GIM INTERNATIONAL

THE GLOBAL MAGAZINE FOR GEOMATICS
WWW.GIM-INTERNATIONAL.COM

ISSUE 4 2021 • VOLUME 35

Automatically Produced True Orthophotos for Large Urban Areas

Balancing Economic Costs with Aesthetic Appearance

SFM PHOTOGRAMMETRY FOR 3D TERRAIN MAPPING

THE KEY PARAMETERS OF A MODERN LIDAR SYSTEM

AUTOMATIC SEGMENTATION OF POINT CLOUDS IN ARCHITECTURE

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 ISSN 1566-9076

COVER STORY

The front cover of this issue shows Ljubljana Castle standing on a small hill in the centre of the Slovenian capital, which was the site of an inspiring true orthophoto project featured in this edition of *GIM International*. The study was conducted in a densely built-up area in the centre of Ljubljana (700m x 500m) and a suburban settlement with residential houses (500m x 400m), thus covering two typical urbanization types. The article starts on page 12. (Courtesy: Shutterstock)

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Waiting game

Despite being a hydrographic surveyor by trade, I understand geospatial surveyors' issues with point clouds all too well. Hydrography, as you may know, largely revolves around measuring depths, i.e. 'bathymetry'. Ever since joining that industry in the 1990s I have been involved in what hydrographic surveyors call multibeam bathymetry: the underwater variant of Lidar altimetry. The first instrument I used was a Reson 9001 capable of giving 60 depths per measurement ('swathe') at around 15 swathes per second. In other words, it produced around 900 depths per second. Today such systems achieve up to 1,000 depths per swathe and 60 swathes per second, totalling 60,000 depths per second. But back then, even 900 depths per second posed a big problem as far as processing was concerned. A full day of surveys would take around half a day to process using our Pentium 75 processors with 8MB of memory (which back then were state-of-the-art!). Data transfer was done using 4-speed CD-ROMs or portable hard disks of 500Mb.

Although the data was gathered as a point cloud, we could not process it that way so it was gridded using a 1x1m2 bin grid for example – and even that would tax the computer at times. Around the turn of the millennium, I got into a discussion with a software vendor who told me his software could handle big datasets without a problem. I replied that our project entailed conducting 20-minute surveys using a system that provided 256 depths per swathe at 40 swathes per second. In other words, a small survey would produce over 12 million points that needed to be visualized. Strangely enough, I never heard from that vendor again…!

Today, multibeam echosounding, Lidar or photogrammetry make those numbers seem laughable. We now have the advantage that computers have become much faster, combined with cheaper data storage on a much larger scale… and yet the problems are still the same. For example, just a few weeks ago I asked a student to prepare a presentation on photogrammetry. Since many of the students at our hydrographic college had returned from their traineeship explaining how they augmented their hydrographic surveys with drone data to connect the land and water parts, we had just purchased our first A1-class drone with a meagre 12MP camera and basic GPS/Glonass/Galileo on board. This particular student had done many such surveys during his recent traineeship on a harbour extension project and had even acquired his drone pilot licence. So to demonstrate the processing workflow, he conducted a survey of a quayside close to the college. He took around 140 photographs at 12MP, created some ground control points which he surveyed using the college's RTK system and started to process his small (max. 30-minute) survey. He ended up with a really impressive 3D model of around 12 million points, but only after a considerable wait (albeit less than half a day). The main difference between now and two decades ago is that he didn't need a state-of-the-art computer, but instead used his own trusty gaming laptop.

I had arranged for one of my PhD students to give a guest lecture to the same class. For his current thesis work on the use of artificial intelligence (AI) for detecting boulders in multibeam echosounder point clouds, he has built some software in Python and is now assessing the accuracy of his tool. He had obtained a dataset of a few million datapoints and split that up into a training set and a 'regular' set. In the guest lecture, he asked the students to help him verify the accuracy of his software by manually 'clicking' on what they thought were boulders using the hydrographic QPS Qimera cloud processing software. On their regular gaming laptops, it took them around 15 minutes for the entire dataset. He then ran his (non-optimized) software on 10% of the dataset, because that was the most his computer could handle at once. The run took around five minutes. Besides discovering that he had to fill a five-minute void of lecture time while watching the status bar slowly advance, he demonstrated that performing elaborate processing on a point cloud takes time, even today.

In conclusion, the time issues associated with processing point clouds have been around for decades, and whenever we think we are about to catch up, the boundaries shift again: new sensors, new requirements or new tools. The only solution is to keep looking for the balance between 'acceptable' processing time and customer satisfaction. When it comes to processing point cloud data, it seems we're destined to forever play the waiting game…

Huibert-Jan Lekkerkerk,
technical editor
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OGC Appoints New Members to Board of Directors

The Open Geospatial Consortium (OGC) has announced the election of Patty Mims, Javier de la Torre and Prashant Shukle to its board of directors. The new appointments bring experience in defence & intelligence, homeland security, cloud-native GIS, data science, environmental data analysis, artificial intelligence (AI), machine learning (ML), Earth observation and more. "Technology-enabled global location services offer the opportunity for us to enable solutions to improve the effectiveness and security of our global village," commented OGC Chair Jeffrey Harris. "The addition to our board of these talented and respected geospatial community leaders will add great value. Their diverse sets of experiences will inform the strategy of the consortium to help instil innovation across people and devices to speed delivery, discovery and decision-making."

▸ **https://bit.ly/3v8Cwfy**

The Role of Galileo in Sweden's CORS Network

Since the introduction of Galileo in SWEPOS, Sweden's continuously operating reference stations (CORS) network for satellite positioning, in 2018, network users have observed higher availability and better performance, especially when using a high cut-off angle or in harsh environments. Connections to the SWEPOS network have increased rapidly, and the number of Galileo users in the region continues to grow. SWEPOS was established in the early 1990s by Lantmäteriet, the Swedish mapping, cadastral and land registration authority, in cooperation with Chalmers University of Technology and Onsala Space Observatory. Over the years the SWEPOS system has been continuously upgraded and developed to meet the needs of its user community, and in February 2018, Galileo was added to the SWEPOS network RTK service. Currently operated by Lantmäteriet, the SWEPOS network numbers 472 stations, with inter-station distances of between 10km and 70km throughout the country.

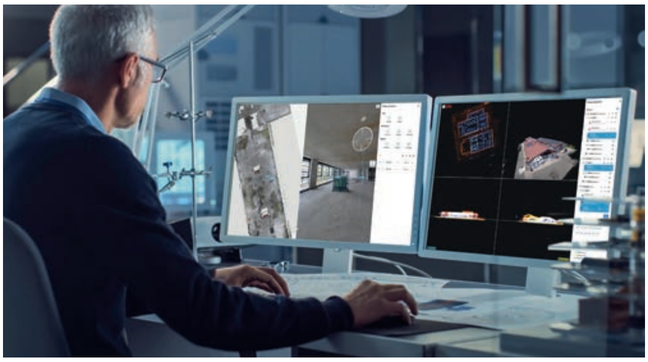
▸ **https://bit.ly/3f7kQeF**

▲ ***SWEPOS reference station test measurement in Stockholm. (Courtesy: SWEPOS)***

NavVis Launches Reality Capture Platform

NavVis has launched the NavVis IVION Core reality capture platform designed to manage 3D scans with intuitive tools for creation, collaboration and publication. The solution was previously known as NavVis IndoorViewer. Based in Germany, NavVis is an innovator in mobile mapping and reality capture. "NavVis IVION Core represents the future of reality capture software," said Lisa Cali, head of product web and cloud at NavVis. "We want to offer our users a next-generation platform that not only transforms their mobile mapping workflows but also extends them so that they can do more with their spatial data." With all the existing features of NavVis IndoorViewer, such as point cloud downloads and virtual measurements, NavVis IVION Core offers both a refreshed look together with new features and improvements.

▸ **https://bit.ly/3ubMXxn**



▲ ***NavVis IVION enables even more precision in the geographical placement of sites and scans.***

Trimble and Amberg Join Forces for Tunnel Surveying

▲ ***The collaboration provides a full-featured workflow specifically for tunnel construction surveys.***

Trimble and Amberg Technologies have entered a collaboration to provide a tunnel survey solution. The combined hardware and software solution will enable construction, mining professionals and surveying service providers in underground environments to utilize a complete field-to-office workflow for increased efficiency and productivity. The partnership is particularly focused on North, Central and South America. The Trimble and Amberg solution enables tunnel surveyors to perform a variety of underground tasks such as excavation guidance, control, automated survey and stakeout of different tunnel elements using design information. In addition, it delivers a comprehensive module for digitalization of tunnel construction and further optimization of related processes.

▸ **https://bit.ly/3hHdaBu**

First Step towards Land and Cadastral Reform in Lebanon

A major reform project in Lebanon at the cadastre and land register department level has started with the support and cooperation of the French development agency and the expertise of France, via the FEXTE project that funds technical cooperation programmes and project-preparation studies in developing countries. Despite the current situation given the COVID-19 pandemic, the Order of Surveyors and Topographers of Lebanon insists on monitoring its activities within the general framework of the profession, especially at the level of national and international partnership. A series of reforms must be tackled, as the World Bank concluded in 2018: "An accountable and transparent land administration and geospatial system will improve the management of public assets in Lebanon, including natural resources, leading to a stronger social contract and trust between citizens and the government."

▸ **https://bit.ly/3ypuGAa**

▲ *The famous Pigeon Rocks, just off the coast of Beirut, Lebanon.*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BY **MARKUS WESTPHAL**, TRIMBLE GEOSPATIAL

DIGITIZING WORKFLOWS, IMPROVING PREDICTABILITY AND REDUCING RISK

The Merging Worlds of Spatial Data and Construction

After a slow, decades-long start, the digitization of construction has finally gained a firm foothold. While it is true that digital models are often used – and sometimes required – to visualize how a building will come together, true digital construction goes well beyond mere visualization. Project owners, engineers and contractors are now looking at and adopting new ways of digitizing their own workflows and finding new ways to collaborate on projects to improve predictability and reduce risk. For surveyors looking for new opportunities in construction, these changes will likely require some new approaches to satisfy the needs of increasingly sophisticated projects and players.

Spatial information plays a significant role across construction projects, from feasibility studies through design, construction, ongoing operation and then even further through retrofit, demolition and recycling. Every component of a structure has a location. Location data is paired with other layers of information such as weight, cost and source as well as the detailed geometries expected from constructible models. When combined, this information provides far more than visualization; it provides the basis for everything from detailed fabrication instructions to analytics for better project plans, improved cost controls and optimized supply chains.

THE ROLE OF SPATIAL DATA

Against the backdrop of all this change, surveyors can stay relevant in the construction space beyond measuring property lines, setting control on a work site and recording key assets such as utilities and topography. This traditional divide between the outside and inside roles is partly the result of some surveyors' limited understanding of the capabilities of building information modelling (BIM), and partly the result of them underestimating the importance of their work. Although many surveyors acknowledge the value of BIM in the building process, they often mistakenly think the role of geospatial information in the context of building projects is limited to scanning, measuring and acquiring XYZ-type positioning data. In fact, their deliverables can provide exponentially more value downstream.

BEYOND POSITIONING DATA

As data collection becomes more efficient and sensors become more powerful, the emphasis is shifting to the office software, feature extraction and modelling automation. For those construction surveyors willing to expand their world view and their business, there is the possibility of mastering the positioning requirements of various models beyond the pure positioning data. By getting an understanding of digital construction, these surveyors can in fact better understand the end game and use that knowledge to improve on the way their work is adding to the efficiency and productivity of projects.

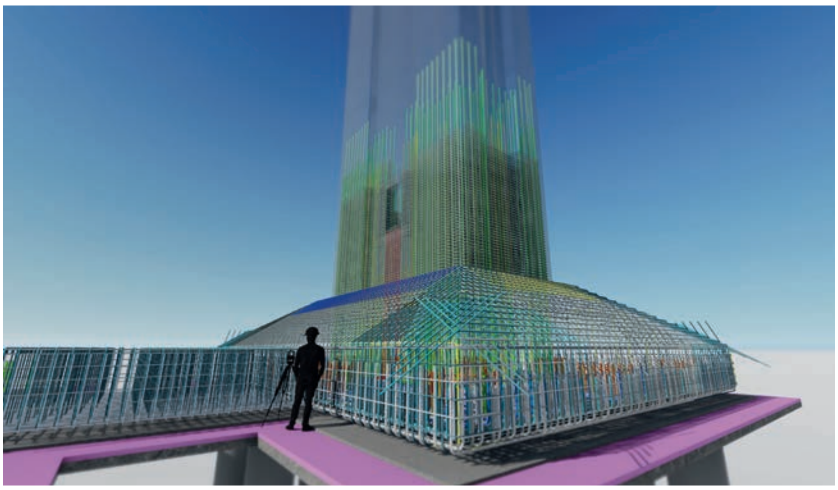
▲ *Today's augmented and mixed-reality systems allow users to not only view but also interact with what they see on a 1:1 scale.*

In an economy where the more successful companies are often industry disruptors, this may be the time for surveyors to no longer 'stay in their lane'.

ABOVE AND BEYOND

Moving forward, this group of surveyors can expand on their role in the construction process. However, they need to rely on themselves to push that agenda because, in many cases, architects or land developers still work with floor plans, building sections and facade elevations in 2D. They are either confined to their traditional ways of working or they simply have no immediate need for 3D or BIM deliverables because their existing customers do not ask for them. However, the market is now clearly moving in the direction of these technologies. By growing an understanding of construction technology, surveyors have the opportunity and the capability to provide higher-quality services and deliver more value to the construction value chain. For example, today's technologies offer the possibility to capture reality in a single project management environment that supports real-time communication between multiple stakeholders. Additionally, many BIM tools feature controls that can render extremely complex models in the field, resulting in intelligent models that promote a richer understanding of the entire scenario. Surveyors can now work directly from live models, instead of staking out or listing data points. In reality, contractors are no longer looking to just get a point cloud; they want an informed answer to their question. In other words, it is the job of surveyors to interpret data rather than just deliver it, and they too can be in the position to offer contractors that richer understanding – even if they need to work with a dedicated architecture or engineering consultancy to do so.

▲ *Trimble's XR10 VR headset enables mixed reality to be applied in construction.*



▲ *Norway's 643-metre Randselva Bridge is the world's longest bridge to be constructed using only 3D modelling.*

DOWNSTREAM VALUE

Surveyors in construction thus need to make information as intelligent and as useful as possible downstream, in the different stages of a project. Surveyors have valuable information to contribute in many of the processes in the stages before the first shovel hits the ground, such as planning, concept development, calculation, design & engineering and bidding. In those early planning stages, surveyors are traditionally tasked with putting together topographic maps and scanning site conditions, up to providing aerial photogrammetry or satellite images as part of complex, often infrastructural, projects. They can proactively provide more value with 3D visuals, illustrating the entire location in great detail, providing wider spatial awareness, documenting as-built assets and historical records. For example, having feature-rich site documentation with existing site conditions in the proposal stage allows for more efficient architectural designs, compliance with legal controls and more accurate estimates and feasibility studies.

CONSTRUCTIBLE MODEL

In the design and engineering stage, rich geospatial data generated by surveyors can help to streamline the civil design process, enabling an easier transition from a concept stage to a constructible model. By providing imaging panoramas, meshes, terrain models, utility locations (both underground and above ground) and corresponding metadata, surveyors can ensure high-quality project design. They can also help to minimize any potential rework and future requests for information (RFIs) in the construction stage in the case of discrepancies over pre-construction conditions or if surrounding assets get damaged in a later stage. Hence, a well-designed 3D model – with the right initial information provided by a surveyor – can speed up the construction process, save time and reduce waste on a job site.

MIXED REALITY

When the construction project hits the next phase, surveyors play a critical role in setting up the control network for the site, staking out the construction elements and performing the quality control, such as inspecting positional accuracies, performing verticality checks and doing real-time or campaign-based deformation monitoring. But especially in this phase, surveyors can play an essential role using BIM models in the field as a source for extracting detailed prefabrication and work drawings. In fact, there are many ways in which data from the 3D model can be accessed to provide additional insights on a job site. Over the last couple of years, the possibilities have grown from using site workstations and tablets to the latest generation of mixed-reality devices, not to mention the possibility to further enrich the 3D information with data from other sensors: GNSS, camera vision and even Lidar sensors on smartphones and tablets that enable a point map to be captured on a mobile device. So surveyors can play a major role in improving and implementing virtual and augmented reality. Mixed reality combined with laser scanners or imaging instruments can make it possible for modellers to adjust a BIM or 3D model based on just-taken scans in the field. Field connectivity and the concept of the 'connected site' play a major role in getting the most up-to-date designs to the field, as well as closing the loop once an element has been properly placed and verification becomes standard practice.

CLOUD TECHNOLOGY

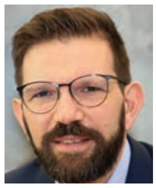
A couple of technologies come together in reducing the time needed to place models in the physical space. First of all there is cloud connectivity, which opens models up to real-time sharing between the office and the field and between the various roles on a construction project, including that of surveyor. If they are stored on cloud platforms, project models can be accessed from several different sources, including from those tools used by other trades. A second important development is the growing availability of mobile and wearable technology that can store and load data to speed the review of modelled data on the work site. Today's augmented and mixed-reality systems allow users to not only view but also interact with what they see on a 1:1 scale, so that they can compare components in the field against design and installation guidance. For example, Trimble's SiteVision lets users visualize georeferenced 3D models from any angle at true-to-life scale, above or below the ground. It features the combination of a mobile device connected to a handheld centimetre-level positioning and electronic distance measurement (EDM) system. Meanwhile, the Trimble XR10 mixed-reality device combines the power of the HoloLens 2 holographic computer and head-mounted display integrated into a hard hat. Its interface lets users make natural gestures, such as clicking with fingers, pinching the screen or moving objects on the screen, to interact with designs and their affiliated data. Users can view digital models using Trimble Connect for HoloLens and can place photos and notes in the model, which can then be fed back to the office.

OPERATION AND MAINTENANCE

In the operation/maintenance phase, stakeholders can use BIM to manage and maintain a building efficiently. For example, a 3D model integrating a surveyor's input can be used to develop an annual maintenance plan or to quickly locate parts that require repairs. Also, any changes to installations or services in the 3D model can be simulated and calculated before applying them. The surveyor's work is at the basis of delivering complete as-built scan and imaging documentation to the building's owner or operator. This collection of additional metadata can be published and shared on a local intranet or website, providing additional value for facility managers, site occupants, owners or potential buyers.

Technology is making tremendous headway in connecting people and information. Surveyors, architects, designers, contractors, engineers, owners and operators are all coming to rely on this one view of reality: a model of the built environment that can deliver the information they are looking for in their role. The surveying community can play a bigger role in the lifecycle of any built asset by providing richer, more valuable and insightful information during a larger part of the building process. ◂

ABOUT THE AUTHOR



Markus Westphal is a sales account manager at Trimble Geospatial and is responsible for looking after the dealer network in Germany, Austria and Switzerland. He is a geographer and journalist by trade and has over ten years' sales experience in the surveying, GIS mapping and drone businesses.

BALANCING ECONOMIC COSTS WITH AESTHETIC APPEARANCE

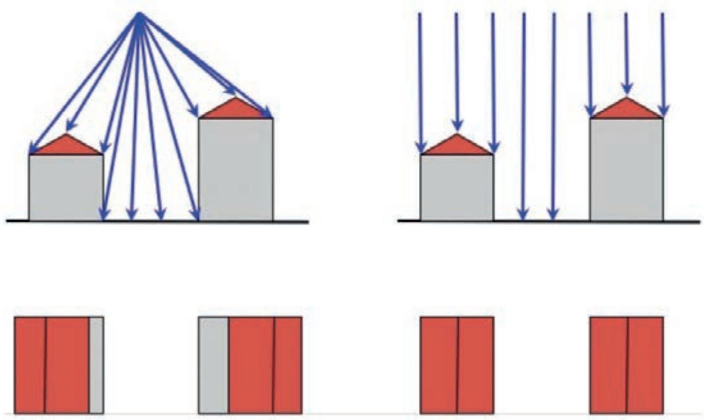
Automatically Produced True Orthophotos for Large Urban Areas

In orthophoto projects of dense urban areas, true orthophotos are preferred over traditional orthophotos because they put building roofs into the correct horizontal position. However, there is still a widespread belief that the production of a true orthophoto is expensive and demanding. The authors set out to explore whether that really is the case based on a study of the production of a true orthophoto of the Municipality of Ljubljana, Slovenia.

Before producing a true orthophoto for the entire municipality of Ljubljana, Slovenia, the authors first tested various approaches in a smaller area in order to find the most economical workflow. One approach used a combination of a digital terrain model and a vector digital building model, and another approach used an automatically generated digital surface model. The resulting orthophotos were then compared against a traditional orthophoto in terms of aesthetic appearance and the manual work needed. Based on the findings, the team decided to use a true orthophoto based on an automatically generated digital surface model. The case study and the final project are outlined below.

DIFFERENCES BETWEEN TRADITIONAL AND TRUE ORTHOPHOTOS

An orthophoto is a photo or an image that is corrected for projection distortions. It has a defined scale and can be used similarly as a planimetric map. Orthophoto projects aim to deliver a seamless orthophoto mosaic produced from single rectified images. To produce an orthophoto, georeferenced aerial images and a digital reference surface model are needed. Traditional orthophotos have been produced worldwide for more than 30 years, being an indispensable data layer in many GIS applications. In traditional orthophoto production, the reference surface is a digital terrain model. As a consequence, objects above the terrain (e.g. buildings, vegetation) are not depicted in the correct horizontal position (Figure 1). In true orthophoto production, a digital building model is considered in built areas, or a digital surface model including vegetation cover is used. In true orthophoto production, the algorithms have to solve two main problems: detection of hidden areas caused by the objects above the terrain in the original image, and prevention of double mapping in these areas. To fill in the missing content in the hidden areas, image overlapping must be at least 50% in both directions.



▲ *Figure 1: Depiction of buildings in a traditional orthophoto (left) and a true orthophoto (right).*

STUDY AREA AND INPUT DATA

The study area was composed of a densely built-up area in the centre of Ljubljana (700m x 500m) and a suburban settlement with residential houses (500m x 400m), thus covering two typical urbanization types. Georeferenced aerial images of 10cm ground sample distance (GSD) and 70%/50% overlapping, as well as a Lidar point cloud with a density of 18 points/m^2 were the main input data. Both datasets were collected in the same aerial survey in April 2019. From a classified point cloud, a digital terrain model and a digital building model were produced (using TerraScan and TerraModeler by TerraSolid). A vector digital building model was first created automatically, but a lot of additional manual work was needed to improve the model due to complex building envelopes in the old city centre. If the edges of roofs are not defined accurately, double mapping occurs in the orthophoto (Figure 2).

THE RESULTS

A traditional orthophoto (in TerraPhoto) and two versions of a true orthophoto were generated from aerial images and a digital terrain model. In the first version, a combination of a digital terrain model and the previously described vector digital building model (in TerraPhoto) was used. The second version was produced in an almost completely automatic procedure in the nFrames SURE software. A digital surface model in the form of an irregular triangulated network was generated from a photogrammetric point cloud, produced with an image matching algorithm. Figure 3 clearly shows the advantages of a true orthophoto over a traditional orthophoto.

In addition, a visual comparison of both versions of the true orthophoto revealed only small differences in the roof edges. In the version based on the automatically produced digital surface model, the roof edges are slightly serrated which is a negligible shortcoming in the otherwise good overall aesthetic quality (Figure 4). One advantage of a true orthophoto produced from a digital surface model is that trees are depicted in the horizontally correct position (Figure 5).

Based on an estimation of the manual work needed in the production of each orthophoto type, the team concluded that the most labour-intensive approach is the production of a true orthophoto based on a combination of a digital

Figure 2: Examples of double mapping in the true orthophoto as a consequence of inaccurately defined roof edges.

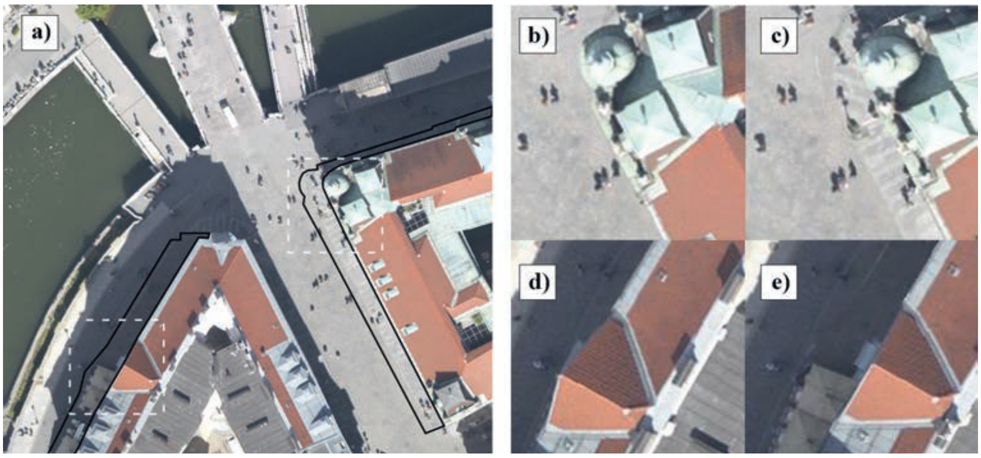


Figure 3: Comparison of a true orthophoto, shown in (a), (c) and (e), with a traditional orthophoto, shown in (b) and (d). Black polygons in (a) define hidden areas in the traditional orthophoto. The three bridges in the centre of Ljubljana are visible in the upper left corner of (a).

terrain model and a vector digital building model. This requires approximately two times more manual work than the production of a traditional orthophoto. On the other hand, an automatically produced true orthophoto takes around 25% less time to produce than a traditional orthophoto. After considering all these aspects, the authors decided to apply the automatic true orthophoto production line in the operational project.

A TRUE ORTHOPHOTO FOR LJUBLJANA

Ljubljana, the capital city of Slovenia, has around 290,000 inhabitants and comprises an area of around 275km^2. Like any large city exposed to rapid changes in urbanization, the municipality requires up-to-date geodata for decision-making purposes. At the national level in Slovenia, a traditional orthophoto is available every three years in 25cm GSD. However, this product does not suit the needs of the Municipality of Ljubljana. In 2020, the municipality therefore funded the production of a true orthophoto mosaic, which was carried out by Flycom Technologies. Aerial data collection was done in April 2020 with image overlapping 80%/60% (and 80%/80% in the centre of the city), with 5cm GSD.

Figure 4: Visual comparison of true orthophotos: (a) and (c) are produced from a vectorized building model, while (b) and (d) are produced from a digital surface model.

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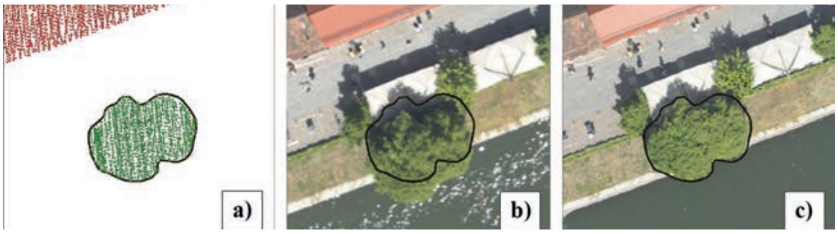
After accomplishing aerial triangulation of images (in Match-AT by Trimble Inpho), a true orthophoto was produced (in SURE) based on a digital surface model (Figure 6). The estimated horizontal accuracy, calculated from the ground checkpoints, was 0.04m in both X and Y directions. As an example of data visualization, a photo-rendered 3D mesh of the city centre was created from nadir images (Figure 7). Based on these good results, the Municipality of Ljubljana has decided to finance the annual production of a true orthophoto from now on.

CONCLUSION

The success of this large-scale project shows that the automatic production of a true orthophoto is already fully operational in real life. The resulting true orthophoto mosaic is of good quality and requires much less manual work than other approaches, thus enabling a substantial portion of the final project costs to be saved. Needless to say, such an approach requires appropriate software, powerful computers and investment in staff education. However, these initial investments can be quickly recouped in the subsequent projects. The authors are keen to point out that a true orthophoto requires a larger overlapping of aerial images than a traditional orthophoto. However, this cost represents only a small portion of the final costs. Considering all the aspects discussed here, the authors conclude that there is no reason not to produce a true orthophoto in an almost fully automatic way in urban areas. ◂



▲ *Figure 5: Horizontal position of a tree: (a) vectorized from the point cloud, (b) in a true orthophoto produced from a vectorized building model, (c) in a true orthophoto produced from a digital surface model.*

▲ *Figure 6: A section of the final true orthophoto mosaic of Ljubljana city centre (in 2020).*

▲ *Figure 7: Photo-rendered 3D mesh of Ljubljana city centre (in 2020).*

FURTHER READING

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ACKNOWLEDGEMENTS

This case study was partly funded by the Slovenian Research Agency core funding (No. P2-0406 Earth observation and geoinformatics). The authors would like to thank Flycom Technologies for data and technical resources as well as the Municipality of Ljubljana for permission to publish the results.

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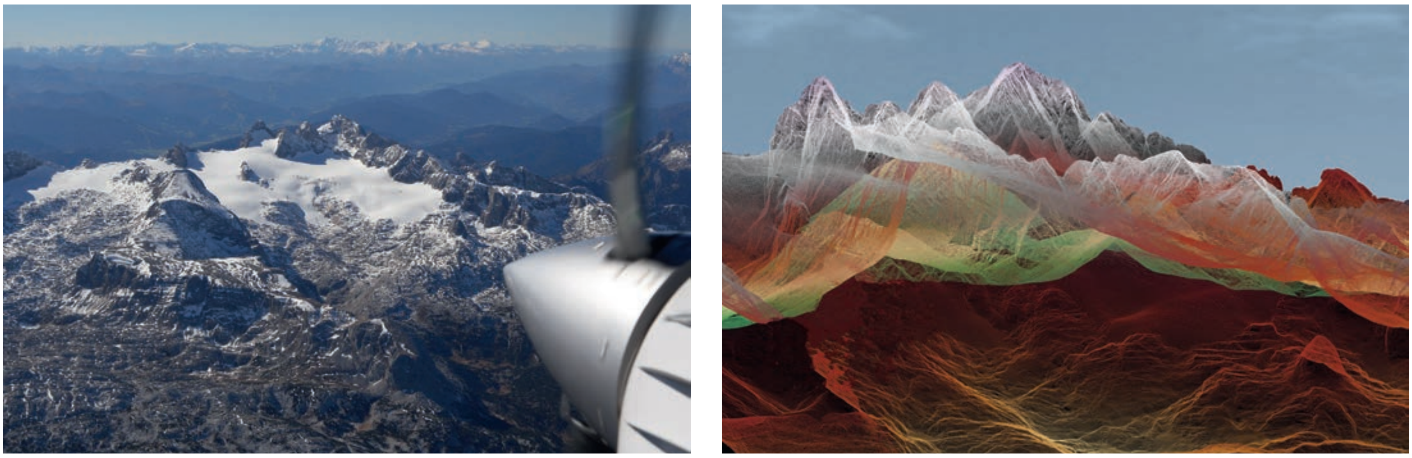
HOW INNOVATIONS IN MEASUREMENT TECHNOLOGY ARE FACILITATING THE WORK OF SURVEYORS

The Key Parameters of a Modern Lidar System

In the past, the effort of hardware integration and the necessary combination of different software tools was a major hurdle to gain a foothold in the field of laser scanning. This hurdle has now been removed, allowing users to focus on data acquisition and data analysis – the 'real work' of a surveyor. But what are the key parameters for a modern Lidar system?

State-of-the art Lidar systems are fully integrated sensor platforms, typically comprising one or more laser scanners, digital cameras of different spectral ranges, inertial measurement units coupled with global navigation satellite system receivers, flight guidance systems and more. But a Lidar system is much more than just the hardware. Nowadays it includes means and measures for determining the optimal configuration of system parameters and flight planning tools to maximize productivity, easy-to-use software for the operator that provides direct in-flight feedback on system status and the quality of collected data and, last but not least, comprehensive data post-processing software. Since the mid-1990s, the development of laser scanning seems to have been following the Olympic motto: 'Citius, Altius, Fortius' (faster, higher, stronger). In the end, however, it's not just about a race between laser scanner manufacturers, but primarily about demanding customers and their requirements to measure ever-larger areas efficiently and cost-effectively with the aim of delivering scan data of constantly increasing resolution and accuracy.

▲ *A fully certified RIEGL company aircraft (a Cessna 206 with a RIEGL VQ-1560-II installed) ready for a calibration flight.*



▲ *The RIEGL VQ-1560II-S dual-channel waveform processing airborne Lidar scanning system is used for wide-area scanning of complex mountainous terrain.*

TECHNOLOGICAL EVOLUTION

The remarkable evolution of laser technology in the last 15 to 20 years, especially in the field of fibre-amplified semiconductor lasers, has enabled an increase in achievable pulse repetition rates for time-of-flight linear Lidar sensors from about 50kHz in the past to up to 2MHz today. For example, a typical airborne laser scanning mission operating at 1,000m AGL (3,300ft) and at a flying speed of 100 knots would result in average point densities of a mere 0.5 points per square metre for the vintage 50kHz scan, and a remarkable 22.5 points/m² for the state-of-the art 2MHz scan.

WAVEFORM ANALYSIS

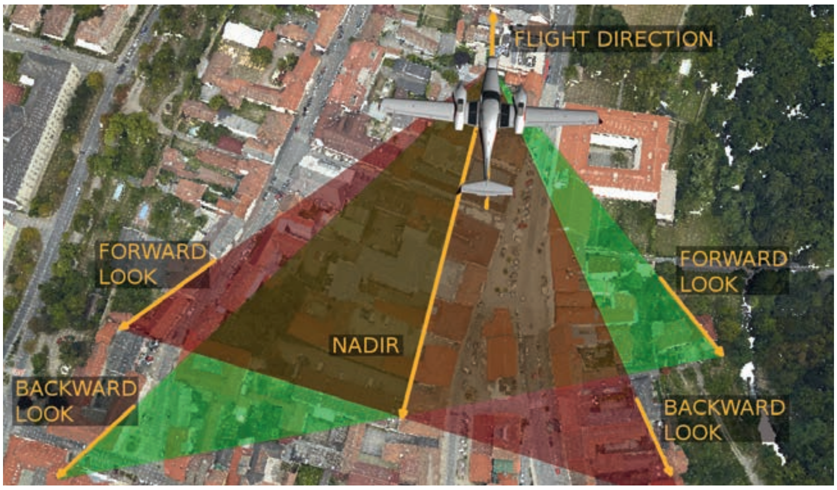
When it was introduced in 2004, the RIEGL LMS-Q560 airborne laser scanner was the first instrument with 'echo digitization and waveform recording' capability, a technology that is now standard and considered a 'must have' in any professional laser scanner sold on the market. Full waveform analysis is the key to high measurement accuracy, excellent multi-target capability and the ability to specify additional target attributes such as calibrated amplitude and reflectance, as well as pulse width. All of this required recording of massive amounts of waveform data and demanding data post-processing in the past. Nowadays, the use of waveform Lidar technology in real time significantly reduces the amount of recorded data and minimizes processing time while maintaining information content and improving measurement performance.

RESOLVING RANGE AMBIGUITIES

The availability of laser sources offering high repetition rates combined with high power opened up a new problem area: the appearance of range ambiguities caused by 'multiple-time-around' (MTA) echoes. Due to the high pulse repetition rate, a large number of laser pulses are constantly moving along the path between the transmitter, the target and the receiver. Without additional measures, an echo cannot be definitely assigned to a laser pulse emission – the measurement range remains ambiguous. In 2011, RIEGL introduced a novel technique based on a specific modulation scheme applied to the transmit pulse train, which allows range ambiguities to be resolved without any additional information necessary. This method is indispensable today; with more than 30 laser pulses simultaneously in the air from an exemplary operating altitude of 1,800m and a pulse repetition rate of 2MHz, it resolves range ambiguities and allows gap-less data recovery over the whole measurement range.

SCANNING MECHANISMS

Last but not least, the scanning mechanism applied plays a central role in multiple aspects of airborne laser scanning. First and foremost, it defines the achievable point distribution and point pattern. Obtaining a regular and even point spacing over the whole swath is crucial for capturing surface details without missing objects in between individual measurements or scan lines. For that purpose, RIEGL airborne laser scanners make use of rotating polygon or prism mirror wheels. This offers a second advantage, namely the flexibility in choosing various scanner configurations optimized for their specific applications – from single-channel airborne laser scanners with a regular point and scan line spacing to more specific dual-channel systems featuring a 'crossfire' scan pattern minimizing shadowing effects, or even miniaturized single-channel scanners for use on unmanned aerial vehicles (UAVs or 'drones') with parallel scan lines and a nadir/forward/backward-looking (NFB) capability at the same time. Lastly, the continuously rotating mirror wheels enable easy control of a wide range of scan speeds to maintain consistent and regular point spacing ▶



▲ *Using the appropriate scanning mechanisms is crucial for specific applications. The 'crossfire' scan pattern of the VQ-1560 series minimizes shadowing effects in urban terrain with narrow street canyons.*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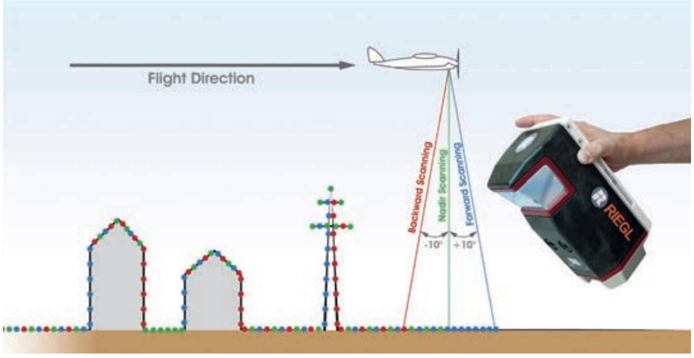


▲ *The RIEGL VUX-120 obtains optimum coverage of vertical structures thanks to the nadir/forward/backward (NFB) scanning technique.*

▲ *A high-resolution scan with more than 50 pts/m² in a single pass, acquired with the VQ-1560-II from an altitude of 770m AGL at a speed of 120kn.*

(regardless of air speed, altitude or pulse repetition rate), a constant wide field of view and remarkable mechanical stability, which is essential for long-lasting system calibration and geometric accuracy of measurements.

FUTURE OUTLOOK

Based on the currently available technologies, a further increase of the maximum measurement range as well as of the measurement rate and the accuracy is only possible with difficulty. Any further increase in pulse repetition rate is already getting close to the physical limits – not only with regard to laser technology, but also to the techniques of resolving range ambiguities with a spatial laser pulse spacing already in the order of the magnitude of the object heights to be measured. With respect to a possible increase of laser power, eye safety regulations are a limiting factor. As the energy density on the ground is limited, a further increase of laser power would require higher flying altitudes, which in turn would lead to larger laser footprints, resulting in a lower spatial resolution. Moreover, adverse atmospheric effects play a significant role in the measurement error budget when scanning from high altitudes.

These challenges provide plenty of incentive for new ideas and innovative advancements. One such attempt in recent years has been the further development of Geiger mode and single photon-counting Lidar sensors for the civilian market, which were previously used for military purposes only. Following new technical approaches, the principle was to reduce the number of photons used for range finding as much as possible, enabling unprecedented flight altitude and thus optimum area yield. Multiple measurements from different angles on the same spot should yield high point density with sufficient accuracy at the same time. From the user's practical point of view, this principle suffers from the same weaknesses as the common methods used in photogrammetry which also relies on sufficiently large image overlap: the multi-target capability and thus the penetration of vegetation to create terrain models is poor to impossible, not to mention the extensive efforts of data preparation. With regard to the detrimental influence of high altitudes on the achievable measurement accuracy, the aforementioned applies equally to all types of Lidar, whether it is Geiger, single photon-counting or linear Lidar.

INCREASING AREA YIELD

A principle drive for future developments is the further increase of area yield and thus the efficiency of data acquisition while maintaining optimal point distribution on the ground. Linear Lidar, and more specifically waveform processing Lidar, will continue to be the technology of choice for providing unparalleled measurement accuracy, low ranging noise and the availability of target attributes such as height-independent calibrated reflectivity and pulse shape deviation.

UAV-LIDAR MAPPING

Unmanned laser scanning is expected to grow significantly in the near future, with the rapid development of the UAV market driving innovation in Lidar measurement technology. Users of laser scanning systems operated on unmanned platforms expect the well-known high data quality, accuracy and similar information content of the measurements of a manned airborne laser scanning (ALS) system. Therefore, almost all known techniques for airborne laser scanners as mentioned here have been adapted or adopted to the primary requirements of unmanned laser scanning – low weight, small dimensions and high energy efficiency – at an early stage. Remarkable miniaturization has led to instruments weighing less than 2kg and operating at up to 1.8MHz pulse repetition rates, which provide survey-grade accuracies of about 1cm (1sigma) from flying altitudes of more than 135m (450ft). In turn, the newly developed manufacturing methods and the use of state-of-the-art lightweight materials are stimulating the development of new and innovative instruments for manned airborne laser scanning. All these innovations in the field of measurement technology are accompanied by immense efficiency gains through the latest developments in software algorithms, as well as simplified data evaluation and processing, which facilitate the work of surveyors. ◀

ABOUT THE AUTHORS

Peter Rieger is manager of the Business Division for Airborne Laser Scanning of RIEGL Laser Measurement Systems located in Horn, Austria. He received an MSc in Telecommunications Engineering from the Vienna University of Technology in 2002. His research interests cover ranging techniques in scanning Lidar, with emphasis on methods for resolving range ambiguities, full waveform analysis and inertial navigation/GNSS.

Dr Andreas Ullrich is chief technical officer and managing director of RIEGL Laser Measurement Systems, where he has been working since 1991. He holds a PhD in Electrical Engineering from Vienna University of Technology and wrote a thesis on 'High-Resolution Optical Doppler Radar' (1987-1990). Since 2001 he has been a lecturer on radar technology at the Institute of Communications and Radio-Frequency Engineering at Vienna University of Technology.

ACCURACY ASSESSMENT USING RTK-BASED POINT-TO-POINT VALIDATION METHOD

SfM Photogrammetry for 3D Terrain Mapping

The technique known as structure from motion (SfM) has been suggested as a valid alternative to traditional photogrammetric methods. In a project in Glasgow, UK, an RTK-based point-to-point validation technique based on two sets of randomly selected ground control points was used to assess the geometric accuracy of SfM technology for 3D terrain mapping over a small area.

SfM photogrammetry is an image processing technique that allows the reconstruction of accurate 3D models from overlapping successive photographs taken from cameras at various angles with or without ground control points (GCPs). These models are not only appealing but also contain spatial information, the quality and accuracy of which depend on both the acquisition method and the processing procedures.

THE FLYING HEIGHT OF 60M CAPTURED A HIGH-RESOLUTION DATASET WHILST KEEPING THE DRONE CLEAR OF THE TREES

The accuracy of an SfM-derived model can be assessed either by comparing it with a reference model or by measuring the deviation of the control points identified on the model. The measurements are taken using classic topographic survey methods and survey instruments of higher accuracy. To contribute to the knowledge of applicability, a real-time kinematic (RTK)-based point-to-point validation technique based on two sets of randomly selected GCPs has been used to assess the geometric accuracy of SfM technology for 3D terrain mapping over a small area.

RTK GNSS SURVEY

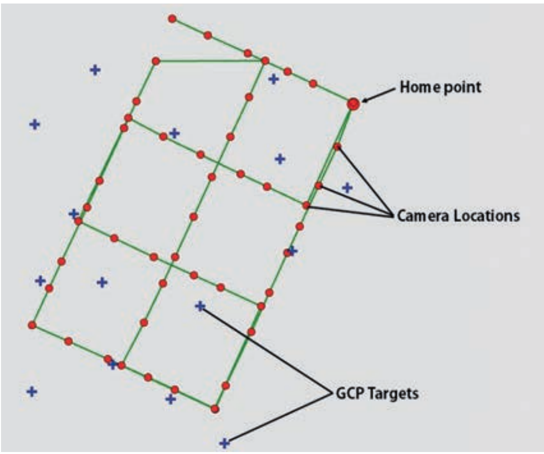
A total of 15 targets (GCPs) were evenly distributed and coordinated in the study area in Glasgow, UK (Figure 1) using Leica network RTK global navigation satellite system (GNSS). The coordination of the targets was linked to the GLAS continuously operating reference station (CORS) via Smartnet. Typically, network RTK solutions within the United Kingdom provide instantaneous results (that is, single epoch coordinate solutions) that achieve root mean square accuracies of around 10-20mm in horizontal position (XY) and 20-40mm in elevation (Z), with relatively small biases. The horizontal positional accuracy obtained from the GNSS RTK survey of the targets ranges from 5.1mm to 11.3mm while the elevation accuracy ranges from 9.2mm to 18.4mm. This result clearly shows a high level of accuracy and good data quality. Therefore, it was considered to be fit for purpose as reference data.

THE DRONE SURVEY

For data collection using an unmanned aerial vehicle (UAV or 'drone'), a DJI Phantom 3 Professional equipped with a focal length of 20mm (35mm equivalent) and a sensor of 12.76 megapixels was used. The flight path was predefined on the drone mapping software. The home point of the drone was set from a zero base at one point and the images were captured in sequence according to the grid pattern shown in Figure 1 in order to ensure good coverage and visibility. At a flying altitude of 60m above ground level and an optimum overlap (75% front and 65% side overlap), the system captured 49 images in a single flight over an area measuring 153m in length and 129m in width. The flying height of 60m was chosen to ensure that a high-resolution dataset was captured whilst avoiding any interference of the drone with the surrounding trees. This also enabled the optimum acquisition of photos and minimized the processing time. All the images captured were geolocated and a ground sampling distance of 2.63cm was achieved.

DATA PROCESSING (SFM WORKFLOW)

The data processing was done using Pix4D Mapper Pro software. The processing workflow started with the initial processing that handles the image alignment and



▲ *Figure 1: Flight plan showing GCPs (targets) and camera locations in the study area, with the green line following the position of the cameras starting from the home point.*

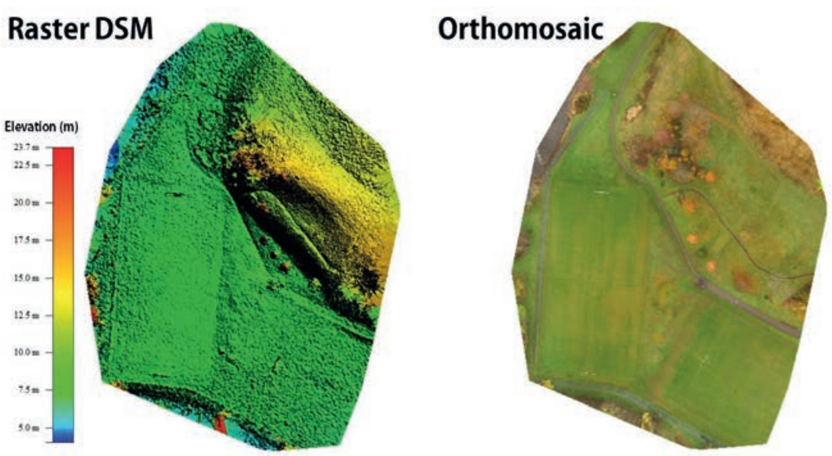
produces sparse point clouds. For this project, half image size was selected for two reasons: (i) to reduce the processing time, and (ii) to address the low texture in the captured images to improve the outputs. The 15 GCPs were imported and matched (georeferenced) using the rayCloud Editor menu available within Pix4D. The processing report revealed that the georeferencing accuracy was within acceptable limits (with mean RMSE of 27mm). The next stage was the point cloud densification. Here, a resampling to a quarter of the original resolution was used based on the recommendation for projects with vegetation. For each input image, a final point cloud was automatically saved to Lidar file format (.las) as selected during the initial processing stage, which is one of the most common formats for exchanging point clouds. Finally, both the raster DSM and orthomosaic were generated and the tiles were merged and saved in a lossless compression format of GeoTiff (.tif) to help preserve the image quality (Figure 2).

VALIDATION TEST

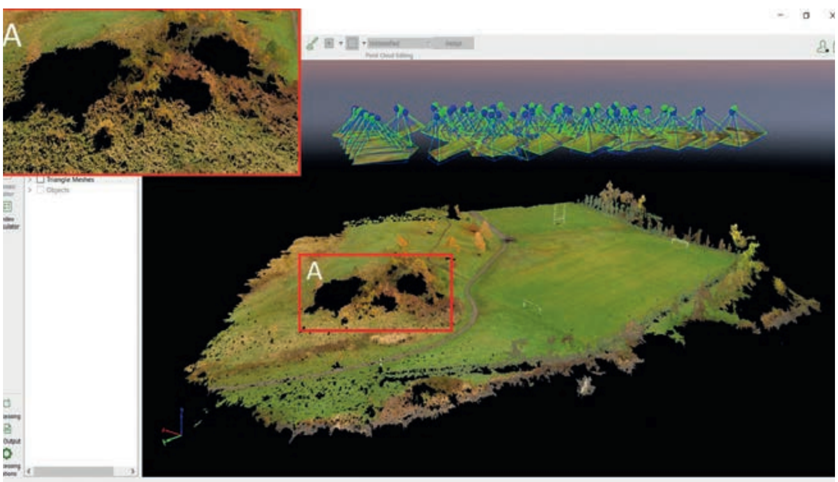
There are three known validation methods for SfM data points: i) point to point (data points that compare two point clouds directly), ii) point to raster (data points that compare SfM-derived rasters such as DSMs with points from topographic data, e.g. GNSS and total stations, and iii) raster to raster (data points that compare SfM-derived DSMs with equivalent raster-based data products derived from another survey technique such as terrestrial laser scanning). However, the choice of validation method is dependent on the available reference data. Since the reference dataset was based on the RTK GNSS-derived coordinates of the target cross-hair, a point-to-point validation method was adopted. The point-to-point validation was done in two ways; firstly by using five of the GCPs as checkpoints, and secondly by using the remaining ten. This was done to evaluate the influence of the number of checkpoints on the root mean square errors (RMSEs) obtained. At this project's flying altitude of 60m, the expected RMSE for a point-to-point validation is 80mm. The results obtained when ten checkpoints were used fell within the expected range (20.93mm, 18.48mm and 46.05mm in the X, Y and Z coordinates respectively). However, when five checkpoints were used, slightly higher RMSEs were obtained (45.90mm, 22.27mm and 75.26mm in the X, Y and Z coordinates respectively).

3D POINT CLOUD RECONSTRUCTION

The point cloud densification operation achieved 3,386,259 points with an average density of 140.46 points per m^2. The 3D point cloud produced is shown in Figure 3. This result is very interesting given the level of detail shown. However, as seen in the inset (A), there were some black areas (gaps) caused by shadows from some



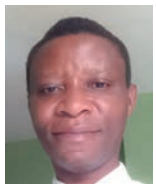
▲ *Figure 2: Digital surface model (DSM) and orthomosaic generated in the study area.*



▲ *Figure 3: 3D point cloud reconstruction showing the gaps in the study area.*

ABOUT THE AUTHORS

Chima Iheaturu is the GIS and database manager for the Wildlife Conservation Society, Nigeria. He holds a bachelor's degree in Surveying & Geoinformatics and an MSc in Geospatial & Mapping Sciences from the University of Glasgow, UK. His current research interest involves using novel geospatial technology to facilitate wildlife conservation activities in Nigeria.



Dr Emmanuel Ayodele obtained a PhD in Civil Engineering (Transport) from the School of Engineering, Newcastle University, UK, with a thesis on the application of Bluetooth wireless communication and technological approaches to intelligent traffic monitoring and management. His broad-based background has been applied in solving many problems ranging from engineering surveying and construction to hydrography, geophysical prospecting, traffic management and road safety. He is currently a lecturer at the University of Lagos, Nigeria.

Chukwuma Okolie is a lecturer at the Department of Surveying and Geoinformatics, University of Lagos. His research interests are GIS and remote sensing applications, data fusion and environmental modelling. The focus of his PhD research at the Geomatics Division, University of Cape Town, is the application of machine learning for digital elevation model fusion.

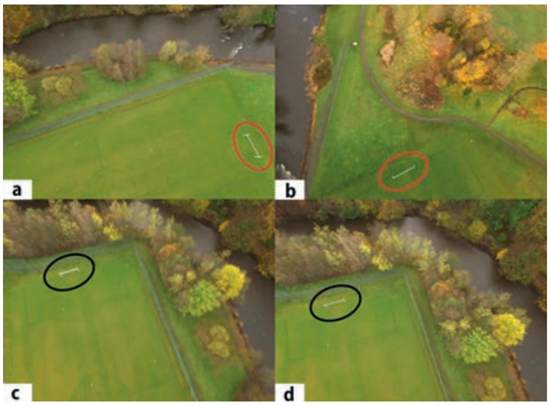
trees. The gaps occurred in those areas due to insufficient camera viewpoints. This implies that better results can be achieved if some of the initial parameters such as the overlap (front and side) and the flying height (60m) are varied. However, these variations may also be at the expense of the storage capability and the processing speed due to the large volume of data that will be involved. Nonetheless, the principle of economy of accuracy – that is, establishing a balance between cost and accuracy – is expected in every project. Thus, it was also considered in this study.

CONCLUSION

This article has examined the application of SfM photogrammetry for 3D terrain mapping. Essentially, the point-to-point method of validation using the RTK GNSS derived coordinates was employed to understand the achievable accuracy of SfM technology. Relevant factors such as overlap, the flying height and ground control points were considered in the assessment. The validation tests suggest that higher numbers of checkpoints, evenly distributed within the study area, could increase the accuracy of the model. However, further analysis would be required to test not only the influence of the number of ground control points on the accuracy, but also their configuration. To avoid black areas (gaps) in the model, it is imperative to have many camera viewpoints and an adequate number of GCPs distributed evenly within the area of interest. Generally, it is to be noted in line with literature that the quality of the data captured is dependent on the methodology adopted and should be taken into consideration.

ACKNOWLEDGEMENTS

The authors are grateful to the School of Geographical and Earth Sciences, University of Glasgow, where the fieldwork for this article was conducted as part of coursework in the Geospatial and Mapping Sciences programme. A special thanks and appreciation go to Pix4D Support who made their help files freely available and accessible. ◂



▴ *A cross-section of images captured during the UAV survey showing different views of the rugby pitch and the adjoining Kelvin River. The red and black circles show regions of overlap between images a and b, and c and d respectively.*

FURTHER READING

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BRINGING A NEW DIMENSION TO VISUALIZATION AND ANALYSIS

Improving Efficiencies with Panoramic Basemaps

Basemap imagery offerings have been relegated to vertical and oblique visualization for decades, but a new basemap now combines 360-degree aerial imagery and precise location data. Providing an immersive new way to view and experience the built world from every cardinal direction, it is garnering considerable attention in the GIS world. Utilizing an immersive basemap allows for an unparalleled level of actionable area familiarization and precise detail for analysis. Moreover, it is the most intuitive way to visualize data.

Aerial imagery is much more than just a picture from above; it provides a different perspective of what can be seen on the ground. Aerial imagery encompasses everything from photographs that were taken from hot-air balloons in the 19th century to modern aerial photography captured from an airborne craft, excluding satellite imagery. Although aerial photography was initially little used because of the high cost and risk, the introduction of powered flight and – more recently – unmanned aerial vehicles (UAVs or 'drones') has changed everything. Aerial imagery is now used by almost every industry in some way, shape or form – whether for planning, reconnaissance, mapping, analysis, development and/or education. From a public-sector perspective, aerial imagery is critical for government functions in maintaining civil society and providing economic, social and environmental sustainability.

Figure 1: Example of a vertical image. (Courtesy: Google Earth)

VERTICAL/ORTHOGONAL IMAGERY

The most familiar form of an aerial photograph is vertical photography, which is used on real-estate websites or in apps that users can zoom in and out when looking at properties from above. They offer the ability to zoom in and out. They can also be scaled, allowing objects and distances to be measured for identification purposes. The images are captured directly over a project or area, whereby the camera lens is perpendicular to the ground (pointing straight down). Vertical images are excellent for making measurements, displaying wide areas of land, street views, detailed analysis and as an overall map substitute. What vertical imagery lacks is height-of-ground perspective which makes it difficult to interpret ground

WHAT IS A BASEMAP?

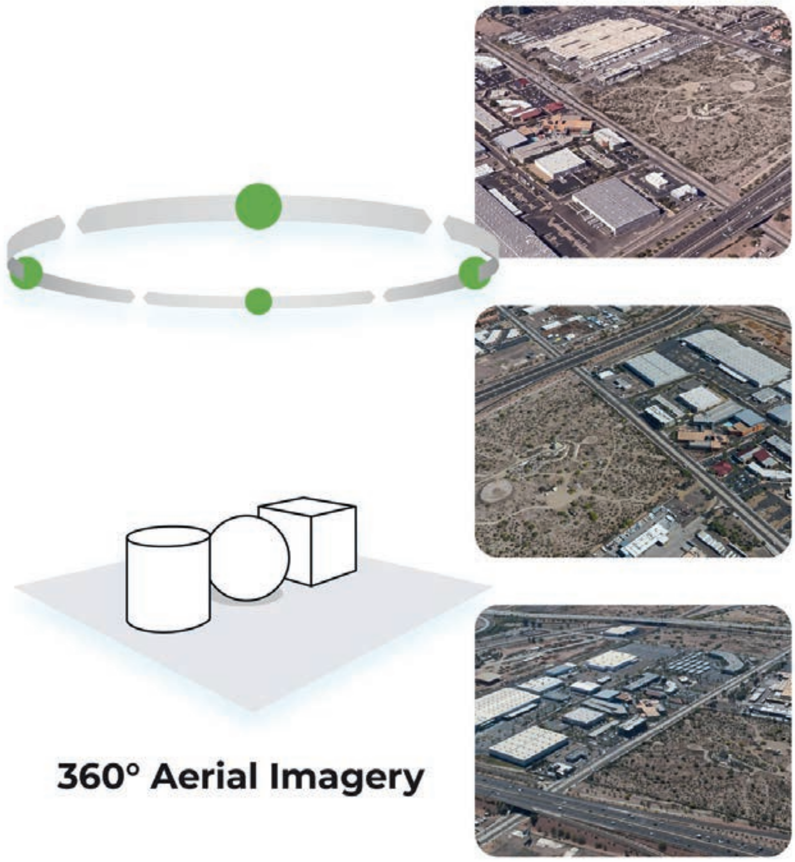
The term 'basemap' is commonly used in the geographical information systems (GIS) world and refers to a collection of GIS data and/or ortho-rectified imagery forming the background detail and providing context for a map and its users for orientation purposes. For example, clicking on the 'satellite' option on a digital map will display a vertical imagery basemap. From Google Maps to Zillow, many consumer applications leverage basemaps to better acquaint users with their location.

truth of a vertical image – with little or no relief, there will always be a divergence between what can be interpreted from the image and the actual situation on the ground.

OBLIQUE IMAGERY

The use of oblique imagery has become a standard in basemaps in many civil and mapping applications thanks to the ability to easily capture imagery from manned and unmanned aerial vehicles. Oblique imagery is typically collected at an angle of 20-45° to the ground (anything tilted more than three degrees is considered oblique.) This angle allows viewers to see and measure not only the top of an object, but the sides as well.

▲ *Figure 2: Example of an oblique image. (Courtesy: Bing)*



▲ *Figure 3: 360° aerial imagery gives perspectives from every cardinal direction with full pan and tilt capabilities.*

Compared to traditional vertical imagery, oblique views are more associative of what is seen from the ground, thus making it easier for non-expert users to interpret data from the imagery. Oblique photographs are helpful to reveal the topography in relief, which is useful for identifying geological or archaeological features.

There are two distinct types of oblique aerial photographs: high obliques and low obliques. Both types can further be categorized as wide-shot photos or close-up photos. Low obliques are normally taken with a camera slanted at an angle of about 30° from the vertical point. They cover relatively small areas and therefore do not include the horizon. High obliques are normally taken with a camera that is slanted at an angle of approximately 60° from the vertical point. In contrast with vertical photographs, this level of tilt produces much more relief, making it easier to identify natural or manmade features.

360-DEGREE AERIAL IMAGERY

360° aerial imagery (also known as panoramic imagery, photospheres, VR photography or bubble-oriented imagery) has been around for a little while, but it has only recently gained real traction as a new basemap layer as different industries are realizing the potential it brings to decision-making and overall immersive experiences. With companies such as YouTube, Google (Street View), Apple (Look Around), Facebook and other large brands already leveraging the technology in their platforms, this technology may have staying power.

360° aerial imagery allows users to view more than a snapshot of the world below. The common cardinal directions (North, South, East and West) can be surpassed so that users can navigate through the viewer as if they were controlling the aerial camera themselves. 360° aerial imagery can be captured by fixed-wing aircraft, helicopters and UAVs. The sweet spot for this type of imagery collection is about 30m to 915m above ground level (AGL). 360° imagery is both engaging and informative for the end user since it provides new vantage points of the built world as well as providing an exhilarating experience from the new perspectives it affords.

In order for this type of imagery to be useful as a basemap layer, it takes much more than just the 360° imagery; each pixel of the high-resolution 360-degree image must be georectified with extreme precision – and this is where the challenge lies. Georectifying a vertical image or even an oblique is pretty straightforward, since the fixed coordinates can be georeferenced with ground control points (GCPs) in an automated fashion. When dealing with 360° images, however, it is necessary to identify a set of points in each image for which the latitude and longitude coordinates are known, and then use them to 'warp' the image into a map projection. Needless to say, this entails a lot of work for an entire city, state, province or country – especially considering that a 360° image has a useful range of roughly 2.4km.

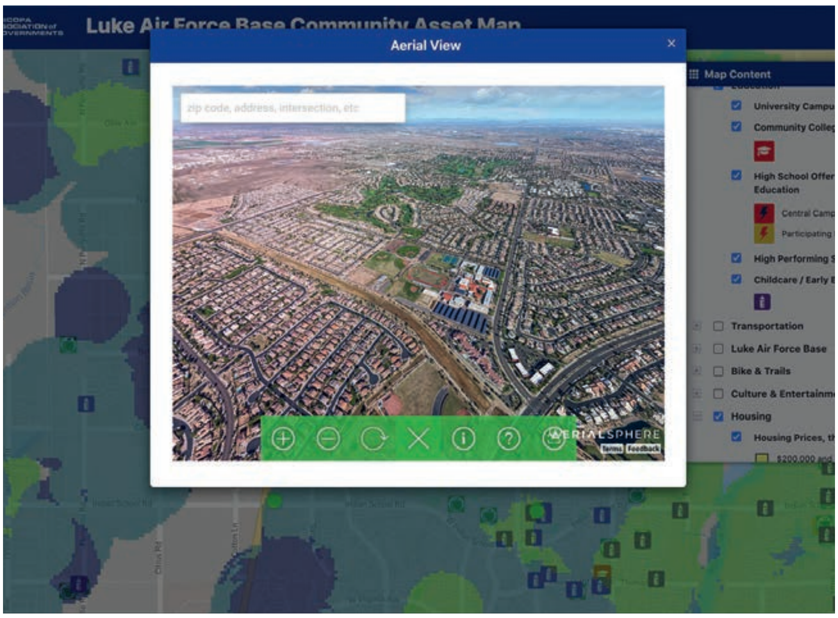
Once georectified and processed, this geoenabled imagery can be paired with digital maps such as Apple, Google or Mapbox. Alternatively, it can be included in cloud-based software such as Esri's ArcGIS or Autodesk's BIM360 to collect, process, manage and analyse all types of data in industries such as real estate, retail, construction, insurance, entertainment, travel and others.

▲ *Figure 4: Example of two location-enabled 360° images side-by-side to compare and contrast an area over time.*

EXAMPLE: AWARD-WINNING STORYTELLING FROM ABOVE

The Maricopa Associations of Governments (MAG) is a regional agency in Arizona, USA, that conducts planning and makes local-government policy decisions that affect the lives of everyone in the greater Phoenix region. The planning area encompasses roughly 17,000km^2. For years, MAG has relied on vertical and oblique aerial imagery to make better decisions and create solutions in the areas of transportation and economic development, but has recently started utilizing georectified, 360° imagery from AerialSphere to better analyse, plan and market the cities, towns and counties it supports.

A big portion of MAG's work revolves around enticing new residents and businesses to help grow local economies. MAG recently integrated 360° imagery into its mission-critical online tool, an interactive map viewer for Luke Air Force Base and its Targeted Growth Management Plan. Luke AFB was recently chosen to be the new training home of the F-35A Lightning II fighter jets, resulting in base personnel growing by an additional 2,234 service members by 2026. The 360° imagery gives users authentic, powerful views of the surrounding area as well as details about workforce, transportation, education and recreation in the West Valley. MAG's use of 360° imagery as a panoramic basemap layer resulted in it being awarded the 2020 Best Regional Plan Award from the American Planning Association.



▲ *Figure 5: Screenshot of MAG's award-winning interactive map viewer with a panoramic map layer. (Courtesy: Luke Air Force Base)*

CONCLUSION

360-degree aerial imagery is opening up an entirely new way to explore the built world. Besides creating exciting and engaging experiences, the location data also allows for the imagery to become actionable and highly informative, resulting in an incredibly intuitive way to visualize data. Panoramic basemaps are fuelling a new way for all types of businesses, governments, municipalities and consumers to digitally experience the physical world and have the potential to change how maps will be viewed and used. ◀

ABOUT THE AUTHOR

Josh Benveniste is vice president of marketing at AerialSphere which has succeeded in combining 360-degree aerial imagery with location data. Josh has over 20 years of experience in bringing technology products to market for a diverse group of industries including software, telecommunications, networking, construction and healthcare. Josh received his bachelor's and MBA from the University of Arizona, USA.

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EXTENDING THE EXISTING METHODS FOR CREATING DIGITAL TWINS

Automatic Segmentation of Point Clouds in Architecture

Over the last decade, the demand for digital twins has increased in the AEC/FM domain. Additionally, point clouds are used to create 3D models within BIM methodologies. A new algorithm has been developed that automatically identifies architectural elements and creates 3D models of building interiors. Called ABM-indoor, the algorithm works with organized and unorganized point clouds and provides 3D models of buildings in vector format. Efforts are now underway to transfer this model to IFC.

The authors developed the ABM-indoor algorithm out of the need to extend existing methods related to automatic processing of point clouds for building information modelling (BIM), especially in the domains of architecture, engineering and manufacturing (AEC) and facility management (FM). The proposed approach has two main objectives: 1) automatic classification of the elements of organized and unorganized point clouds (floors, ceilings, walls, columns, etc.), and 2) three-dimensional modelling of the classified elements according to an LOD 300 model. The approach focuses on the geometric information of point clouds. Two datasets were used to test ABM-indoor. One of the point clouds represents an office space with an area of approximately 800m^2 and three million points. It was obtained from a static terrestrial laser scanner (TLS). In this case, the data acquisition performs multiple scans where the position of the sensor is known so the point cloud is organized. The second point cloud was acquired in a multistorey car park using a dynamic TLS, NavVis M6, an indoor mobile mapping system (MMS) with six cameras that obtain 360° images, four laser scanners at various heights and a 6D simultaneous localization and mapping (SLAM) system. In this case, the point cloud is approximately 1,000m^2 and contains 14 million points.

METHODOLOGY

The ABM-indoor workflow has two main steps: 1) segmenting and labelling the point cloud using automatic clustering, and 2) creating 3D surfaces of each classified element (Figure 1). Floors, ceilings and walls are considered planar elements. On the one hand, a slicing method is used to identify the plane that best fits a cluster of points. Firstly, the algorithm identifies floors and ceilings as horizontal elements by using the height value. Secondly, ABM-indoor creates 3D surfaces of floors and ceilings using Delaunay Triangulation (Isenburg et al., 2006). Lastly, the algorithm applies minimum area constraints to eliminate irregular and useless surfaces and performs automatic edge fine-tuning to smooth surface boundaries. Before classifying the rest of the point cloud, the algorithm defines the principle direction of the building using edges longer than four metres.

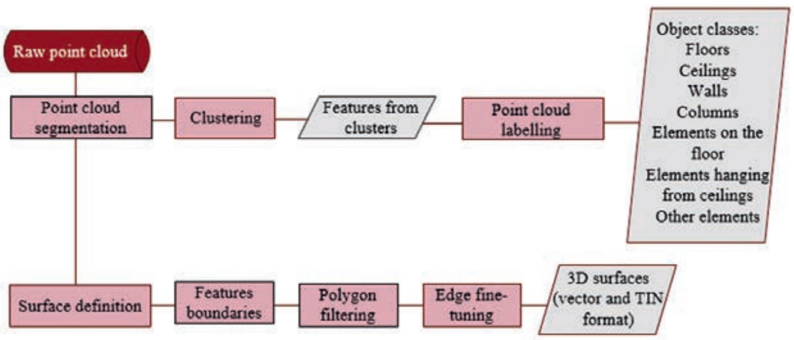


Figure 1: ABM-indoor workflow.

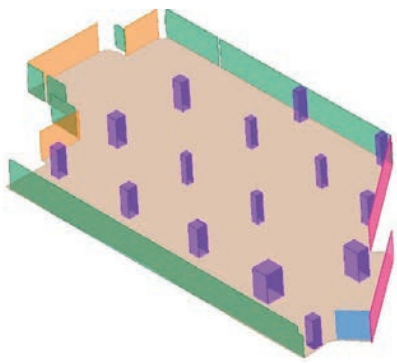
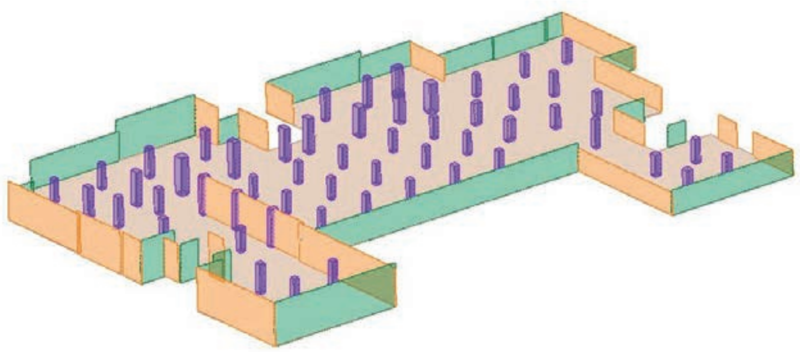


Figure 2: The created surfaces for the office space.

On the other hand, ABM-indoor uses the principle direction of the building and the cluster direction value to identify walls. To create surfaces from wall clusters, the algorithm first projects the boundaries horizontally using Helmert 3D transformation, and lastly applies polygon filtering and edge fine-tuning. The algorithm also identifies non-planar elements, such as columns. Columns are vertical elements connected to the floor slab and to the ceiling of the building. ABM-indoor uses existing gaps in the floor and ceiling to identify points that are on the vertical between the two gaps.

Once the floors, ceilings, walls and columns have been classified and modelled, the algorithm processes the remaining points to identify non-planar elements. The approach identifies content elements, such as cars, motorbikes, tables, chairs, etc. To identify and model the aforementioned irregular elements, ABM-indoor uses a tetrahedrization algorithm (Romero-Jarén & Arranz, 2020).



▲ *Figure 3: The created surfaces for the car park.*

▲ *Figure 6: Tetrahedrization for a vehicle in the car park point cloud.*

EXPERIMENTAL RESULTS

Two indoor datasets were used to test the algorithm: the office space (Figure 2) and the car park (Figure 3). In the office space, five dominant directions were established (x in orange, y in green, j in pink, k in blue, and z is height), whereas in the car park, three dominant directions were identified (x in orange, y in green, z is height).

After processing the point cloud, the approach developed a precision analysis using a confusion matrix. The matrix results were used to calculate the false positive and true positive rates and these were plotted on a receiver operating characteristics (ROC) graph. Figure 4 shows the ROC graph for the office space point cloud classification. In this case, the best classified object classes are floors, ceilings and walls (directions j and k, Figure 2). For the car park point cloud, the best classified object classes are floors and ceilings (Figure 5). For both point clouds, the least favourable classification results correspond to the ‘Other Object’ object class. Nevertheless, both datasets were classified with a global precision of more than 90%.

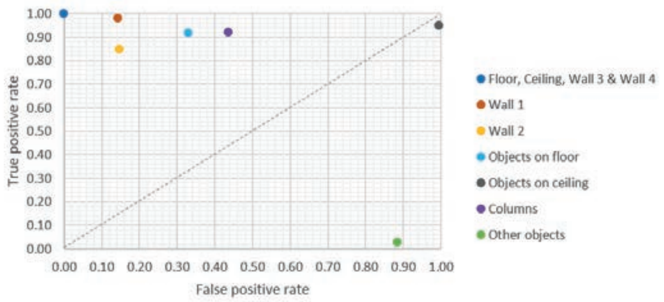
Non-planar elements are located on floors or hanging on ceilings. As mentioned above, ABM-indoor uses a tetrahedrization algorithm to classify the points belonging to these elements in order to create 3D surfaces. For instance, Figure 6 shows the 3D model of a car located in one of the point clouds. Content elements are identified and modelled as individual elements.

SOLUTION IMPLEMENTATION

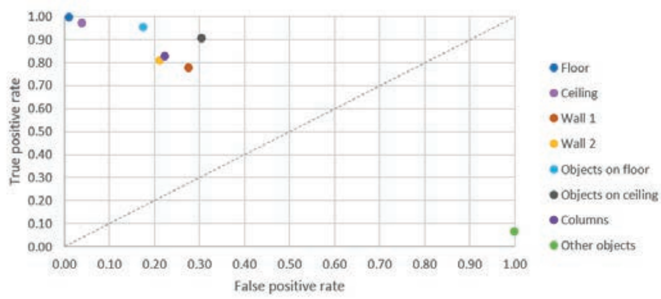
ABM-indoor has been incorporated as an additional module that works within the MDTopX (Digi21) software, which was created more than 20 years ago. It offers multiple tools for editing point clouds and digital models. MDTopX has an interface mainly based on toolbars and dialogue boxes, available in both English and Spanish. Nowadays it is used by dozens of national and international engineering companies and public institutions. The ABM-indoor module is based on functional and commercially available libraries of the MDTopX software.

CONCLUSION

ABM-indoor is an approach for automatically classifying and modelling unorganized and organized point clouds. The algorithm has an iterative workflow, as shown in Figure 1, which starts by classifying and modelling floors and ceilings, and continues with walls, columns and content elements. Only the geometric information of the point cloud was considered. Triangulation algorithms were used to create 3D surfaces of the elements. The authors tested the algorithm with two indoor datasets and the classification results had a global accuracy of over 90%. The algorithm can be applied to point clouds from mobile and static systems. Since no constraints of horizontality or verticality have been imposed, the approach is capable of determining any deformations or inclinations of elements. Future work will involve studies related to



▲ *Figure 4: ROC graph with the false and true positive rates of the office space.*



▲ *Figure 5: ROC graph with the false and true positive rates of the car park.*

deformation and displacements.
AMB-indoor provides files in vector format for planar elements and in TIN format for non-planar elements. The algorithm will be used to create as-built models (ABMs) of buildings. The authors are currently working to further improve the algorithm, since up until now ABM-indoor is limited to modelling visible elements. This needs to be complemented with data from drawings and the information gathered from inspections to consider hidden elements such as beams. ◀

ACKNOWLEDGEMENTS
The study is based on an industrial PhD (in progress) in which two institutions cooperate: Universidad Politécnica de Madrid and Geolyder S. L. Spain, NIF: B86901543. The current project is jointly financed by the Community of Madrid, Spain, Project Reference Number: IND2017/TIC-7869 and the aforementioned company. Additionally, the authors express their gratitude to José Ángel Martínez Torres for assisting with the file format conversion.

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FIG has been bringing surveyors and geospatial experts together since 1878. Apart from the inauguration in 1878 and the second meeting in 1910, surveyors have met almost every single year since 1926: a total of 91 times if we only count the main annual events. This 92nd annual meeting in June 2021 will again bring surveyors together, albeit differently. Thanks to the digital era, you can now attend the first ever FIG e-Working Week.

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1. Esri founder Jack Dangermond and FIG President Rudolf Staiger discuss new trends in technology related to the profession and the impact of COVID-19
2. The impact of COVID-19 on the profession – a discussion between Benjamin Davis from FAO, Steven Ramage from GEO and Lea Bodossian from Eurogeographics, moderated by Kate Fairlie
3. A Decade of Fit-for-Purpose Land Administration: Key lessons and future directions moderated by Jaap Zevenbergen with panelists including FIG Honorary President Stig Enemark and Amy Coughenour Betancourt from Cadasta Foundation
4. UN-GGIM Integrated Geospatial Information Framework (IGIF) – how are we now moving towards country-level action plans? With Greg Scott from UN-GGIM and Rosamond Bing from Tonga, moderated by Anders Sandin
5. A discussion on the importance of making the land and property sector sustainable and resilient: Ensuring Diversity and Inclusion, moderated by FIG Vice President Diane Dumashie
6. How can digital twins support legal security? This session by the local Dutch organizers is aimed at inspire you to use the Triple Helix to work on digital twins
7. In this inspirational session on 'success', Katriona Lord-Levins, chief success officer at Bentley Systems, takes you through perspectives on success: your personal success, at work, with your customers and clients, your immediate team, etc. How do you define success?

The journey is waiting for you – your colleagues are just a mouse-click away. Secure your ticket now: www.fig.net/fig2021

Paula Dijkstra and Louise Friis-Hansen, co-conference directors of FIG e-Working Week 2021

More information
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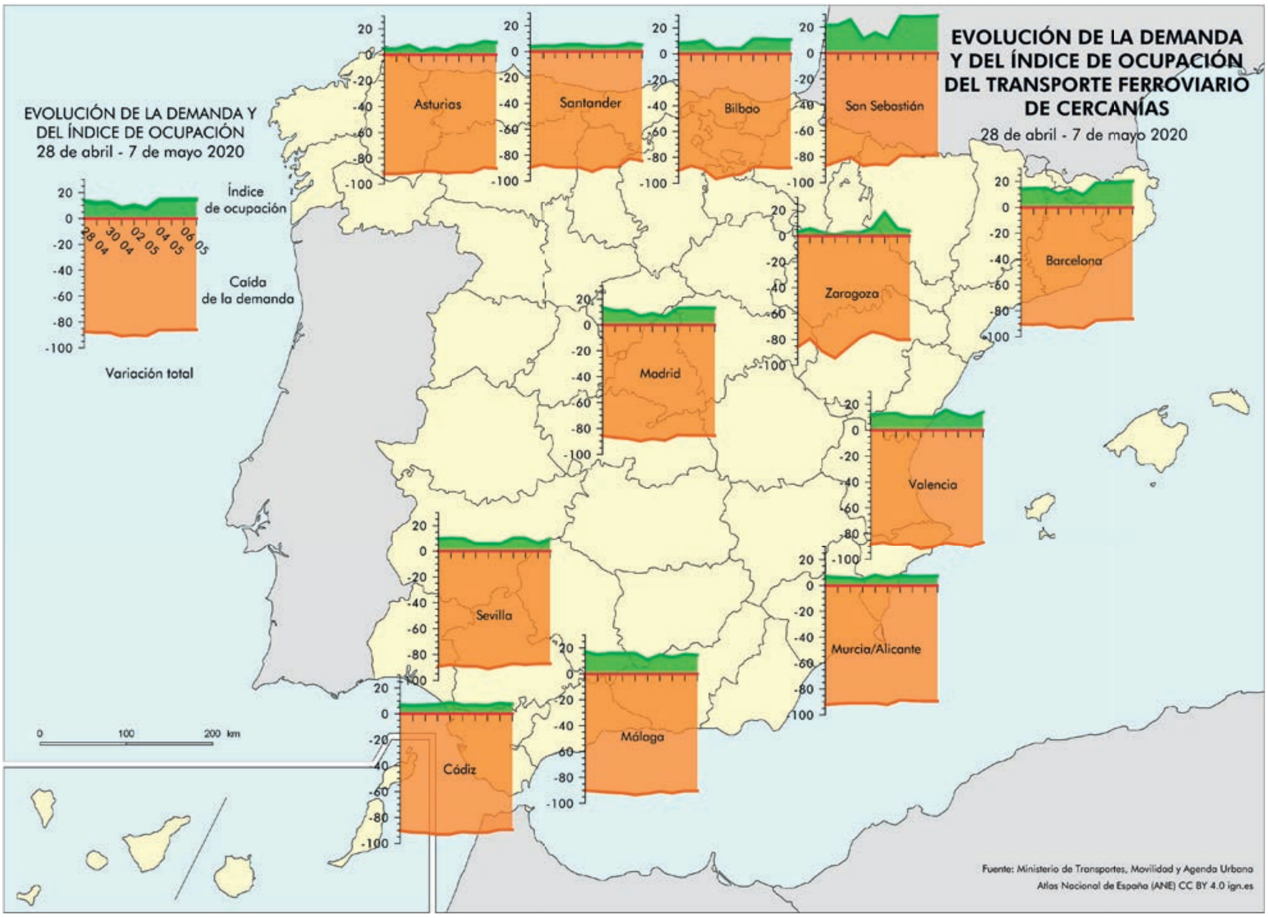
Cartography: An Essential Tool for Managing the World

In challenging situations such as the one we have been living through over the last year, it is crucial that we cartographers respond to the great challenges of humanity and highlight the value of our discipline as an essential tool for managing the world. That is why, before bringing the 2020-2021 academic year to a close and going on summer holidays, we must remind everyone about the International Cartographic Conference ICC2021 which will be held in Florence in December this year. This conference will be an excellent opportunity to meet again after the pandemic, to reinforce our discipline and to deepen the study of cartography as an essential tool for managing the world of today and tomorrow.

The ICA is the international reference organization in the field of cartography. It involves around 120 organizations – all of them linked to cartography – from 80 countries on all six continents. The ICA works internally in 28 commissions as well as several working groups. Some are focused on scientific aspects, others on more technical



▲ *Visualization of the drop in traffic in all types of transport in Spain during the most acute phase of the first lockdown.*

matters and others on more artistic topics of our discipline.

The ICA holds an International Cartographic Conference (ICC) every two years, each one attended by thousands of participants from all around the world. This time the International Cartographic Conference will be held in Florence, Italy, from 14-18 December 2021. The ICC2021 will be organized along 36 thematic lines. Everyone is welcome to submit a paper and participate (physically or online) at the ICC this year. The International Cartographic Exhibition will also be held in parallel at a wonderful venue in Florence. We encourage you to send samples of maps from the different countries. We also encourage countries to participate in the Barbara Petchenik International Children Map Competition 2021.

Amongst many other topics, the discussion during the International Cartographic Conference in Florence will address two aspects that are critical in challenging times: how maps support crisis management in the short term, and how cartography helps to foster a more sustainable world for the long term.

SUPPORTING CRISIS MANAGEMENT

In the short term, we have seen over the last year how maps may help in managing crises around the world. As seen in previous issues of this magazine, countless maps have appeared over the last year aimed at supporting the management of the pandemic. Initiatives have had varying levels of success, yet the overall quality has gradually improved, as seen before. In this regard, two initiatives from the National Geographic Institute of Spain are worth mentioning. On the one hand, during the first wave of the pandemic (from March to June 2020), the Department of National Atlas cooperated with various ministries of the Spanish National Administration by representing their data on maps. For instance, the drop in traffic in all types of transport during the most acute phase of the first lockdown was visualized, which helped the Ministry of Transport to control mobility at a time when it needed to be as low as possible (Figure 1). On the other hand, in June 2020 the same Department of National Atlas within the National Geographic Institute of Spain started working on a 120-page monograph on the coronavirus pandemic. This work is expected to be published in the near future in both paper and digital formats, both in Spanish and in English for the first time. The aim is to help manage the pandemic as well as to explain through maps how the pandemic has affected three areas: the world in general (Chapter 1) (Figure 2), Spain in particular in terms of health (Chapter 2), and the Spanish economy, society and environment (Chapter 3). This project uses cutting-edge mapping technologies. Moreover, it draws expertise from numerous organizations as it is a collaborative project that involves dozens of institutions throughout the country.

PROMOTING SUSTAINABLE DEVELOPMENT

In the long term, for its part, cartography must also promote a more sustainable approach to development. In this sense, the ICC in Florence will focus on the following aspects, amongst many others: 1) The ICA needs to attract young people towards cartography and we must always take the younger generation into account when addressing the future, 2) *The Barbara Petchenik Children Map Competition Book* (Figure 3), published by the National Geographic Institute of Spain on the occasion of its 150th anniversary, will be presented and distributed in Florence. The book reinforces the role of children and young people in our discipline as a driving force for the future, 3) There will also be a thorough look at the recently published book on sustainable development, also mentioned in previous issues, which is an extraordinary example of how our discipline can help to promote more sustainable development and a more viable future within the framework of the 2030 Agenda for Sustainable Development Goals, and 4) The recently created ICA Working Group on Cartography and Sustainable Development is looking for people interested in this subject. The plan is for those who are interested in participating to meet in Florence during the conference to kick-start this flourishing working group.

We look forward to seeing you at the International Cartographic Conference in Florence this December!

More information
https://www.icc2021.net/

Invitation to Participate in XXIV ISPRS Congress 2021

This year, in view of the ongoing pandemic situation, ISPRS is organizing an extended digital edition of the XXIV Congress from 5-9 July, with all the features of an ISPRS congress. This follows on from the great success of the 2020 digital edition of the XXIV Congress, which attracted more than 2,000 registered participants and featured 300-plus presentations.

This 2021 edition will offer a very rich programme spanning five full days, from 5-9 July. Seven exciting keynotes are scheduled, including from Airbus on the new Pléiades Neo NEO very-high-resolution satellite constellation, from INPE-Brazil on the Amazônia-1 satellite and its applications for the monitoring of deforestation, from Microsoft and ETH-Zurich on computer vision for augmented reality with Hololens2, and from KIT on autonomous and aided driving. These innovative topics will provide the registered participants with excellent insight into the current status and science and technology trends across all the areas of ISPRS (Earth observation, remote sensing, photogrammetry & computer vision, GIS and more).

TECHNOLOGY TRACKS AND ONE-HOUR LECTURES

More than 500 papers will be presented in the various scientific tracks and sessions throughout the week. In addition to these presentations, participants will also have the possibility to interact and network face to face with the authors in individual videoconference rooms. In order to help the registered participants choose relevant sessions and presentations so that they can build their own programme for the week, pre-recorded video presentations of the papers will be made available before the beginning of the event through the congress platform.

A FREE ISPRS GEOSPATIAL LECTURE DAY IS BEING HELD ON 9 JULY TO PROVIDE UPDATES ON THE LATEST SCIENTIFIC ADVANCES IN THE GEOSPATIAL DOMAIN

The 2021 edition will also integrate a technology track enabling presentation of the latest innovations and technologies from the industry as well as a virtual exhibition to facilitate interaction between the participants and the sponsors and exhibitors (including Airbus, Esri, Thales Alenia Space, Hexagon, ESA, Aerometrex, Agisoft, Pix4D, Racurs, Riegl, Trimble, DAT/EM Systems International, AIR6 Systems, Euspaceimaging, Geodyn, GGS, IGI Systems, LucCarta Technology, RESE Applications, Resonon, SI Imaging Systems, Spectral Evolution and Vexcel Imaging).

In addition to through this technology track, participants will have the possibility to interact with sponsors through chat sessions and in videoconference rooms.

The registration fees for this 2021 edition have been kept as low as possible to encourage maximum participation. To further extend the reach to a much larger audience, a free ISPRS geospatial lecture day is being held on 9 July to provide updates on the latest scientific advances in the geospatial domain. The day will comprise eight one-hour lectures on various hot topics: Earth data cubes, PS-Insar for surface estimation, trends in airborne Lidar, deep learning for 3D point cloud analysis, deep learning for time series classification, dynamic networks, georeferencing of mobile mapping systems, and collaborative humanitarian mapping.

More information about the programme, the latest updates and the registration process can be found on the website.

The organizers would like to extend a warm thank you to all the participants, sponsors and exhibitors who have constantly supported ISPRS during this difficult period. They are looking forward to hosting you and meeting you digitally during this 2021 edition!

More information
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