

Airborne And Terrestrial Laser Scanning

This guidance is designed to help those intending to use airborne laser scanning (ALS), also known as lidar, for archaeological survey. The aim is to help archaeologists, researchers and those who manage the historic environment to decide first, whether using lidar data will actually be beneficial in terms of their research aims, and second, how the data can be used effectively. The guidance will be most useful to those who have access to data that have already been commissioned, or are planning to commission lidar for a specific purpose. They also provide an introduction to data interpretation in order to separate archaeological and non-archaeological features. Although important themes are introduced, this guidance are not intended as a definitive explanation of the technique or the complexities of acquiring and processing the raw data, particularly as this is a still developing technology. This document is intended to complement 3D Laser Scanning for Heritage, which covers a wider range of uses of laser scanning for heritage purposes (Historic England 2018). This Guidance is a revision of The Light Fantastic: Using Airborne Lidar in Archaeological Survey published by English Heritage in 2010. The text has largely been maintained except for certain areas where major changes have occurred in the ensuing years. This is particularly true with regard to increased access to data and the wide range of visualisation techniques now available. The case studies have also been updated to reflect more recent survey activity and to include examples from outside Historic England.

This book collects the papers in the special issue "Airborne Laser Scanning" in Remote Sensing (Nov. 2016) and several other selected papers published in the same journal in the past few years. Our intention is to reflect recent technological developments and innovative techniques in this field. The book consists of 23 papers in six subject areas: 1) Single photon and Geiger-mode Lidar, 2) Multispectral lidar, 3) Waveform lidar, 4) Registration of point clouds, 5) Trees and terrain, and 6) Building extraction. The book is a valuable resource for scientists, engineers, developers, instructors, and graduate students interested in lidar systems and data processing.

Written by a team of international experts, this book provides a comprehensive overview of the major applications of airborne and terrestrial laser scanning. It focuses on principles and methods and presents an integrated treatment of airborne and terrestrial laser scanning technology. After consideration of the technology and processing methods, the book turns to applications, such as engineering, forestry, cultural heritage, extraction of 3D building models, and mobile mapping. This book brings together the various facets of the subject in a coherent text that will be relevant for advanced students, academics and practitioners.

The book covers the international state-of-the-art research in the field of 3D geo-information modeling. It focuses on comparing several types of 3D models. Due to the rapid developments in sensor techniques more and more 3D data becomes available. Effective algorithms for (semi) automatic object reconstruction are required. 3D analysis and 3D simulation techniques explore and extend the possibilities in spatial applications.

The concept of remote sensing as a way of capturing information from an object without making contact with it has, until recently, been exclusively focused on the use of Earth observation satellites. The emergence of unmanned aerial vehicles (UAV) with Global Navigation Satellite System (GNSS) controlled navigation and sensor-carrying capabilities has increased the number of publications related to new remote sensing from much closer distances. Previous knowledge about the behavior of the Earth's surface under the incidence different wavelengths of energy has been successfully applied to a large amount of data recorded from UAVs, thereby increasing the spatial and temporal resolution of the products obtained. More specifically, the ability of UAVs to be positioned in the air at pre-programmed coordinate points; to track flight paths; and in any case, to record the coordinates of the sensor position at the time of the shot and at the pitch, yaw, and roll angles have opened an interesting field of applications for low-altitude aerial photogrammetry, known as UAV photogrammetry. In addition, photogrammetric data processing has been improved thanks to the combination of new algorithms, e.g., structure from motion (SfM), which solves the collinearity equations without the need for any control point, producing a cloud of points referenced to an arbitrary coordinate system and a full camera calibration, and the multi-view stereopsis (MVS) algorithm, which applies an expanding procedure of sparse set of matched keypoints in order to obtain a dense point cloud. The set of technical advances described above allows for geometric modeling of terrain surfaces with high accuracy, minimizing the need for topographic campaigns for georeferencing of such products. This Special Issue aims to compile some applications realized thanks to the synergies established between new remote sensing from close distances and UAV photogrammetry.

Geomatics, the handling and processing of information and data about the Earth, is one geoscience discipline that has seen major changes in the last decade, as mapping and observation systems become ever more sensitive and sophisticated. This book is a unique and in-depth survey of the field, which has a central role to play in tackling a host of environmental issues faced by society. Covering all three strands of geomatics - applications, information technology and surveying - the chapters cover the history and background of the subject, the technology employed both to collect and disseminate data, and the varied applications to which geomatics can be put, including urban planning, assessment of biodiversity, disaster management and land administration. Relevant professionals, as well as students in a variety of disciplines such as geography and surveying, will find this book required reading. This rapidly developing field uses increasingly complex and accurate systems. Today, technology enables us to capture geo-data in full 3D as well as to disseminate it via the Web at the speed of light. We are able to continuously image the world from space at resolutions of up to 50 cm. Airborne LiDAR (laser surveying) sensors can be combined with digital camera technology to produce geometrically correct images of the Earth's surface, while integrating these with large-scale

topographic maps and terrestrial as well as aerial images to produce 3D cityscapes that computer users can explore from their desktops.

Published on the occasion of the XX1st Congress of the International Society for Photogrammetry and Remote Sensing (ISPRS) in Beijing, China in 2008, *Advances in Photogrammetry, Remote Sensing and Spatial Information Sciences: 2008 ISPRS Congress Book* is a compilation of 34 contributions from 62 researchers active within the ISPRS. The book covers

Geomorphometry is the science of quantitative land-surface analysis. It draws upon mathematical, statistical, and image-processing techniques to quantify the shape of earth's topography at various spatial scales. The focus of geomorphometry is the calculation of surface-form measures (land-surface parameters) and features (objects), which may be used to improve the mapping and modelling of landforms to assist in the evaluation of soils, vegetation, land use, natural hazards, and other information. This book provides a practical guide to preparing Digital Elevation Models (DEM) for analysis and extracting land-surface parameters and objects from DEMs through a variety of software. It further offers detailed instructions on applying parameters and objects in soil, agricultural, environmental and earth sciences. This is a manual of state-of-the-art methods to serve the various researchers who use geomorphometry. Soil scientists will use this book to further learn the methods for classifying and measuring the chemical, biological, and fertility properties of soils and gain a further understanding of the role of soil as a natural resource. Geologists will find value in the instruction this book provides for measuring the physical features of the soil such as elevation, porosity, and structure which geologists use to predict natural disasters such as earthquakes, volcanoes, and flooding. * Technical details on a variety of software packages allow researchers to solve real-life mapping issues * Provides soil and agronomy researchers best practice techniques for soil data analysis to assist in enhanced land-use and planning * Offers geologists essential tactics for better environmental management by providing a comprehensive analysis of the physical features of soil * Companion website includes access to the latest technological advancements previously unpublished in any other comprehensive source: geomorphometry software, DEM data sources, and applications

The first edition of *3D Laser Scanning for Heritage* was published in 2007 and originated from the Heritage3D project that in 2006 considered the development of professional guidance for laser scanning in archaeology and architecture. Publication of the second edition in 2011 continued the aims of the original document in providing updated guidance on the use of three-dimensional (3D) laser scanning across the heritage sector. By reflecting on the technological advances made since 2011, such as the speed, resolution, mobility and portability of modern laser scanning systems and their integration with other sensor solutions, the guidance presented in this third edition should assist archaeologists, conservators and other cultural heritage professionals unfamiliar with the approach in making the best possible use of this now highly developed technique.

Structure from Motion with Multi View Stereo provides hyperscale landform models using images acquired from standard compact cameras and a network of ground control points. The technique is not limited in temporal frequency and can provide point cloud data comparable in density and accuracy to those generated by terrestrial and airborne laser scanning at a fraction of the cost. It therefore offers exciting opportunities to characterise surface topography in unprecedented detail and, with multi-temporal data, to detect elevation, position and volumetric changes that are symptomatic of earth surface processes. This book firstly places Structure from Motion in the context of other digital surveying methods and details the Structure from Motion workflow including available software packages and assessments of uncertainty and accuracy. It then critically reviews current usage of Structure from Motion in the geosciences, provides a synthesis of recent validation studies and looks to the future by highlighting opportunities arising from developments in allied disciplines. This book will appeal to academics, students and industry professionals because it balances technical knowledge of the Structure from Motion workflow with practical guidelines for image acquisition, image processing and data quality assessment and includes case studies that have been contributed by experts from around the world.

This book has been developed as a forest inventory textbook for students and could also serve as a handbook for practical foresters. We have set out to keep the mathematics in the book at a fairly non-technical level, and therefore, although we deal with many issues that include highly sophisticated methodology, we try to present first and foremost the ideas behind them. For foresters who need more details, references are given to more advanced scientific papers and books in the fields of statistics and biometrics. Forest inventory books deal mostly with sampling and measurement issues, as found here in section I, but since forest inventories in many countries involve much more than this, we have also included material on forestry applications. Most applications nowadays involve remote sensing technology of some sort, so that section II deals mostly with the use of remote sensing material for this purpose. Section III deals with national inventories carried out in different parts of world, and section IV is an attempt to outline some future possibilities of forest inventory methodologies. The editors, Annika Kangas Professor of Forest Mensuration and Management, Department of Forest Resource Management, University of Helsinki. Matti Maltamo Professor of Forest Mensuration, Faculty of Forestry, University of Joensuu. **ACKNOWLEDGEMENTS**

This book gives a comprehensive view of the developed Procrustes models, including the isotropic, the generalized and the anisotropic variants. These represent original tools to perform, among others, the bundle block adjustment and the global registration of multiple 3D LiDAR point clouds. Moreover, the book also reports the recently derived total least squares solution of the anisotropic Procrustes model, together with its practical application in solving the exterior orientation of one image. The book is aimed at all those interested in discovering valuable innovative algorithms for solving various photogrammetric computer vision problems. In this context, where functional models are non-linear, Procrustean methods prove to be powerful since they do not require any linearization nor approximated values of the unknown parameters, furnishing at the same time results comparable in terms of accuracy with those given by the state-of-the-art methods.

"TRB's National Cooperative Highway Research Program (NCHRP) Report 748: Guidelines for the Use of Mobile LIDAR in Transportation Applications presents guidelines for the application of mobile 3D light detection and ranging (LIDAR) technology to the operations of state departments of transportation. Mobile LIDAR uses laser scanning equipment mounted on vehicles in combination with global positioning systems (GPS) and inertial measurement units (IMU) to rapidly and safely capture large datasets necessary to create highly accurate, high resolution digital representations of roadways and their surroundings. "--Publisher's description.

This book gathers the latest advances, innovations, and applications in the field of information technology in civil and building engineering, presented at the 18th International Conference on Computing in Civil and Building Engineering (ICCCBE), São Paulo, Brazil, August 18-20, 2020. It covers highly diverse topics such as BIM, construction information modeling, knowledge management, GIS, GPS, laser scanning, sensors, monitoring, VR/AR, computer-aided construction, product and process modeling, big data and IoT, cooperative design, mobile computing, simulation, structural health monitoring, computer-aided structural control and analysis, ICT in geotechnical engineering, computational mechanics, asset management, maintenance, urban planning, facility management, and smart cities. Written by leading researchers and engineers, and selected by means of a rigorous international peer-review process, the contributions highlight numerous exciting ideas that will spur novel research directions and foster multidisciplinary collaborations.

3D surface representation has long been a source of information describing surface character and facilitating an understanding of system dynamics from micro-scale (e.g. sand transport) to macro-scale (e.g. drainage channel network evolution). Data collection has been achieved through field mapping techniques and the use of remotely sensed data. Advances in this latter field have been considerable in recent years with new rapid-acquisition methods being developed centered around laser based technology. The advent of airborne and field based laser scanning instruments has allowed researchers to collect high density accurate data sets and these are revealing a wealth of new information and generating important new ideas concerning terrain characterisation and landform dynamics. The proposed book collates a series of invited peer reviewed papers presented at the a conference on geoinformatics and LIDAR to be held at the National Centre for Geocomputation based in the National University of Ireland, Maynooth. Current constraints in field survey and DEM construction are reviewed together with technical and applied issues around the new technology. The utility of the data in process modelling is also covered. The book will be of great value to researchers in the field of geomorphology, geostatistics, remote sensing and GIS and will prove extremely useful to students and practitioners concerned with terrain analysis. The proposed work will: Highlight major technological breakthrough in 3D data collection. Feature examples of application across a wide range of environmental areas. Critically evaluate the role of laser based techniques in the environment. Detail theory and application of laser techniques in the natural environment.

Airborne and Terrestrial Laser Scanning CRC Press LLC

This book provides a complete overview of novel and state of art sensing technologies and geotechnologies relevant to support management and conservation of CH sites, monuments and works of art. The book is organized in an introduction stating the motivations and presenting the overall content of the volume and four parts. The first part focuses on remote sensing and geophysics for the study of human past and cultural heritage at site scale and as element of the surrounding territory. The second part presents an overview of non invasive technologies for investigating monuments and works of art. The third part presents the new opportunities of ICT for an improved and safe cultural heritage fruition, from the virtual and augmented reality of historical context to artifact tracking. Finally, the fourth part presents a significant worldwide set of success cases of the exploitation of the integration of geotechnologies in archeology and architectural heritage management. This book is of interest to researchers, experts of heritage science, archaeologists, students, conservators and other professionals of cultural heritage.

A unique compendium of the most important and widespread soils of Australia and their associated landscapes.

An authoritative guide to close range photogrammetry. The first comprehensive modern text on this subject in English, expanded and updated from the German text by Luhmann. This book provides a thorough presentation of the methods, mathematics, systems and applications which comprise the subject of close range photogrammetry, which uses accurate imaging techniques to analyse the three-dimensional shape of a wide range of manufactured and natural objects. Close range photogrammetry, for the most part entirely digital, has become an accepted, powerful and readily available technique for engineers and scientists who wish to utilise images to make accurate 3-D measurements of complex objects. After an introduction, the book provides fundamental mathematics, including orientation, digital imaging processing and 3-D reconstruction methods, as well as presenting a discussion of imaging technology including targeting and illumination, hardware and software systems. Finally it gives a short overview of photogrammetric solutions for typical applications in engineering, manufacturing, medical science, architecture, archaeology and other fields.

Remote Sensing of Geomorphology, Volume 23, discusses the new range of remote-sensing techniques (lidar, structure from motion photogrammetry, advanced satellite platforms) that has led to a dramatic increase in terrain information, and as such provided new opportunities for a better understanding of surface morphology and related Earth surface processes. As several papers have been published (including paper reviews and special issues) on this topic, this book summarizes the major advances in remote sensing techniques for the analysis of Earth surface morphology and processes, also highlighting future challenges. Useful for MSc and PhD students, this book is also ideal for any scientists that want to have a single volume guideline to help them develop new ideas. In addition, technicians and private and public sectors working on remote sensing will find the information useful to their initiatives. Provides a useful guideline for MSc and PhD students, scientists, technicians, and land planners on the use of remote sensing in geomorphology Includes applications on specific case studies that highlight issues and benefits of one technique compared to others Presents future trends in remote sensing and geomorphology

This edited volume gathers the proceedings of the Symposium GIS Ostrava 2016, the Rise of Big Spatial Data, held at the Technical University of Ostrava, Czech Republic, March 16–18, 2016. Combining theoretical papers and applications by authors from around the globe, it summarises the latest research findings in the area of big spatial data

and key problems related to its utilisation. Welcome to dawn of the big data era: though it's in sight, it isn't quite here yet. Big spatial data is characterised by three main features: volume beyond the limit of usual geo-processing, velocity higher than that available using conventional processes, and variety, combining more diverse geodata sources than usual. The popular term denotes a situation in which one or more of these key properties reaches a point at which traditional methods for geodata collection, storage, processing, control, analysis, modelling, validation and visualisation fail to provide effective solutions. >Entering the era of big spatial data calls for finding solutions that address all "small data" issues that soon create "big data" troubles. Resilience for big spatial data means solving the heterogeneity of spatial data sources (in topics, purpose, completeness, guarantee, licensing, coverage etc.), large volumes (from gigabytes to terabytes and more), undue complexity of geo-applications and systems (i.e. combination of standalone applications with web services, mobile platforms and sensor networks), neglected automation of geodata preparation (i.e. harmonisation, fusion), insufficient control of geodata collection and distribution processes (i.e. scarcity and poor quality of metadata and metadata systems), limited analytical tool capacity (i.e. domination of traditional causal-driven analysis), low visual system performance, inefficient knowledge-discovery techniques (for transformation of vast amounts of information into tiny and essential outputs) and much more. These trends are accelerating as sensors become more ubiquitous around the world.

This book focusses on new technologies and multi-method research designs in the field of modern archaeology, which increasingly crosses academic boundaries to investigate past human-environmental relationships and to reconstruct palaeolandscapes. It aims at establishing the concept of Digital Geoarchaeology as a novel approach of interdisciplinary collaboration situated at the scientific interface between classical studies, geosciences and computer sciences. Among others, the book includes topics such as geographic information systems, spatiotemporal analysis, remote sensing applications, laser scanning, digital elevation models, geophysical prospecting, data fusion and 3D visualisation, categorized in four major sections. Each section is introduced by a general thematic overview and followed by case studies, which vividly illustrate the broad spectrum of potential applications and new research designs. Mutual fields of work and common technologies are identified and discussed from different scholarly perspectives. By stimulating knowledge transfer and fostering interdisciplinary collaboration, Digital Geoarchaeology helps generate valuable synergies and contributes to a better understanding of ancient landscapes along with their forming processes. Chapters 1, 2, 6, 8 and 14 are published open access under a CC BY 4.0 license at link.springer.com.

This book is the translated English version of a text on industrial surveys, originally published in Slovak by SPEKTRUM STU Publishing. This updated version is not only a translation of the original, but also a reviewed, extended version, which reflects up-to-date international standards and regulations. The book covers topics in engineering surveying not available in other publications in this complex form, and addresses the design methodology, data processing and implementation of geodetic measurements under specific conditions to make industrial work environments safer and more efficient. The book begins by introducing readers to these conditions, and then discusses design of maps, geodetic networks and information systems of industrial plants, the usage of cartesian and polar coordinate measuring systems, terrestrial laser scanning technology, as well as measurement of cranes, rotary kilns and special objects of nuclear power plants. The book will be of use to teachers, students, practitioners (e.g. surveyors), quality production managers, equipment designers and mechanical engineers.

Written by a team of international experts, this book provides a comprehensive overview of the major applications or airborne and terrestrial laser scanning.

This book presents the latest advances in remote-sensing and geographic information systems and applications. It is divided into four parts, focusing on Airborne Light Detection and Ranging (LiDAR) and Optical Measurements of Forests; Individual Tree Modelling; Landscape Scene Modelling; and Forest Eco-system Modelling. Given the scope of its coverage, the book offers a valuable resource for students, researchers, practitioners, and educators interested in remote sensing and geographic information systems and applications.

A systematic, in-depth introduction to theories and principles of Light Detection and Ranging (LiDAR) technology is long overdue, as it is the most important geospatial data acquisition technology to be introduced in recent years. An advanced discussion, this text fills the void. Professionals in fields ranging from geology, geography and geoinformatics to physics, transportation, and law enforcement will benefit from this comprehensive discussion of topographic LiDAR principles, systems, data acquisition, and data processing techniques. The book covers ranging and scanning fundamentals, and broad, contemporary analysis of airborne LiDAR systems, as well as those situated on land and in space. The authors present data collection at the signal level in terms of waveforms and their properties; at the system level with regard to calibration and georeferencing; and at the data level to discuss error budget, quality control, and data organization. They devote the bulk of the book to LiDAR data processing and information extraction and elaborate on recent developments in building extraction and reconstruction, highlighting quality and performance evaluations. There is also extensive discussion of the state-of-the-art technological developments used in: filtering algorithms for digital terrain model generation; strip adjustment of data for registration; co-registration of LiDAR data with imagery; forestry inventory; and surveying. Readers get insight into why LiDAR is the effective tool of choice to collect massive volumes of explicit 3-D data with unprecedented accuracy and simplicity. Compiled by leading experts talking about much of their own pioneering work, this book will give researchers, professionals, and senior students novel ideas to supplement their own experience and practices.

Airborne Laser Scanning (ALS), or lidar, is an enormously important innovation for data collection and interpretation in archaeology. The application of archaeological 3D data deriving from sources including ALS, close-range photogrammetry and terrestrial and photogrammetric scanners has grown exponentially over the last decade. Such data present numerous possibilities and challenges, from ensuring that applications remain archaeologically relevant, to developing practices that integrate the manipulation and interrogation of complex digital datasets with the skills of archaeological observation and interpretation. This volume addresses the implications of multi-scaled topographic data for contemporary archaeological practice in a rapidly developing field, drawing on examples of ongoing projects and reflections on best practice. Twenty papers from across Europe explore the implications of these digital 3D datasets for the recording and interpretation of archaeological topography, whether at the landscape, site or artefact scale. The papers illustrate the variety of ways in which we engage with archaeological topography through 3D data, from discussions of its role in landscape archaeology, to issues of context and integration, and to the methodological challenges of processing, visualisation and manipulation. Critical reflection on developing practice and implications for cultural resource management and research contextualize the case studies and applications, illustrating the diverse and evolving roles played by multi-scalar topographic data in contemporary archaeology.

For a long time, the dynamics of urban and coastal areas have been the focus of administrators and decision makers in charge of public policy in order to better take into account anthropogenic pressure and the impact of climate change. This volume presents applications of remote sensing in urban environments and coastal zones, including the use of remote sensing in city planning (urban expansion, light pollution, air quality, etc.), observation of the properties of ocean color, the study of coastal dynamics (identifying coastlines and estimating sediment balances, etc.) and analysis of the dynamics of mangroves. This book, part of a set of six volumes, has been produced by scientists who are internationally renowned in their fields. It is addressed to students (engineers, Masters, PhD), engineers and

scientists, specialists in remote sensing applied to the coastal environment and urban areas. Through this pedagogical work, the authors contribute to breaking down the barriers that hinder the use of Earth observation data. Clear-and-concise descriptions of modern methods of remote sensing for a variety of applications Explores the most current remote sensing techniques, with physical aspects of their measurement (theory) Presents physical principles, measurement, and data processing chapters that are provided for each technique described

Airborne laser scanning (ALS) has emerged as one of the most promising remote sensing technologies to provide data for research and operational applications in a wide range of disciplines related to management of forest ecosystems. This book provides a comprehensive, state-of-the-art review of the research and application of ALS in a broad range of forest-related disciplines, especially forest inventory and forest ecology. However, this book is more than just a collection of individual contributions – it consists of a well-composed blend of chapters dealing with fundamental methodological issues and contributions reviewing and illustrating the use of ALS within various domains of application. The reviews provide a comprehensive and unique overview of recent research and applications that researchers, students and practitioners in forest remote sensing and forest ecosystem assessment should consider as a useful reference text.

Contents: Radiation Theory, Artificial Sources, Natural Sources, Atmospheric Scattering, Atmospheric Absorption, Propagation Through Atmospheric Turbulence, Optical Materials, Optical Design, Optical Elements-Lenses and Mirrors, Optical-Mechanical Scanning Techniques and Devices, Detectors, Charge-Coupled Devices, Imaging tubes, Photographic Film, Cooling Systems, Detector-Associated Electronics, Reticle and Image Analyses, Displays, Imaging Systems, Radiometry, Warning Systems, Tracking Systems, Ranging, Communications, and Simulation Systems, Aerodynamic Influences on Infrared System Design, and Physical Constants and Conversion Factors.

Laser scanning technology plays an important role in the science and engineering arena. The aim of the scanning is usually to create a digital version of the object surface. Multiple scanning is sometimes performed via multiple cameras to obtain all slides of the scene under study. Usually, optical tests are used to elucidate the power of laser scanning technology in the modern industry and in the research laboratories. This book describes the recent contributions reported by laser scanning technology in different areas around the world. The main topics of laser scanning described in this volume include full body scanning, traffic management, 3D survey process, bridge monitoring, tracking of scanning, human sensing, three-dimensional modelling, glacier monitoring and digitizing heritage monuments.

A review of stem volume and biomass equations for tree species growing in Europe is presented. The mathematical forms of the empirical models, the associated statistical parameters and information about the size of the trees and the country of origin were collated from scientific articles and from technical reports. The collected information provides a basic tool for estimation of carbon stocks and nutrient balance of forest ecosystems across Europe as well as for validation of theoretical models of biomass allocation.

This book presents contributions from the joint event 8th INGEN International Conference on Engineering Surveying and 4th SIG Symposium on Engineering Geodesy, which was planned to be held in Dubrovnik, Croatia, on April 1-4, 2020 and was canceled due to COVID-19 pandemic situation. Editors, in cooperation with the Local Organisers, are decided to organize the Conference on-line at October 22-23, 2020. We would like to invite you to participation through <http://ingeo-sig2020.hgd1952.hr/index.php/2020/08/31/ingeosig2020-virtual-conference-october-22-23-2020/>. The event brought together professionals in the fields of civil engineering and engineering surveying to discuss new technologies, their applicability, and operability.

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