mapping for in-vehicle, web and mobile uses. Cygan is actively participating in the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) as a UN-GGIM Geospatial Societies board member (and past chair), is the executive secretary of the User Community of Geospatial Authorities and is on the board of directors of the International Map Industry Association (IMIA).
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From the Perspective of Developers and Users

The Photogrammetric Platform Strategy Approach

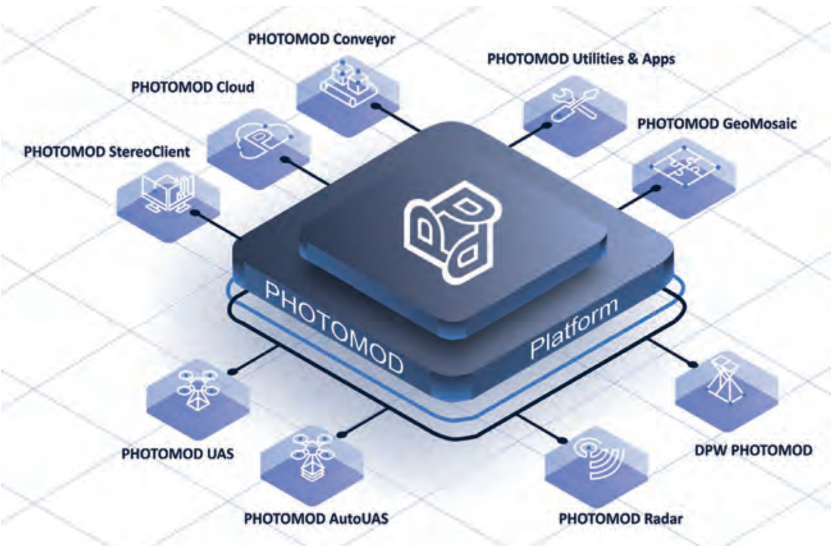
'Platform' has become somewhat of a buzzword nowadays and is widely used in the context of economics, finance, social networks and IT. At Racurs, however, they believe it is more than just a buzzword and have been implementing the platform strategy approach for the development of software products since 2020. This article introduces the concept of a photogrammetric platform that is built upon the software set of the PHOTOMOD system.

As repeatedly confirmed by market research, the last couple of decades have seen explosive growth in spatial data processing technologies. Photogrammetry is no exception, despite its long history. New user queries are emerging, dozens of remote sensing data satellites are being launched, and new sensors and hardware are being developed. In response to these changes, developers of photogrammetric solutions have to quickly adapt their solutions to the market – not only at the functional level, but also at the level of photogrammetric manufacturing systems. Likewise, the implementation of photogrammetric technologies is a complex process that entails many factors. In both of these cases, a platform strategy approach can offer a solution. The concept of the platform in its two applications – photogrammetric developer platform and photogrammetric user platform – is examined below.

DEVELOPER PLATFORM

Data processing methods, calculation algorithms, processing chains and so on are all key in the development of high-quality products. Reliable operation of the algorithms and methods enables two main functions of the photogrammetric platform from the point of view of product development: configuration and customization.

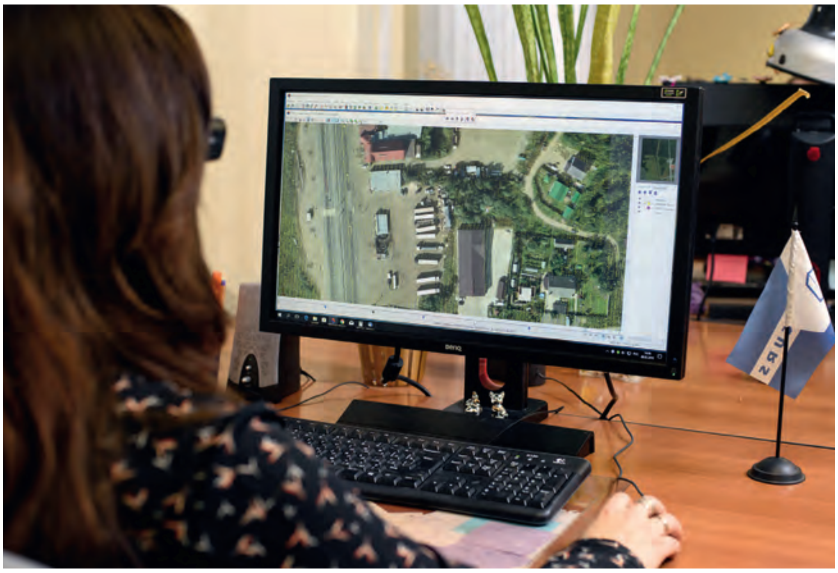
- **Configuration:** Algorithms of photogrammetric processing must work well in different computing environments and operational systems – from a laptop to a cluster, and from a local company network to global cloud services. Photogrammetric platform software must also support stable operation in the course of geodetic fieldwork where there is no internet access, or in large enterprises equipped with modern cluster systems and gigabit networks. The development of cloud technologies and the improvement of data transmission speed is removing limitations on the creation of remote workspaces, but it remains crucial to follow all the stages of photogrammetric data processing. Stereoprocessing was a limiting factor for a long time, but this problem has been solved as well. PHOTOMOD StereoClient enables users to connect to a server via the internet and access PHOTOMOD data, projects and software as well as execute stereovectorization and stereomeasurements remotely using 'thin client' technology in the same way as on a local computer.



▲ *The photogrammetric PHOTOMOD platform structure.*

- **Customization:** Implementation of current data processing algorithms facilitates fast software solutions in line with the needs of clients from different industries. For instance, the StereoMeasure app was developed for forest evaluation needs. This app is based on PHOTOMOD stereocapabilities. New user solutions can be developed by building processing chains from software modules that are using algorithms. For example, PHOTOMOD AutoUAS is 'one-button' software for unmanned airborne system (UAS) data processing that is based on the same algorithms and methods as other PHOTOMOD photogrammetric platform products.

One of the most important features of a platform is the network effect, i.e. the



Photogrammetrist at work.

3D model of the city of Graz, Austria.

platform value grows as the number of users grows. Can it be said that software products, especially ones as complex and specialized as photogrammetric products, create a network effect? The two important features of the platform mentioned above – configuration and customization – are key to create a network effect. The number of users of photogrammetric products is growing; the market is no longer limited to the classic aerial and satellite survey industry. The rapid development of new functions and applications on the basis of reliable algorithms allows photogrammetric technologies to be implemented in various areas, often far removed from geoinformatics. This is driving not only growth in the number of users of the photogrammetric platform, but also growth in its value.

USER PLATFORM

The photogrammetric software that is being developed must support the efficiency of the user platform in terms of both financial resources and human resources. From its own long-standing experience, Racurs knows that two features must be taken into account when developing the user platform development: scaling and integration.

- **Scaling:** The number of specialists involved in the production – whether one specialist in a small company or dozens of staff members in large national mapping agencies or cartographic agencies – is irrelevant to the effective implementation of the photogrammetric platform. The platform must enable easy restructuring of the production workflow and be adaptable to the number of users. Historically, PHOTOMOD is based on a modular architecture in which each programme module is designed for the execution of the required operations at each project stage. Such an architecture allows large photogrammetric production systems to be built. For instance, when the PHOTOMOD platform was implemented in Uzbekistan as part of the creation of the National Geographical Information System, 60 workspaces were arranged within the shortest possible period of time by optimizing the number of modules and adjusting the network processing.

- **Integration:** Due to the wide variety of photogrammetric processing tasks, the implementation of only one general-purpose product is ineffective. Clients may have different queries that are subject to change, while enterprises evolve and may shift their focus onto other types of production. As the number of programmes and separate modules increases, it is important to ensure their mutual integration. This requires platform components to use the same algorithms and methods, to complement each other in terms of technology and to have a common system of data storage and data management. This allows the development of optimal processing chains for remotely sensed Earth observation data on the basis of different software solutions, while taking different levels of user expertise into account. For example, algorithms with a high level of automation and reliability facilitate automatic photogrammetric processing without requiring the involvement of experienced photogrammetrists. In the case of strict confidentiality and precision requirements, however, all the stages of data processing must be supervised interactively by an experienced specialist.

So is it possible to achieve a network effect for a user platform? The photogrammetric platform creates an intermediate link between the source data and end users. This intermediary position complies with the network effect concept. In other words, the photogrammetric platform acts as a kind of bridge – not only connecting operators of remotely sensed Earth observation data with end users, but also connecting end users with one another.

Apart from the developer platform and the user platform, Racurs' development strategy involves collaboration with technology and production partners as well as scientific and educational organizations. The company firmly believes that this approach based on mutual support and development will allow it to create a truly valuable photogrammetric platform. ◂

MORE INFORMATION
https://en.racurs.ru/

INSIGHTS INTO THE LATEST FFPLA INNOVATIONS AND IMPLEMENTATIONS

Providing Secure Land Rights at Scale

The Fit-For-Purpose Land Administration approach, which was first formally conceptualized around five years ago, is now gaining momentum and growing in acceptance across the land sector. This is documented in a new special issue of the Land journal highlighting the latest FFPLA innovations and implementations from approximately 20 countries around the world.

The phrase 'fit for purpose' is commonly used for any intervention or activity that is appropriate, and of a necessary standard, for its intended use. The Fit-For-Purpose Land Administration (FFPLA) concept was developed in response to the lack of security of tenure in most developing countries, where up to 90% of the land and people are outside of the formal land administration systems. This mainly favours the elite. The concept includes three core components: the spatial, the legal, and the institutional frameworks. Each of these components includes the relevant flexibility to meet today's actual needs, and can be incrementally improved over time in response to societal needs and available financial resources. The FFPLA approach is participatory in data capturing, affordable for governments to establish and operate, and attainable within a relatively short time frame.

The FFPLA approach is already triggering an influential change towards providing secure land rights at scale and providing greater social equity, leaving no one behind. These are the key findings in a special issue of Land, collated from 26 articles focusing on various aspects of the FFPLA approach and its application. One group of articles discusses various conceptual innovations related to the spatial, legal and institutional aspects of FFPLA and its wider applications within land use management. The other group focuses on case studies from a range of countries around the world, providing evidence and lessons learned from the FFP implementation process.

THE FFPLA SPECIAL ISSUE

The main motivation for the special edition of Land was to share experiences and research into the FFPLA approach in order to help accelerate its implementation at scale and quickly resolve the global insecurity of tenure crisis. Indeed, the articles illustrate the significant progress that has been achieved over the past decade. They provide some very encouraging lessons learned, as well as exciting, innovative technologies to inspire land professionals to achieve the challenging objectives of the Sustainable Development Goals (SDGs). Although Land is a scientific publication, the range of topics (see Table 1) within the special edition will also be of great interest to decision-makers and professional land practitioners.

The articles are published on an open-access website and also in a two-volume book (see Figure 1). A few highlights from the wide range of articles addressing FFPLA innovations and country implementations are provided below (see Figure 2).

CONTENTS OF THE SPECIAL ISSUE ON FFPLA	
FFP Conceptual Innovations (Volume 1)	**FFP Country Implementation (Volume 2)**
- Assessing procedures of maintenance to be secured upfront of any FFPLA project - Assessing adjudication and quality assurance for legal and geospatial data - Applying innovative geospatial tools to FFPLA - Using decentralization as a strategy for scaling FFPLA - Assessing the role of FFPLA for violent conflict settings - Applying the FFP approach to wider land management functions - Applying the FFP approach to urban resilience, climate change and COVID-19 - Exploring the role and opportunities of the private financial sector and public-private partnerships within FFPLA.	- Assessing the impacts of applying the FFPLA approach in China and Vietnam - Analysing the strategies for implementing the FFPLA approach in Indonesia, Nepal, Uganda and Mozambique - Analysing the cases of piloting FFPLA tools for land recordation in Ghana, Kenya, Uganda, Zambia and Namibia - Analysing the impact of applying the FFPLA approach in South Africa - Using the FFP approach for upscaling of land administration in Benin - Applying the FFPLA approach in post-disaster response in the Caribbean - Assessing FFPLA applications in Colombia and Ecuador.

Table 1: Contents of the special issue on FFPLA.

▲ *Figure 1: The two volumes of the FFPLA books.*

▲ *Figure 2: The FFPLA country assessments and implementations addressed in the special issue.*

VOLUME 1: CONCEPTUAL INNOVATIONS

Private-sector FFP Land Financing. Purchase of land for informal settlers can be facilitated through loans managed by private institutions. In the case of Brazil, a private social enterprise (Terra Nova) acts as a coordinator and broker for buying out the underlying private owners at discounted values and coordinating with municipal governments to provide infrastructure. This has demonstrated that the concept of FFP land regularization can be widened to include FFP land financing with relevance for wider efforts in informal settlement regularization and upgrading. An analysis of parcel-level repayments to land owners and property price data provides some evidence of the sustainability of the business model and the increase of property values of the regularized parcels (pre-COVID-19). Since 2001, the private social enterprise has regularized over 20,000 informal parcels, primarily in São Paolo and Curitiba, and it is contended that the approach is widely replicable. Another case study from Côte d'Ivoire shows that similar innovation is taking place with new FFP Public-Private Partnership (PPP) models, including partnerships involving consortia of food industry leaders and private land documentation firms.

The Wider FFP Approach. The FFP approach has predominantly been applied to the land tenure aspects of land administration but can be expanded into a wider set of land management functions as has been verified by three World Bank urban case studies focusing on land valuation, housing resilience and waste management. Machine learning techniques can extract information, such as about building materials, from drone and street-level imagery to produce minimum viable product models to support these applications, as well as land tenure. Interestingly, there is a common set of geospatial datasets that can be captured once and shared across many other FFP land management functions in an urban environment. This will allow the current single land intervention projects to be holistically integrated into a wider programme of land management functions and deliver greater benefits to society much earlier.

VOLUME 2: COUNTRY IMPLEMENTATIONS

National FFPLA Strategies in Uganda and Nepal (see Figure 3). The GLTN publication 'Fit-For-Purpose Land Administration: Guiding Principles for Country Implementation' provides countries with guidance on how to formulate FFPLA implementation strategies. The special edition provides excellent in-depth examples from several countries where FFPLA national strategies have been created. Uganda has over 23 million unregistered parcels with varying tenure types and Nepal has over 10 million. Both countries implemented several pilot projects in order to identify how lessons learned from these case studies could inform the FFPLA implementation strategy in terms of building the spatial, legal and institutional frameworks. They found that the pilot projects provided opportunities to explain the benefits and obtain the necessary political, community and stakeholder support. This resulted in a national dialogue and consensus among all stakeholders and was a very promising way of advancing the FFPLA concept and creating a country implementation strategy. These approaches are building on the experience of significant early FFP programmes implemented in China and Vietnam.

THE FFP APPROACH HAS PREDOMINANTLY BEEN APPLIED TO THE LAND TENURE ASPECTS OF LAND ADMINISTRATION BUT CAN BE EXPANDED INTO A WIDER SET OF LAND MANAGEMENT FUNCTIONS

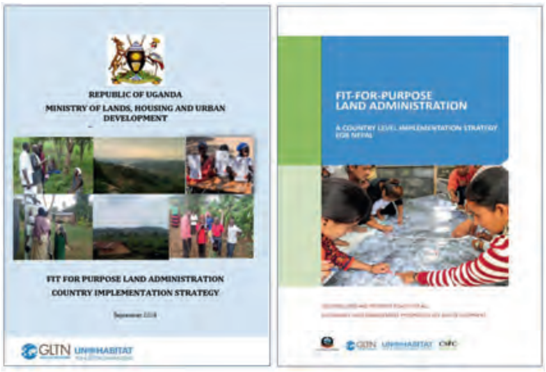
Assessing FFP Approach for South Africa. The Surveyor General investigates whether South Africa could adopt FFPLA to provide security of tenure to the five million land occupants who exist outside the formal land tenure system on communal land, in informal settlements, in resettled communities, in off-register housing schemes, and as farm dwellers, labour tenants and other occupants of commercial farms. The case study demonstrates how adjustments to the institutional, legal and spatial frameworks could develop a fully inclusive, sufficiently accurate land administration system that fits the purpose for which it is envisioned. The existing land tenure complexities, shaped by the evolution of land tenure systems in South Africa, are highlighted through the institutional, legal and spatial framework lenses. There is optimism that the adoption of the FFPLA approach with political support, trust built through community participation, and endorsement of the approach by land professionals will provide security of tenure that is beneficial and acceptable to all. There are many positive aspects already in place and no outstanding issues that are insurmountable. Solutions proposed for South Africa may well find application in many other countries.

LESSONS LEARNED

The articles offer a mixed overview of experiences, developments and implementations. This results in some promising lessons learned and key experiences, including:

- The FFPLA pilot projects are easy to implement, well accepted and understood by the local community.
- By using a participatory approach and working in parallel throughout the country, FFPLA national projects can be completed at affordable costs of less than US$10 per parcel and within a few years. In principle, this is a national top-down approach that requires strong political will and support from key senior civil servants.
- Technological advancement is a key driver in terms of providing the relevant mapping and registration tools, e.g. machine learning to extract information from drone and street-level imagery.
- Innovative financing can be obtained, e.g. through new types of PPPs and private-sector support for regularization and upgrading of informal settlements.
- The FFPLA approach is unfolding beyond providing security of tenure, e.g. for mitigating land issues in violent conflict settings and for wider land management functions such as valuation, urban resilience, climate change and pandemics.

The FFPLA approach is gaining momentum and acceptance within the land professional community – including among the younger generation – as a game changer in achieving key aspects of the global agenda (the SDGs) towards greater social equity, leaving no one behind.



▲ *Figure 3: National strategies for implementing the FFPLA approach in Uganda (left) and Nepal (right).*

FURTHER READING

Enemark, S.; McLaren, R.; Lemmen, C. (editors) *Fit-For-Purpose Land Administration Providing Secure Land Rights at Scale, Volume One: Conceptual Innovations, Volume Two: Country Implementation* MDPI, Basel, Switzerland, 2021
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How Disruptive Technologies Shape the Policy and Social Landscape

A Look Ahead to the XXIV ISPRS Congress in June 2022

Powerhouses of photogrammetry and remote sensing science and industry are set to gather in Nice, France, for the XXIV Congress of the International Society for Photogrammetry and Remote Sensing (ISPRS) from 6 to 11 June 2022. The ISPRS Congress is the premier event for researchers and practitioners in the fields of photogrammetry, remote sensing and geospatial information.

Participants will enjoy a week of immersion, this time with a special focus on how photogrammetry, remote sensing and spatial information contribute to science and society, including public policies and main aspects of life and work today. A central theme is how disruptive technologies (sensors and methods) shape and improve the current technology, policy and social landscape, and how they create new fields of application and opportunities for the public and private sectors, as well as interactions between them.

A GATHERING WITH A HISTORY

The ISPRS Congress has been held every four years for almost a century. The XXIV edition, originally planned for 2020, was postponed twice due to COVID-19 travel restrictions and impacts. In the meantime, digital events were held in 2020 and 2021 to enable authors to publish and present their work to a large audience of digital imaging system designers, photogrammetrists, remote sensing specialists and spatial information scientists.

For the physical event in 2022, the organizers are putting an array of health and hygiene measures in place to ensure they can safely welcome a very large number of experts in Nice and allow for meetings, networking and cross-fertilization among colleagues in the same and related fields. For those unable to attend in person, hybrid participation formats will be made available.

INTERDISCIPLINARY AND UBIQUITOUS

The ISPRS Congress exhibits the interdisciplinarity of the science today and the ubiquity of the application of sensing, whatever the platform (from satellite to citizen). The conference programme will feature ten thought-provoking keynotes and some 1,500 scientific presentations, as well as thematic sessions, technology deep dives, fora with roundtables, an industry exhibition, pre-conference tutorials and events for young professionals. The conference days are carefully programmed to give all attendees the opportunity to either delve into a single main topic or get a glimpse of major achievements and future trends in multiple domains.

The ten programmed keynotes are:

- The Pléiades Neo Constellation and its 3D mapping capacities (Michael Tonon, Airbus)
- The European Earth Observation Programme (Simonetta Cheli, ESA)
- Global remote sensing for sustainable development goals (Chen Jun, Chinese Academy of Engineering)
- Digitizing endangered cultural heritage (Yves Ubelman, ICONEM)
- Autonomous, agile and vision-controlled drones (Davide Scaramuzza, ETH-Zurich)
- AI for self-driving cars (Raquel Urtasun, Waabi and University of Toronto)
- Geometry processing and learning for 3D modelling of complex scenes (Pierre Alliez, INRIA)
- Education and serious games, the Netherlands in 3D Minecraft (Willemijn van Leuven, Geofort)
- Geoinformation and geoprocessing for

smart cities and smart mobilities (Sisi Zlatanova, University of New South Wales, Sydney)
- Geospatial for pandemic monitoring, mitigation and prevention (Fazlay Faruque, University of Mississippi).

Pre-recorded video presentations of the papers will be available to registered participants via a digital platform before and during the event. These will help attendees choose sessions and presentations and build their own programme during the week. The digital platform will allow on-site and remote participants to also access the live streams and replays of all live sessions during and after the event. Live remote presentations of authors unable to join the congress on-site will be seamlessly integrated into the live sessions in the congress rooms and will be streamed on the digital platform. Remotely presenting authors will be able to interact with on-site chairs and participants in the session rooms as if they were present.

FOUR PROGRAMME TRACKS

In addition to the plenary events, the ISPRS Congress is being organized around four programme tracks:

- Scientific track sessions provide the core of the scientific programme, emphasizing advances in the various branches of the science. These are being organized in line with the five ISPRS Technical Commissions: (1) Sensor Systems, (2) Photogrammetry, (3) Remote Sensing, (4) Spatial Information Science, and (5) Education and Outreach.
- Forum track sessions will focus on the interface between science and society. Rather than presenting innovations per se, participants from public organizations and industry, alongside influential decision-makers on current topics, will discuss and explore how innovations might impact society and potential roles the geospatial community could play in this changing context, such as by providing collective visions and roadmaps towards a better future. Topics considered range from global mapping to resource and climate change monitoring, smart cities and mobilities, autonomous navigation, digital globes and geoplatforms, spatial data infrastructures, open science/sources/data and scientific reproducibility, and cultural heritage.
- Technology track sessions will showcase the very latest in technologies, products and services. To supplement oral presentations, an industry exhibition will provide space for developers to demonstrate their latest innovations. The exhibition hall will be open from the afternoon of the first conference day (Monday 6 June) up to and including the fourth conference day (Thursday 9 June).
- Youth track sessions organized by the ISPRS Student Consortium will spotlight and inspire up-and-coming talent and young professionals. The main purpose will be to link students, young researchers and professionals in different countries and continents and provide a platform for information exchange, student-centred events and other actions to integrate young people more effectively into ISPRS. For example, there will be 'speed dating' with industry and academia, a summer school and a focus on activities of bachelor's, master's and PhD students.

BRIDGING WITH INDUSTRY PROGRAMME

The XXIV edition will be the first ISPRS Congress to offer the 'Bridging with Industry' programme, aimed at consolidating and developing tighter links within ISPRS between science and industry. Mimicking the setup of the conference as a whole, the 'Bridging with Industry' programme offers two parallel tracks, specifically fora track and technology track sessions, as well as an industry exhibition. These are being designed with companies in mind, while also seeking to expand conference attendance by decision-makers, local authorities, developers, end-users and others.

The fora track will offer roundtables covering current topics from a variety of perspectives, such as societal needs, policymaking and decision-making, business models and science and technology. These will provide opportunities for insightful exchanges between decision-makers, market leaders, start-ups, leading scientists and technologists. Technology track events will offer companies a platform to present their innovations and products without the need to submit a scientific paper. These will target sales, marketing and technical staff, as well as customers and end-users.

CALL FOR PAPERS NOW OPEN

Conference organizers opened the call for papers on 1 November and will be accepting submissions until 10 January 2022. To be successful, submissions must showcase new achievements (in terms of methods, experiments and fields of application) that help shift understanding and advance the knowledge frontier. Submissions should fall within the scope of the five ISPRS Technical Commissions:

- Sensor Systems
- Photogrammetry
- Remote Sensing
- Spatial Information Science
- Education and Outreach

Alternatively, submissions may concern application-driven or method-driven contributions on topics that do not exactly

fall into the above areas. Examples include, but are not limited to:

- Geospatial information for climate change
- GIS, health and pandemic
- Perception and georeferencing for autonomous navigation
- Automated forest inventory from remote sensing sensors
- Pattern analysis and machine learning methods for scene understanding
- Deep learning and learned representations of spatial data
- Parallel and distributed computing for upscaling processing methods
- BIM, semantic modelling, development and linking of ontologies
- Quality and uncertainty modelling
- The Internet of Things, sensor web, SDI and linked data
- Digital globes, geospatial platforms, geospatial data infrastructures and Earth data cubes
- In-person and distance educational framework and training
- Open-source and reproducible science
- Geospatial data economics

Lastly, authors can submit their work to one of the following thematic sessions:

- Web-based sharing of resources for mass awareness programmes
- AI for knowledge discovery in geosciences
- CIPA (Comité International de la Photogrammétrie Architecturale)
- Cultural heritage
- Deep learning for satellite image time series analysis
- Digital twins vision papers
- New approaches in radio sciences for disaster management and remote sensing
- EuroSDR/national mapping and cadastral agencies
- Polarization remote sensing and photogrammetry
- Unsupervised and weakly supervised deep learning for Earth observation
- Simulation and visualization
- Processing of multi-satellite and bi-static synthetic-aperture radar (SAR) constellation data
- Open Geospatial Consortium (OGC) standards, driving reproducibility of scientific workflows
- Towards resilient and ubiquitous navigation
- ISPRS scientific and educational and capacity building initiatives
- Preliminary assessment of Airbus Pleiades Neo geoimagery for photogrammetric and radiometric workflows.

MORE INFORMATION

For more information on the ISPRS conference, to register or to submit an abstract: https://www.isprs2022-nice.com/


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Let's Meet Again – In Person!

The FIG e-Working Week 2021 showed that an online conference is doable, but the feedback was clear: there is a strong wish to meet in person. And we will do so in 2022… so mark your calendar now. Let us meet again from 11 to 15 September 2022 in Warsaw, the beautiful and vibrant capital city of Poland. We hope and believe that it will be possible to meet in person next September with a more 'normalized' travel situation. Until then, we have sufficient time to make all the preparations for the event, such as the call for papers, the practical arrangements, organizing a good conference programme, etc.

WHAT IS THE FIG CONGRESS? (AND WHY IS IT NOT CALLED A 'FIG WORKING WEEK', AS BEFORE?)

The FIG community meets once a year for a conference with technical sessions, meetings, discussions and for the annual General Assembly (FIG Working Week). Every four years, a new president is elected, which happens at the FIG Congress, and also two (out of four) new vice presidents are elected. The FIG Congress also marks the final year of the current president, council, commission chairs and their working groups and the finalization of their work plans and activities. This means that the FIG Congress is a larger event with more participation.

YOUR PARTICIPATION IS IMPORTANT

The chairs-elects will use the congress to plan the coming four-year term. You can join them, and this is your opportunity to influence the future of their work. Within FIG, the expression 'Surveyor' is used as a generic term comprising all occupations and professions working in conjunction with geospatial data, such as land surveyors, quantity surveyors, construction surveyors, cadastral surveyors, mining surveyors, photogrammetrists, topographers, cartographers, hydrographers, valuers, geo-informaticians, land and town planners, etc.

VOLUNTEERING FOR THE FUTURE

Surveyors have always been a solid pillar of society in Poland, and the local host – the Association of Polish Surveyors (SGP) – has just celebrated its 100th anniversary. Bringing the international surveying community to Poland is an opportunity to highlight current topics which are reflected in the overall theme: 'Volunteering for the future – Geospatial excellence for a better living'. This theme is divided into the following sub-topics:

- Surveyor 4.0 – future applications for cadastre, environmental questions, engineering and mining
- Our profession in and after COVID-19 times
- Open data and open access – are these the bullet points of the future roadmap?
- Surveying competence for other disciplines

These topics underline the significant change in our profession. Decades ago, the typical product of a land surveyor was a topographic map or a cadastral plan. In general, this product was only partly accessible and often reserved for military and state administration purposes only. This has changed radically. Today, geoinformation and all related products are seen in a much broader context and as public goods that are beneficial for the well-being and betterment of society as a whole. In addition to this, we can observe that the current geodata products are gaining in quality and are becoming increasingly available to users free of charge.

SUBMIT YOUR ABSTRACT NOW

For a chance to be part of the technical programme and proceedings, submit your abstract before the deadline of 31 January 2022 (and 2 January 2022 for peer review papers).

More information
www.fig.net/fig2022

Knowledge Transfer during the Pandemic: ISPRS Technical Commission IV

Despite the challenges of the global pandemic, members of the ISPRS Technical Commission IV are working tirelessly by organizing special journal issues, collaborating, publishing intensively, acquiring research grants and organizing workshops.

The lockdowns of the last two years have taken a toll and reduced opportunities for members of the ISPRS geospatial community to share their research findings and demonstrate their work in traditional and direct face-to-face environments. However, this lack of direct interaction and discussion has made our research community thirsty for knowledge. Being aware of these challenges, Commission IV, in collaboration with the ISPRS Student Consortium, agreed to host a webinar series leading up to the ISPRS Congress in 2022. The webinars are designed to reconnect and allow each of the working groups to showcase their work and speak about emerging topics. The webinars, which are outlined in more detail on the next page, are intended to introduce students, researchers and others from across the world to the state of the art in the geospatial sciences.

SERIES OF WEBINARS

The first webinar, organized by WG IV/1, took place in July 2021. Dr Ken Ohori and Mr Stelios Vitalis (TU Delft) gave an interesting talk on ‘CityJSON, a JSON-based encoding for storing 3D city models’. In their presentation, the speakers introduced CityJSON and used numerous examples to show both the major developments in CityJSON and the state of the art. The webinar was moderated by Dr Umit Isikdag (Mimar Sinan Fine Arts University).

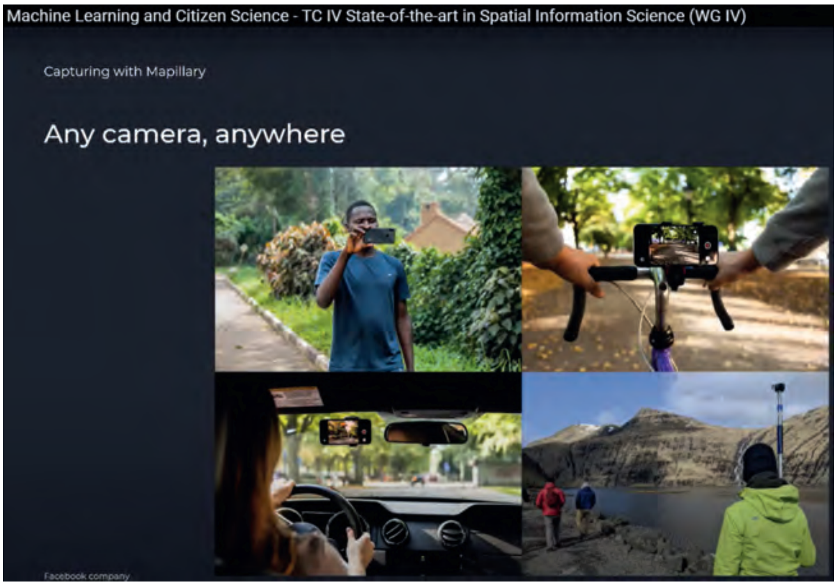
The second webinar, organized by WG IV/3, took place in September, on the subject of ‘Advances and New Directions in Spatial Statistics’. Prof Mahmoud Delavar (University of Tehran), Prof Michael Goodchild (University of California), Prof Alfred Stein (University of Twente) and Dr Gerhard Navratil (Vienna University of Technology) delivered intriguing visions, which triggered a vivid discussion with the audience.

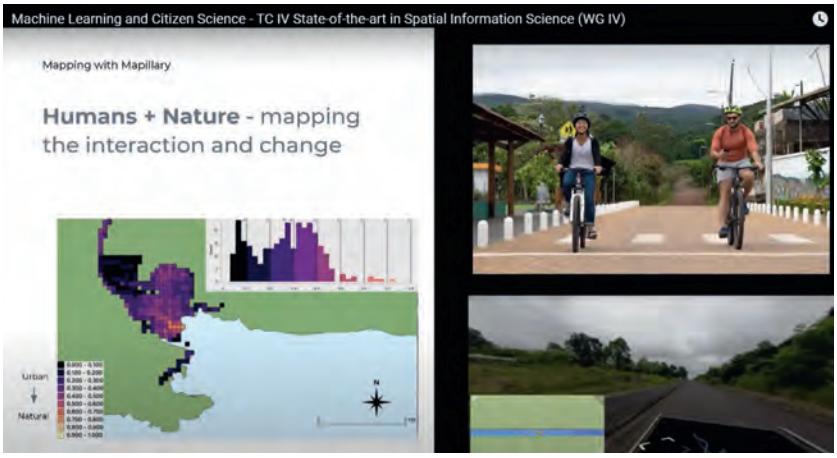
The third webinar was on 7 October, organized by WG IV/4. Sven Schade (JRC European Commission), Dr Maryam Lotfian (Politecnico di Milano) and Dr Christopher Beddow (Facebook Reality Labs) touched upon some advanced analytics within the subject of ‘Machine Learning and Citizen Science’. The talks and the discussion were moderated by Prof Maria Antonia Brovelli (Politecnico di Milano).

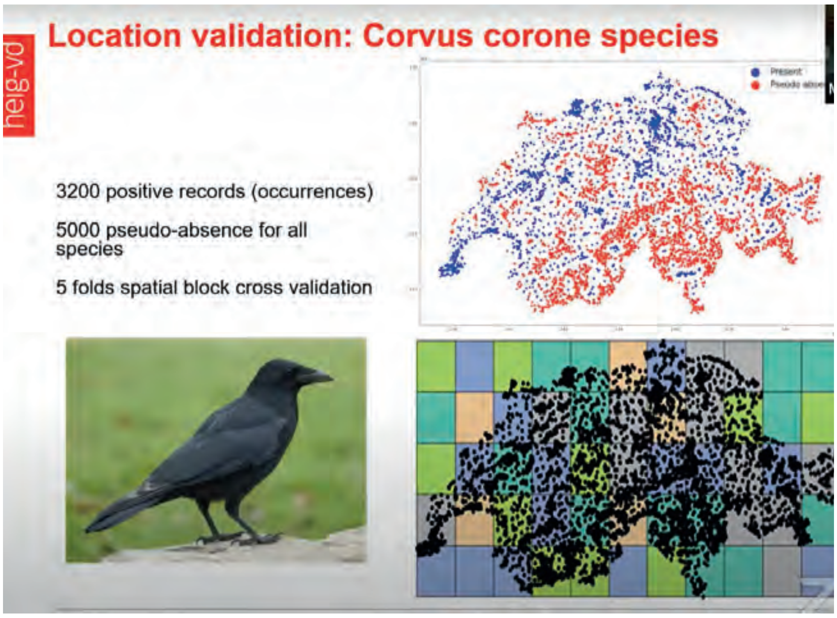
The fourth webinar was held on 4 November, organized by WG IV/5 on the subject of ‘Development of software tools for IndoorGML’.

So far, the webinars have drawn participants from across the world and many questions have been asked and exchanged. More webinars will be organized in the months ahead.

More information
Webinar recordings: https://www.youtube.com/c/ISPRSSC/videos
Upcoming webinars: https://www2.isprs.org/commissions/comm4/events/







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