EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Exploratory Workshop Scheme

Standing Committee for Life, Earth and Environmental Sciences (LESC)

Standing Committee for Physical and Engineering Sciences (PESC)

ESF Exploratory Workshop on

Laser Scanning Spatial Data Infrastructure (LaSDI)

Heidelberg (DE), 8-11 September 2011

Convened by:
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SCIENTIFIC REPORT

1. Executive summary

Detailed topographic information is important in a great variety of research fields aiming at mapping, modeling, exploiting and increasing the understanding of phenomena located on the Earth surface. Topographic airborne LiDAR, also referred to as Airborne Laser Scanning (ALS), has revolutionized the acquisition of elevation data by providing a tool for rapid, highly accurate and cost-effective data acquisition. The last decade has witnessed heavily increasing research effort on improving laser scanning sensors, data quality enhancement and stimulating new applications of the valuable datasets. A strong European expertise has been built-up since the 1990s and sensor manufacturers and data providers are closely cooperating with research institutions. Research initiatives and the respective results are strongly fragmented into isolated applications. Spatial Data Infrastructures (SDIs) play an important role in sharing, accessing, visualizing and distributing spatial data in decentralized way connecting multiple levels of competence and authorities. However, the integration of 3D laser scanning point cloud data and processing workflows into SDIs has not been discussed in an interdisciplinary scientific context and the broader benefits have not been assessed yet.

The Exploratory Workshop *Laser Scanning Spatial Data Infrastructure (LaSDI)* aimed at bringing together the scientific domains of Geographical Information Science (GIScience) and Remote Sensing & Laser Scanning technology in order to explore new concepts of integrating 3D laser data in SDIs. The LaSDI demands for novel interdisciplinary strategies, incorporating the rapid technological and scientific development of multiple research communities. The long-term goal of the workshop was to provide a kick-off for the development of an interdisciplinary European research infrastructure for laser scanning data and tools embedded in service-oriented SDI in order to support the vision of a *Digital Earth*.

The workshop rationale and agenda included:

- Provide scientific background and input for either community as basis for discussion
- Identification and formulation of key issues for integrating laser scanning point cloud data and analysis functionality into a (web-based) SDI
- Identify new interdisciplinary research directions and assessment of LaSDI applications with most benefit
- Initiate follow-up research and communication activities on a national and European level involving external organizations (e.g. EuroSDR, ISPRS and EGU) and stakeholders (e.g. public authorities)
- Develop a roadmap for collaborative research projects based on short-term and long-term milestones

The two-day workshop, 9-10 September 2011, was held in Heidelberg (Germany) at the Internationales Wissenschaftsforum Heidelberg (IWH) - a workshop center of the University of Heidelberg located in the old town at the foot of the impressing castle. Accommodation was provided at the IWH as well as nearby hotels in walking distance of the workshop center. The workshop hosted 19 participants from 11 countries (10 European countries and the US) and brought together 13 experienced and 6 young researchers. The two scientific domains i) GIScience/SDI and ii) Remote Sensing/LiDAR were represented almost equally w.r.t. participants. The speaker from the US (C. Baru) could not attend the workshop physically at last minute but provided a recorded presentation as well as impulse questions for discussion. The recorded presentation was no disadvantage at all as it was a very valuable input to the workshop.

The first workshop day was dedicated to scientific input organized in three sessions with two keynote presentations (N. Pfeifer and M. Craglia) of either scientific community. The aim was to "learn from each other" and to provide an adequate background (e.g. terminology) in either domain to foster discussion. Each session block comprised short presentations and a joint discussion on the session topic at the end of each session. The session discussion was moderated by the session chair(s). The second day was designed to start with two reports on running successful pilot reference projects (e.g. NSF OpenTopography and the Dutch national 3D SDI) followed by an extensive discussion block where the group was split into three groups. Each group defined a specific case study and use cases of a future LaSDI including the definition of SDI services, required data and tools. Thereafter, the outcome of the groups was discussed in the plenum and cross-links were identified. Finally, a summarizing and concluding plenary discussion at the end of the two days provided the basis for research directions and concrete short-term and long-term follow-up activities.

The general atmosphere of the workshop was very positive as all participants were highly motivated and actively participating throughout the whole workshop as well as thereafter for organizing the follow-up activities. Informal interaction between the participants (and ESF representatives) took place in the numerous coffee and lunch breaks. Furthermore, the social program included a guided night tour through the old town of Heidelberg on the evening of the day of arrival. After the first workshop day a workshop dinner was held in the old town of Heidelberg where further exchange of ideas and discussion took place in a relaxed setting.

The overall conclusions of the workshop were that the laser scanning point cloud (not only the derivatives) is an important source of 3D geoinformation. **Substantial added value can be generated by providing and making the point cloud available in spatial data infrastructures**, but there is a **lack of standards** for data (including metadata) and processing in a SDI environment. Participants were clear that a paradigm change has to take place for a LaSDI because **data and tools to process and analyze the data have to be provided together**. Laser data and tools shall be exchanged (e.g. open source project for data and tools in Europe): Several institutions would provide their data and tools. Furthermore, special focus should also be put on **combining/fusion 3D laser data with other (complementary) geospatial data** already available in SDIs (e.g. imagery). **Interdisciplinary research is required** for a laser SDI: More scientific disciplines (e.g. computer science and geosciences) as well as stakeholders have to be included in the future. Agreed future activities include in a short-term a LaSDI session and meeting at the next European Geosciences Union (EGU) general assembly 2012, a joint proposal to extend the INSPIRE D2.8.II.1 Data Specification on Elevation by 3D point clouds, as well as a joint publication of the outcome (e.g. in a scientific journal). In a long-term, national funding accompanied by funding of European networking activities should lead into a substantial FP7 research project.

Public relations and dissemination of the ESF workshop was done on the workshop website - lasdi.uni-hd.de - where the programme booklet, presentations, materials and this report are available online. Furthermore, a press release on the university main website as well as a short article in the leading regional newspaper (Rhein-Neckar-Zeitung) could be launched.

2. Scientific content of the event

The workshop was divided into four sessions with direct scientific input by means of two keynote and several short presentations. At the end of each presentation session a discussion block was scheduled in order to discuss and summarize the presentations of each session in detail. Furthermore, two special sessions were dedicated to intensive discussion: One session with discussion in small groups followed by a session with a moderated plenary discussion (see Section 5). Details on the schedule (e.g. coffee breaks, lunch and dinner) can be found in the workshop programme (Section 4). The following summary of the scientific content was compiled based on protocols provided by the session chairs Felix Morsdorf, George Vosselman, Martin Rutzinger and Marketa Potuckova.

Friday, 9 September 2011

The workshop was opened with a welcome address and mission statement presentation by the conveners held by **Bernhard Höfle**. This presentation gave a foundation of the workshop rationale as well as the need and benefit of a Laser Scanning Spatial Data Infrastructure from a European perspective. Additionally an overview was given of the scientific topics to be discussed (Fig. 1) and the scientific domains - i.e. 1) Laser Scanning/Remote Sensing and 2) GIScience Research - to be joined at this workshop. In order to give a clear structure and aim of the workshop several impulse questions were addressed such as:

- What type of laser scanning data should be included?
- Where do we generate added value of laser scanning data?
- Which Geo-Webservice and data format specifications have to be extended or newly drafted for a fully functional LaSDI?
- Which applications/domains benefit most from such a LaSDI (use cases)?

The introductory presentation ended with an overview of the workshop schedule including scientific and social program.

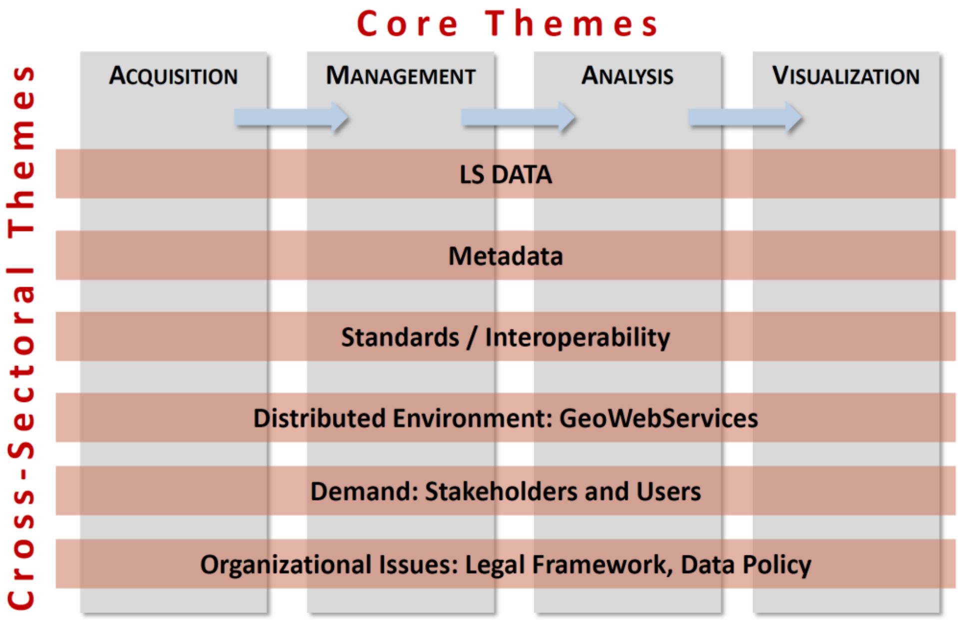

Fig. 1: Core and cross-sectoral topics of a LaSDI reflecting the framework for the scientific exchange of the workshop.

Next, the presentation of the European Science Foundation was held by the official ESF rapporteurs **Constantin Doukas** for the Standing Committee for Life, Earth and Environmental Sciences (LESC) and **Ramiz Hamid** for the Standing Committee for Physical and Engineering Sciences (PESC). They introduced the goals, agendas and structure of this independent association across 30 European countries and all scientific domains. Importantly, the funding instruments and ESF activities were explained in detail. Furthermore, the latest organizational developments such as the possible transition of the ESF to *ScienceEurope* were shortly announced and explained.

Session 1, chaired by **Felix Morsdorf**, provided an introduction into the technical basics of airborne laser scanning (ALS) (Norbert Pfeifer, Keynote), a view on ALS data management using different data bases and spatial indexing schemes (Gottfried Mandlburger) as well as an insight into compression methods for 2.5D elevation data (Maria A. Brovelli).

►The first keynote presentation, held by EuroSDR Commission II president **Norbert Pfeifer**, aimed at giving a broad overview of the laser scanning technology and data for the GIScience community. The presentation included the physical foundation and the measurement principle, properties of the primary result (i.e. the 3D point cloud) and what current and future developments on sensor, platform and application side are expected. It was concluded that airborne laser scanning technology has a continuing development w.r.t. acquisition parameters (e.g. flying height, pulse repetition frequency, radiometric measurements and multiple wavelengths) and accuracy improvement by georeferencing. Complementary to airborne platforms, dynamic and static terrestrial platforms are increasingly applied. Furthermore, investigations for future satellite platforms for global coverage are ongoing. Processing of laser scanning data is an integral part of quality of raw data and derived products. To date, the wealth of information is not exploited due to missing standardized access to data and tools.

►Next, **Gottfried Mandlburger** gave a presentation of "LiDAR Data Management from a trans-national perspective". Based on a specific example, the OPALS Data Manager, it was shown that 3D point cloud spatial indexing for huge data volumes (~10^9 points) is feasible. This requires a bridge between the persistent storage in a geodatabase and a spatial cache during data processing. It was shown that solutions (e.g. spatial indexing) for point cloud management in existing geodatabases and international standards for vector data are already available. Standardization efforts are still required for spatial referencing (e.g. vertical transformations), in particular across countries, and for temporal referencing in the laser scanning domain. Furthermore, LiDAR has to be seen as multi-sensor systems, in particular airborne LiDAR where having access to the trajectory is as important as the point cloud.

► **Maria A. Brovelli** presented the problem of efficiently store and transfer the high resolution digital terrain models (DTMs) nowadays available through the Internet, without losing their original accuracy. In a distributed web-based SDI as well as for virtual globes the challenge of improving data transfer by compression without loss of accuracy plays an important role. An approach for DTMs from LiDAR is shown using an analytical model (where only the coefficients in different levels have to be transferred). The presented approach was evaluated and a drastic increase in data volume (and thus transfer time and bandwidth) could be achieved (>90%), indicating the potential for new compression techniques for high density, highly accurate LiDAR DTMs and their usage in web-based server-client environments such as a future LaSDI.

►In the following discussion, it became evident that ongoing standardization efforts (e.g. through INSPIRE) of digital elevation data do not cover the point cloud, the raw data product of ALS, on which all following products are based. From G. Mandlburger's presentation, it was drawn that flight strip based file formats for storing the ALS point cloud (including GPS time stamps, e.g. LAS) and an additional file containing the flight trajectory will be need to allow for re-processing of the data and are the most efficient in terms of I/O. Another question raised was whether upcoming on-board processing of full-waveform (FW) ALS into discrete points would mean that valuable information is hidden from the (educated/scientific) user. However, more research on the value of FW-ALS (especially for vegetation applications) will be needed to answer this question. Still, it should be noted that there are currently no open formats for the storage and exchange of FW-ALS data.

Session 2, chaired by **Lars Bodum**, provided an introduction into the next generation SDI embedded in the vision of a Digital Earth (Max Craglia, Keynote), the importance of metadata (Claire Ellul) and how efficient processing can be standardized in a SDI (Sandra Lanig). This session aimed at giving a scientific input to the Laser Scanning Community from the SDI community side.

► **Max Craglia** of the European Commission Joint Research Centre (JRC) gave a keynote lecture on next generation spatial data infrastructures embedded in the vision of a Digital Earth. First, a short introduction of the JRC was given, which for example has the task of the technical coordination of INSPIRE. It was emphasized that most grand challenges for understanding and managing the complex interactions between society and the environment (e.g. environment and natural resources, global change, etc.) require a global to local perspective in 3D/4D (e.g. inside buildings and under water) and a tool to visualize present, past and future through historical data and integrated models (i.e. models across disciplinary boundaries). This *Digital Earth* shall contribute to a shared understanding how the Earth system works and how human activity impacts. The Digital Earth shall be dynamic and interactive as well as participative where people provide data (e.g. volunteered geographic information) but also make sense of science. Furthermore, the Digital Earth shall be ubiquitous, meaning that it is open and accessible for people and things on line at all times.

The JRC contributions to building the Digital Earth are
- Spatial Data Infrastructures: Data and services seamlessly across borders
- Multi-disciplinary interoperability
- Citizen science and social networks

The INSPIRE directive is developing an infrastructure for spatial information in Europe based on those established and maintained by the member states. First fruits of INSPIRE such as increased interoperability of metadata and services in Europe, with new data specifications and data models are on their way. Future initiatives will further integrate additional data streams (e.g. more real-time and quality-controlled data, sensor networks and data from citizens via social networks) and further public participation. But more heterogeneous and dynamic data require however to address new scientific challenges in their own right including issues of data quality, data synthesis, spatio-temporal analysis and visualization. Another important issue pointed out in the presentation was the interoperability of processes in order to answer the questions "what do you do with the data", which directly applies to LiDAR data as well.

►In the presentation of **Claire Ellul** the importance of metadata was highlighted. After an introduction on metadata the SECOA project (EU FP7 multi-national project) was introduced. It was raised whether metadata acquisition and automated metadata analysis are solved problems or still open issues. For example, who decides what metadata should be captured? Shall it be agreed in committees or driven by (research) applications? Who makes the differentiation between data and metadata and where to store the metadata? What kind of detail should be captured - differentiating between minimal metadata, which is easy to produce but perhaps not useful for evaluation, and over-detailed metadata, where production is an onerous task but the results may be more useful. In general, metadata helps to make appropriate use of datasets possible. Without metadata, it is very difficult to perform valid scientific comparisons and build generic models and to correctly, scientifically use datasets and integrate datasets from multiple sources. The presentation concludes that there is a great similarity between the metadata requirements for the LaSDI and other SDI. However, what elements of metadata shall be captured, can be automated or automatically triggered (e.g. by integration of data and metadata into one system) may be specific for a LaSDI.

►In her presentation **Sandra Lanig** gave insights into efficient 3D geoprocessing in a SDI based on standardized services and tools. Main emphasis was put on the Open Geospatial Consortium (OGC) Web Processing Service (WPS) as tool for 3D geoprocessing in a service-oriented architecture. Main issues point out were i) interoperability of processes (e.g. granularity of processes and domain versus generic processes to be defined) and ii) performance and storage challenges when dealing with vast amounts of laser scanning data. To solve the processing performance issue, it is shown that Grid computing technology based on Open Grid Service Architecture (OGSA) Standards can be applied. In the presented approach Grid services (WSRF) are encapsulated via OGC WPS. This so-called "Grid-enablement" of OWS to a Grid environment allows the processing of large 3D datasets exemplified by a Geotesselation and a Terrain Level-of-Detail Service. W.r.t. laser scanning data the standardization of processes as via OGC WPS profile (e.g. for laser scanning data) can ensure fully-automated interoperability in geoprocessing. This would make reuse of code possible, allow orchestration of processes and semantically-driven service discovery. The question remains whether elementary operations for laser data can be defined and described in WPS profiles (including semantics and a taxonomy)?

►The discussion addresses the need for communication of science with respect to a Digital Earth, which includes SDIs and thus the LaSDI. It is noted that the organizational cross-sectoral theme (Fig. 1) "legal framework" can and should not be subject of this workshop.
Furthermore, the taxonomy for laser scanning specific web processes is put into question as the benefit of such a taxonomy is not given for certain participants.

<u>Session 3</u>, chaired by **George Vosselman** and **Martin Rutzinger**, gave an overview of laser scanning data applications including analysis and visualization. Recommendations for further research as well as the discussion afterwards are summarized below.

► **Frédéric Bretar** presented the task of segmentation of LiDAR data based on 3D point cloud and full-waveform data. Examples of clustering and classifying point clouds in urban areas and object extraction in forested areas were presented. Remarks on future actions included that i) we should create a collection of available LiDAR data in Europe, ii) we are in need of a benchmark for point cloud segmentation algorithms, iii) landscape predictors are required to optimize classification and recognition, iv) airborne and terrestrial laser scanning should be linked in an SDI. Furthermore, v) the tradeoff between costs/resolution and algorithm performances should be analyzed and vi) the synergy with other sensors should be further explored.

► **Felix Morsdorf** explained the possibility to derive biophysical vegetation parameters from airborne laser scanning. It was shown why the 3D point cloud should be used for derivation (e.g. no loss of information and 3D structure contained). However, algorithm development and implementation of point cloud algorithms are more complicated than for raster models. He concluded that i) handling of huge data volumes is a problem, ii) relevant metadata should be maintained along the processing chain, iii) knowledge transfer to users is necessary to provide future-proof data, and iv) understanding of the measurement process is required to serve the applications.

► **Pauline Miller** reported on the LiDAR applications and challenges in the context of natural hazards and engineering solutions. It was shown that LiDAR data offers a valuable resource to meet the demands of high quality geospatial information in the case of natural hazard applications (e.g. landslides/rockfalls, coastal erosion and volcanoes). She concluded that i) airborne and terrestrial laser scanning should be linked, ii) synergy with other sensors should be further explored, iii) there's a lack of expertise in point cloud analysis and processing, and more knowledge exchange is required, iv) point cloud processing should move from file based to spatial databases management, v) better integration into GIS is required, vi) distributed processing should be further studied and vii) point clouds should be accompanied by better metadata. Furthermore, a standardization of LiDAR attributes (e.g. intensity values and waveform parameters) should be achieved.

► **Monika Sester** presented the current research on 3D generalization comprising simplification of geometry, terrain-dependent aggregation of 3D city models, semantic based generalization as well as generalization of dense digital terrain models while enhancing important objects/structures. It is concluded that i) definition of LOD's should be further developed for specific semantic 3D objects (e.g. bridges and aggregated buildings), ii) further research is required on 3D semantic generalization and quality description of generalizations, iii) when generalizing landmarks should be emphasized such as for navigation tasks but for certain applications raw LiDAR point clouds are sufficient. Furthermore, the full range between visualization of raw data and partially/fully interpreted data should be explored. The question was raised whether raw data need specific approaches for SDI or is it "just" a technical problem?

►The discussion was based around three prepared statements:

(1) Point clouds are nice for making visualizations and DTMs, but there's a big gap between point clouds on the one side and an object oriented 3D SDI on the other side. Massive point clouds can only be useful when tools are available for point cloud understanding (cf. scene understanding in computer vision). How to close the gap?

<u>Opinions</u>:

- Processing algorithms are part of the SDI. More emphasis should be given on formal descriptions of processes.
- Both, point clouds and derived products, e.g. DTM, should be available through SDIs (cf. presentation of C. Baru on OpenTopography below).
- Making data publicly available may boost the development of applications.

(2) Point cloud sizes are not the problem. Internet bandwidth and technology for database management, streaming, and compression are well suitable for interactive browsing through petabyte point clouds. We just need good software engineers to implement it.

Opinions:
- Point cloud compression required further study as well as level of detail and generalization of point clouds.
- Point cloud services should be able to work with distributed databases.

(3) We have already point clouds acquired at different times (multi-temporal point clouds). Which strategies do we need to store and analyze multi-temporal point clouds?

General opinion:
- Storage is not the problem, but tools for analysis need to be developed.

Saturday, 10 September 2011

In Session 4, chaired by **Marketa Potuckova**, two case studies demonstrating an implementation of 3D data sets on different levels of (pre)processing into spatial data infrastructures were presented during the session by Jantien Stoter and Chaitan Baru.

► **Jantien Stoter** presented results of the "3D Pilot" run in the Netherlands from March 2010 to June 2011. Starting from the point that technologies for 3D data acquisition as well as tools for its processing and managing have rapidly developed in the last decade while its implementation in everyday processes is seldom, the pilot objectives were to demonstrate the advantage of 3D in comparison to 2D topography and to define what steps and efforts are necessary to exploit its added value. 68 partners from public, private and scientific institutions joined the project to share datasets, technologies and experience. As a result, a new standard - 3D CityGML implementation profile for large scale topography called CityGML-IMGeobased - was established and a need of a nationwide reference 3D dataset was expressed. An example of 3D topography created by a combination of 2D topography and objects derived from high density ALS data was presented as another promising output of the pilot. The questions asked after the presentation referred to the following points:

1. The pilot was opened for a large community and the number of active participants was relatively high. To achieve this, a large number of potential users of 3D data was addressed and up-to-date communication tools were utilized within the project e.g. Twitter.
2. Implementation of the CityGML standard.
3. Access to the original point clouds.

► **Chaitan Baru** introduced the project *OpenTopography* that represents a web service proving an access to high resolution laser scanning data (both point clouds and automatically derived DTMs or DSMs) and tools for visualization, processing and management of LiDAR data. The available data sets cover selected areas of the US OpenTopography is a part of the Geoscience Network (GEON) project supported by the National Science Foundation. In the presentation the data infrastructure, storage and data management issues were addressed. Diagrams showing statistics of data access by users were presented. As the speaker could not attend the workshop, the presentation was played from a recording C. Baru performed the day before.

► Discussion after the presentations addressed the following topics:

1. OpenTopography is an example of an SDI containing point clouds as well as tools for their processing. The question is if it covers all the needs of the LiDAR community, if it is an option to develop a similar service for European users or to extend OpenTopography to other areas out of the US where the data sets are available. Another issue is financing of such a project (FP of EC, EuroSDR).
2. In connection to both projects the question of free access to point clouds and derived products as well as tools for data visualization and processing was discussed.
3. As a lesson learned from the presentation of J. Stoter, the discussion about importance and advantages of integration of point clouds to SDI should be brought to the broader geo-community (also geographers, geologists, etc.).

After the last session with presentations <u>extended discussions in small groups</u> followed. The superior topics of the groups were defined by the conveners and staffed to reach a relatively homogeneous distribution of scientific domains and competences. The goal of the groups was to identify the required i) data/metadata and ii) services for three specific use cases that could be part of a LaSDI. The use cases/groups were

1. LaSDI and Digital Terrain Model (DTM) with access to elevation and slope
2. LaSDI and Man-Made Environment: Wheelchair routing
3. LaSDI and Vegetation: Monitor growth of individual tree for precision forestry for the municipality of Heidelberg

After the group discussions the outcome was presented by the group speakers in the auditorium. For example the following conclusions and research questions were raised:

- The point cloud (and even flight path) including metadata and additional point attributes (e.g. timestamp, strip ID) should be included in a LaSDI.
- Data quality (e.g. of point cloud and DTM) can change with different/new assessment approaches and reference data (--> store original data).
- For implementation of use cases stakeholders have to be included in the discussion.
- Is it possible to have/include laser scanning from the crowd (volunteered geographic information), e.g. by using the Kinect sensor?
- How to formalize processes in a specific domain (ALS point cloud processing)?
- How to use which metadata in order to derive processing parameters automatically?

The last block of the workshop was dedicated to discuss <u>future activities and funding opportunities</u>. The ESF representatives provided additional input for possible grant opportunities.

3. Assessment of the results, contribution to the future direction of the field, outcome

The workshop brought together experts from the Geographical Information Science and from Laser Scanning/Remote Sensing research. This first meeting of its kind allowed discussing new innovative topics from different point of views. In particular the small group discussions dealing with concrete case studies amplified the exchange of knowledge and ideas. The feedback from the participants during and after the meeting was very positive. Lessons learned included on the one hand a better understanding of (web) processing services in a SDI for laser scanning experts as well as more insight into aspects such as standards of data and services, metadata, ontology/semantics of processes, which are fundamental for a service-oriented SDI. On the other hand, the benefit of highly accurate topographic data from LiDAR (with focus on future spaceborne systems with global coverage) for the vision of a *Digital Earth* for a sustainable social, environmental and economic development was emphasized. This includes the public access and availability of data as well as tools and algorithms to dynamically analyze and interpret the data for specific applications and needs.

The workshop clearly confirmed the high importance and relevance of the scientific rationale of a LaSDI and the expected impact on a multitude of other scientific disciplines making use of the data and tools (e.g. geosciences; ecological, forest and agricultural sciences). Furthermore, the high social relevance of the LaSDI, such as important source of information in disaster management and emergency response, was underlined.

<u>Research objectives identified and agreements are</u>:

- The original LiDAR point cloud is a very important source of (3D) information. The technology for management and visualization of huge point clouds is already available in beta versions but there is a lack of standards for data and processing in a SDI environment.
- LiDAR data and tools (i.e. algorithms) belong together. This would be a paradigm change in SDI design where up to now data repositories and processing tools are separated (in different services).
- Interdisciplinary research is essential: Currently multiple disciplines research on and use LiDAR data, but interdisciplinary research is required for a laser SDI. More disciplines have to be included in the future (e.g. computer science and geosciences). Furthermore, domain experts, stakeholders and users have to be identified and included in the development process (e.g. also SMEs).
- The LaSDI is a tool for a multitude of use cases without any doubt. However, what are the specific social benefits that can be achieved? Specific pilot studies have to be initiated to clearly demonstrate the potential and broader benefit of the LaSDI.
- Laser scanning data is only one source of geospatial information: The combination and even fusion with other data sources is prior goal where fundamental research is required. Other data streams for combination/fusion range from are existing remote sensing data (satellite imagery), (point clouds from) aerial imagery to heterogeneous crowdsourced geoinformation (in 2D and even 3D).
- There is a clear motivation to integrate LiDAR (point cloud) algorithms in a SDI due to the valuable feedback of a large user community and diversity of datasets that will be applied. This will lead to more robust and generic algorithms: from experimental research tools to operational functionality. Furthermore, "re-inventing the wheel" will

be avoided if existing tools can be accessed and used as atomic parts in new workflows (i.e. chaining of processes). This requires a clear description of processes (e.g. metadata and taxonomy) in a standardized way.

Concrete actions and plans:

The future actions are divided into i) immediate actions of the workshop consortium and ii) mid-term to long-term actions with additional collaboration partners. It was discussed whether a new "European LaSDI" is really necessary: As a first step a close collaboration with existing solutions (e.g. NSF OpenTopography) should be sought and particularly the data specification of the European SDI (i.e. INSPIRE directive) should be extended to cover 3D point clouds. The national contact points of INSPIRE have already been contacted in order to extend the Data Specification on Elevation (see below). It was concluded that a joint full FP7 proposal should be prepared at the earliest 2012/2013. For this purpose further meetings of the workshop consortium will be organized. The next meeting will be at the European Geosciences Union (EGU) General Assembly in 2012 where a dedicated session will be installed (cf. EGU Session ESSI1.6: *Laser Scanning: 3D Spatial Data, Analysis, and Infrastructures in Geosciences*).

Immediate actions:

- Proposal to extend the *INSPIRE D2.8.II.1 Data Specification on Elevation* by 3D point clouds
- Dedicated session at the EGU General Assembly 2012 (cf. ESSI1.6)
- Collaboration with NSF OpenTopography (C. Baru): Assessment of collaboration possibilities (e.g. NSF Science Across Virtual Institutes)
- Dissemination of outcome in the EuroSDR (European Spatial Data Research Network, an organization bringing together academia and National Mapping Agencies from more than 25 European countries) via Commission 2 (N. Pfeifer) at the next regular meeting in Udine, Italy, 26.-28.10.2011.
- Special Issue in the International Journal of Spatial Data Infrastructures Research (IJSDIR) including a position paper of the outcome of the ESF workshop
- Publication of workshop presentations, protocols and scientific report on workshop website (http://lasdi.uni-hd.de)

Mid-term / Long-term actions:

- Assessment of laser scanning datasets that would be available to be integrated into a LaSDI: via EuroSDR and research institutions
- Assessment of potential tools/algorithms to be integrated into a LaSDI: via research institutions and companies
- Application of national grants to cover research accompanied by EU Networking Activities (e.g. ESF COST Action and FP7 Marie Curie Actions) in order to prepare a substantial European research project and strengthen the existing network of the ESF workshop
- Joint proposal to the FP 7 ICT / Environment Research (FP7-Cooperation, FP7-Capacities)

3D POINT CLOUD – AN ESSENTIAL GEODATA TYPE

The 3D point cloud is an essential geodata type that needs to be considered in the **INSPIRE D2.8.II.1 Data Specification on Elevation**. Some arguments are listed below advocating for the inclusion of the point cloud in the specification.

INTERFACE
A point cloud after proper geo-referencing containing all attributes originally measured is a well-defined product containing all the information captured. Metadata is necessary for describing its properties. It is the interface between data acquisition and data interpretation.

MODEL VARIETY
Models derived from the point cloud are tailored to a specific application. There is neither a proper definition of the (one and only) digital terrain model, nor the (one and only) digital surface model, in order to name just two. Elaborating this further, the terrain model has different desired properties for archeological prospection, ortho photo production, or stream network derivation. These properties include the type of surface represented, e.g., considering some objects to be part of the surface, or not, but also other properties like generalization or smoothing are of importance. Therefore, there is not one DTM that can serve all needs.

MODEL COMPLEXITY
There is a number of applications that require the point cloud to obtain results. Especially all cases where the structure in the 3rd dimension is of importance need to be performed on the point cloud. This applies, e.g., to some forestry applications. You could argue, that complex models are derived from that point cloud and that these models should be stored. However, this would generate a large number of models, some of which may only be relevant and understandable for a small group on the one hand, and they may only be of transient nature, on the other hand. Thus there placement within an SDI is questionable.

FUTURE MODELS
The point cloud is a complete documentation of what was surveyed at the time of the mission. Storing only an interpreted version of these measurements, i.e. some models, may prevent future applications to exploit other aspects of it.

CORRECTION
Performing an application where 2 sources of data are combined or compared always allows a quality check. This may result in the conclusion that the point cloud is in some way wrong (location of points, value of attributes, or the metadata). Correcting or annotating the point cloud, rather than the derived model, will ensure that other applications benefit from the correction as well.

TRACEABILITY
Not only legal regulations concerning liability, but general standards on how to proper execute a certain task, require that this work can be re-done. This is only possible, if the raw data is available. Liability issues, for example, may force data providers to store the original point cloud. So it becomes a question of organization and data sharing policy how and where this point cloud is stored and how it is made accessible.

4. Final programme

Thursday, 8 September 2011

Afternoon	*Arrival*
ca. 20:00	*Guided Night Tour Old Town of Heidelberg*

Friday, 9 September 2011

Morning	*Arrival*
10:00-10:20	**Welcome and Mission Statement by Convenors** **Bernhard Höfle** (University of Heidelberg, DE), **Norbert Pfeifer** (Vienna University of Technology, AT) and **Alexander Zipf** (University of Heidelberg, DE)
10:20-10:40	**Presentation of the European Science Foundation (ESF)** **Constantin Doukas** (ESF Standing Committee for Life, Earth and Environmental Sciences - LESC) and **Ramiz Hamid** (ESF Standing Committee for Physical and Engineering Sciences - PESC)
10:40-12:10	**Session: LiDAR Data Acquisition and Management** **Chair:** **Chaitan Baru** (UC San Diego, US)
10:40-11:10	Keynote: **Lidar Principles and Airborne Scanning Lidar** **Norbert Pfeifer** (Vienna University of Technology, AT)
11:10-11.30	**LiDAR Data Management from a trans-national perspective** **Gottfried Mandlburger** (Vienna University of Technology, AT)
11:30-11:50	**Efficient data storage and network transfer by means of a compressed multiresolution DTM model** **Maria Antonia Brovelli** (Politecnico di Milano, IT)
11:50-12:10	**Discussion**
12:10-13:45	*Lunch*
13:45-15:35	**Session: Spatial Data Infrastructure (SDI)** **Chair:** **Lars Bodum** (Aalborg University, DK)
13:45-14:15	Keynote: **Towards the Next Generation Spatial Data Infrastructures: New Data, New Opportunities** **Max Craglia** (Joint Research Centre, European Commission, IT)
14:35-14:55	**Providing Guidance on Metadata Capture to A Multi-National Team** **Claire Ellul** (University College London, UK)
14:55-15:15	**Efficient LiDAR Processing in Standardized SDIs for Web-based 3D City Models** **Sandra Lanig** (University of Heidelberg, DE)
15:15-15:35	**Discussion**
15:35-16:05	*Coffee / tea break*
16:05-17:45	**Session: LiDAR Data Analysis and Visualization** **Chair:** **George Vosselman** (University of Twente, NL), **Co-Chair:** **Martin Rutzinger** (University of Innsbruck, AT)
16:05-16:25	**Segmentation of LiDAR data: Application on 3D point cloud and full-waveform data** **Frédéric Bretar** (Public Works Regional Engineering Office (CETE), FR)

16:25-16:45	**Derivation of biophysical vegetation parameters from airborne laser scanning** **Felix Morsdorf** (University of Zurich, CH)
16:45-17:05	**Applications and challenges in the context of natural hazards and engineering solutions** **Pauline Miller** (Newcastle University, UK)
17:05-17:25	**3D generalization** **Monika Sester** (Leibnitz Universität Hannover, DE)
17:25-17:45	**Discussion**
17:45	**Concluding Remarks** **Convenors**
19:30	*Dinner*

Saturday, 10 September 2011

08:30-09:45	**Session: Reference Projects** **Chair: Marketa Potuckova** (Charles University in Prague, CZ)
08:30-09:00	Case Study: **OpenTopography.org** **Chaitan Baru** (UC San Diego, US)
09:00-09:30	Case Study: **A national 3D SDI: case of The Netherlands** **Jantien Stoter** (TU Delft & Kadaster & Geonovum, NL)
09:30-09:45	**Discussion**
09:45-10:15	*Coffee / Tea Break*
10:15-11:45	**Brainstorming and Group Discussions: Discussion in small groups - LaSDI Requirements and Research Objectives to be identified:** **- Management** (Speaker:**Gottfried Mandburger**, AT) **- Analysis** (Speaker: **Frédéric Bretar**, FR) **- GeoWebServices** (Speaker: **Alexander Zipf**, DE) **- Standards and Interoperability** (Speaker: **Jantien Stoter**, NL) *- … further topics to be identified on Day 1*
11:45-13:00	*Lunch*
13:00-14:00	**Report of Results of Group Discussions** **Speakers of Groups**
14:00-14:30	*Coffee / Tea Break*
14.30-16:30	**Roadmap and Collaborative Activities** **Chairs: Convenors / ESF Representatives**
14:30-15:30	**Moderated Discussion: Definition of Joint Research Agenda**
15:30-16:30	**Specific Planning of Activities** **(e.g. Project proposal, Special Issue, White Paper)**
16:30	*End of Workshop and departure*

Sunday, 11 September 2011

Morning	Departure

5. Final list of participants

Convenor:

1. **Bernhard Höfle**
   Institute of Geography, University of Heidelberg

Co-Convenor:

2. **Norbert Pfeifer**
   Institute of Photogrammetry and Remote Sensing, Vienna University of Technology

3. **Alexander Zipf**
   Institute of Geography, University of Heidelberg

Participants:

4. **Chaitanya Baru**
   San Diego Supercomputer Center, University of California San Diego

5. **Lars Bodum**
   Department of Development and Planning, Aalborg University

6. **Frédéric Bretar**
   Public Works Regional Laboratory, CETE Normandie Centre

7. **Maria Antonia Brovelli**
   Laboratorio di Geomatica, Politecnico di Milano - Campus Como

8. **Massimo Craglia**
   Spatial Data Infrastructures Unit, Institute for Environment and Sustainability, European Commission Joint Research Centre (JRC)

9. **Claire Ellul**
   Civil, Environmental & Geomatic Engineering, University College London

10. **Sandra Lanig**
    Institute of Geography, University of Heidelberg

11. **Gottfried Mandlburger**
    Institute of Photogrammetry and Remote Sensing, Vienna University of Technology

12. **Leena Matikainen**
    Remote Sensing and Photogrammetry Department, Finnish Geodetic Institute (FGI)

13. **Pauline Miller**
    CESER Centre for Earth Systems Engineering Research, University of Newcastle

14. **Felix Morsdorf**
    Remote Sensing Laboratory, Geographisches Institut, University of Zurich

15. **Marketa Potuckova**
    Department of Applied Geoinformatics and Cartography, Charles University in Prague

16. **Martin Rutzinger**

Institute of Geography, University of Innsbruck

17. Monika Sester
Institute of Cartography and Geoinformatics, Leibnitz Universität Hannover

18. Jantien Stoter
OTB Research Institute for the Built Environment, Delft University of Technology

19. George Vosselman
Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente

ESF Representatives:

20. Constantin Doukas
Department of Historical Geology and Palaeontology, University of Athens

21. Ramiz Hamid
Ulusal Metroloji Enstitüsü, TÜBITAK National Metrology Institute

6. Statistical information on participants

In total 19 persons actively participated in the workshop. Chaitan Baru (US) could not join the workshop in person but provided a recorded presentation and important questions for discussion.

Countries of origin:

The workshop hosted participants from 11 countries (10 European countries and the US):

1. Austria (AT):	3	(15.8%)
2. Czech Republic (CZ):	1	(5.3%)
3. Denmark (DK):	1	(5.3%)
4. Finland (FI):	1	(5.3%)
5. France (FR):	1	(5.3%)
6. Germany (DE):	4	(21.1%)
7. Italy (IT):	2	(10.5%)
8. Netherlands (NL):	2	(10.5%)
9. Switzerland (CH):	1	(5.3%)
10. United Kingdom (UK):	2	(10.5%)
11. United States (US):	1	(5.3%)

M/F repartition:

- Female participants: 8 (42.1%)
- Male participants: 11 (57.9%)

The participants can also be divided into the two major scientific groups that formed the workshop.

Main scientific specialty:

- Remote Sensing/LiDAR/Photogrammetry: 9 (47.4%)
- GIScience/Computer Science: 10 (52.6%)

Age Bracket:

No detailed information on age was collected.

The composition of young and senior scientists according to the ESF definition (*'a young scientist/researcher is someone who at the time of the application has not been in an established position for more than 5 years'*) was as follows:

- Young scientists: 6 (31.6%)
- Senior scientists: 13 (68.4%)