Leica MobileMatriX

Mobile Data Collection and Maintenance Solution

Technical White Paper

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1 INTRODUCTION

1.1 THE LEICA MOBILEMATRIX STORY

The world can be represented in GIS (Geographic Information System) and CAD (Computer Aided Design) systems, showing us the position and attributes of objects, the location of reference points and countless other kinds of spatial information. Reference points are important for surveyors as they form the basis for computing new points to locate features together with their associated attributes.

Features are shapes in a spatial data layer, such as points, multi-points, lines, or polygons that represent real world geographic objects. These features are stored in databases. Only measuring points with features codes in the field leads to expensive subsequent work including data transfer from the sensor to office software, computation of new points, completeness control, and creation of new features with attributes according to code lists. LEICA MobileMatriX combines all these steps in one piece of software. Direct connection to field sensors allows both computation of new points, data collection and maintenance of shapes and attributes directly in the field. A map with a large amount of data and real world symbols provides immediate feedback for completeness and quality control.

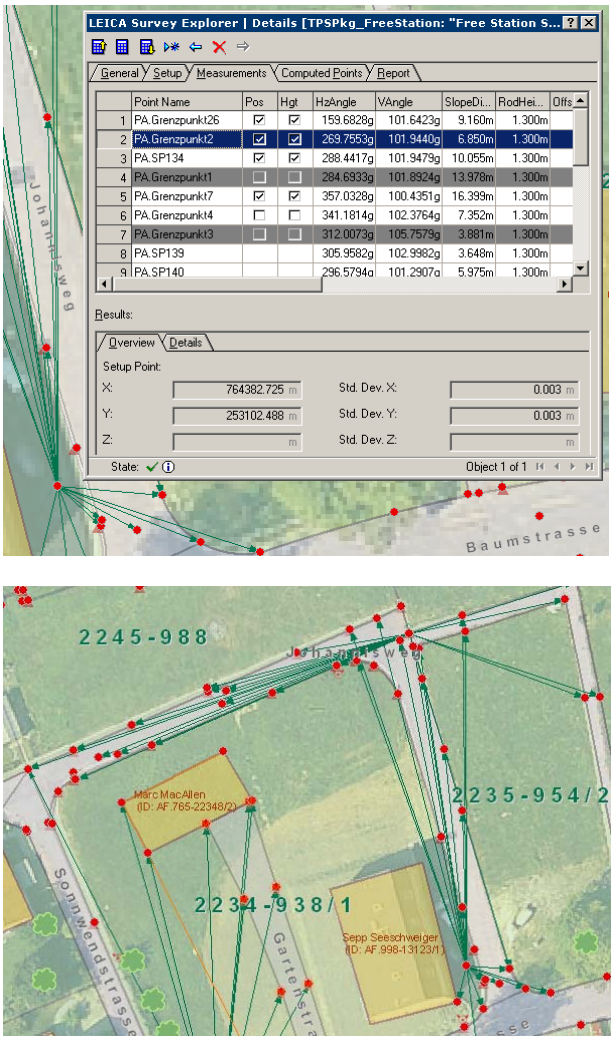


Figure 1.1: You see what you get: Quality and completeness control.

LEICA MobileMatriX allows the user to add points and measurements, completed by a surveyor in the field using either a TPS (Total Positioning System), GPS (Global Positioning System), or manual data entry from tape measurements, LEICA Disto™, etc., to the map. With LEICA MobileMatriX, you keep the history of the data and the data source is stored. This ensures that the quality of the data is always known. Additionally, it is also possible to write the attributes you see in the field directly into the database as objects are measured. This functionality extends GIS activities from the office to the field.

LEICA MobileMatriX combines surveying sensors (GPS, TPS, etc.) with a field computer. With LEICA MobileMatriX field crews have the possibility to directly control sensors, edit, collect, visualize objects, and perform mapping tasks directly in the field. Such functionality provides an opportunity for direct control of the completeness and quality of the work in the field. It also avoids expensive re-measuring when office quality control activities detect deficiencies. Field crews traditionally use to work with paper maps in the field; such techniques have several disadvantages, including hard handling, updating in the office, hardly usable in bad weather conditions.

Figure 1.2: Use of raster images (orthophotos, area photos, etc.) for easier orientation in field.

With LEICA MobileMatriX, field crews continue to take maps in the field, but in digital form, as background maps. This functionality provides significantly enhanced usability for field workers and makes their daily work easier.

The work of a surveyor does not end upon completing the fieldwork; fieldwork must be documented. This documentation is often conducted by means of creating a map. The task of map creation can easily be fulfilled with the layout functionality supported in LEICA MobileMatriX.

LEICA MobileMatriX provides interfaces to a wide variety of different office software solutions, such as GIS and CAD packages. Upon completing survey activities, synchronization of surveyed features and their attributes is seamless and easy using in LEICA MobileMatriX.

Few governments or private companies can afford money to measure a whole country or city by using GPS or TPS within a justifiable time. On the other hand, surveyors are measuring small parts of our world every day. Why not combine this data within one system? If the data could be combined, surveyors and GIS users could conduct their daily activities in harmony. By actively using GIS databases, surveyors can continually update the GIS database to reflect the most recent situation. LEICA MobileMatriX supports these workflows by disconnected editing.

1.2 Who uses LEICA MobileMatriX?

A LEICA MobileMatriX user is any person responsible for managing and collecting spatial information. They make measurements using sensors in the field to create and update maps and plans. LEICA MobileMatriX is suitable for:

- Cadastral offices
- Engineering companies (such as private surveyors, planners, utility companies, offshore companies)
- Governments and governmental agencies (such as mapping agencies and local authorities)
- Local governments and municipalities (e.g.: environmental and fiscal agencies, forestry departments, asset managers, regional and urban planning departments)
- Public safety organizations (military, police, fire departments, etc.)
- Consultants
- Facility managers
- Archeologists
- And many more.

Typical field crew problems and how LEICA MobileMatriX solves it:

Problem	Solution
More and more complex mapping areas and tasks	Graphical feedback and raster background (e.g.: orthophoto)
Collection and maintenance of huge amount of spatial information	TabletPC power, performance, and display size combined with complex data queries
Sensor flexibility	GPS/TPS connection, extensible with 3rd party sensors
One man field work (robotic)	Configuration of TPS through software/TPS tools such as joystick, TPS status/big map view for displaying the data
Increase of attribute collection	All information is stored in databases, customisable design of user interface
Surveyors are used to work with TPS and GPS and often not highly familiar with Windows user interface	TPS and GPS status similar to display on TPS and GPS sensors
Expensive re-measuring when something was measured wrong or forgotten	Completeness and quality control out in the field - you see what you do and what you get.
Office – field – office transfer will become more important	Check in/out of measured features
Survey point could have multiple thematic meanings	Multiple feature editing
Survey work is complex – sights not always possible – e. g. finishing feature not possible at all times	Pending feature editing
Information not available in the field (revision cycles)	All data (survey data and feature information) is available in the field – not only point IDs and their coordinates
Paper field books have disadvantage: updating in the office, not usable in bad weather conditions	TabletPC with electronic ink writing notes, doing sketches on the map

1.3 Why TabletPC instead of PocketPC?

Pros and Cons of PocketPC (PDA) and TabletPC:

	PocketPC (PDA)	TabletPC
Weight	**Light** (0.1 – 0.25 kg)	Heavy (< 1 kg – 2.5 kg)
Display	Small (3'' - 4'')	**Big** (8.5'' – 12'')
Performance	Low (> 500 MHz)	**High** (> 1.2 GHz)
Data and background info	Less (100 – 200 MB)	**Full** (20 – 80 GB)
Price	**Low range**	Mid range
Robustness	Less robust PDA	**IP67** TabletPC available
Outdoor usability	Less outdoor readable screen	**"Sunlight" screen**
Other usability	Limited	Other purposes

1.4 Product Concept

LEICA MobileMatriX is a software solution for the interactive processing, visualization and maintenance of survey data directly in the field. LEICA MobileMatriX is based on the latest ArcGIS™ technology from ESRI Inc., Redlands, CA and has been developed for the seamless dataflow between field and office. It was designed especially for the needs of field surveyors and GIS data collectors. With this new field solution, it is possible to extend the ArcGIS environment into the field. TPS and GPS sensors are now directly linked to the software. LEICA MobileMatriX performs extended survey data management for a variety of different computations. Processing functions are available in the field resulting in significantly simplified data acquisition and revision cycles. Furthermore, being graphical based, data quality and completeness control can be done immediately as data is acquired. LEICA MobileMatriX provides more than data collection and feature creation, points can be easily selected and staked-out using either TPS or GPS instruments.

All LEICA MobileMatriX products provide the same surveying, data collection, and maintenance functionality. Differences between the products are found only on the GIS side: With LEICA MobileMatriX Editions based on ArcGIS Desktop OEM versions certain GIS functionality is not available compared to standard ArcGIS Desktop installations.

- **LEICA MobileMatriX Standard Edition** is based on the ArcView OEM version of ArcGIS Desktop 9. Main functionality:
  - Easy management of survey projects and survey- and feature classes
  - Coordinate management supports multiple coordinates per survey point
  - Storage of raw measurements for post-processing
  - Multiple and pending feature editing
  - TPS and COGO Computations with customizable reporting
  - Computation Network Analyst
  - Import and export of survey data
- **LEICA MobileMatriX Professional Edition** is based on the ArcEditor OEM version of ArcGIS Desktop 9. Additional functionality to LEICA MobileMatriX Standard Edition includes:
  - Support of full ArcGIS data model
  - Disconnected editing
- **LEICA MobileMatriX on ArcGIS Edition** is an ArcGIS Extension running on any installed ArcGIS Desktop 9 product (ArcView, ArcEditor, and ArcInfo). Differences to LEICA MobileMatriX Standard and Professional Edition: Complete GIS functionality of underlying ArcGIS Desktop available.
  Product specific differences of ArcGIS Desktop product family (ArcView, ArcEditor, ArcInfo) can be found on http://www.esri.com/software/arcgis/about/desktop.html.
- **LEICA MobileMatriX Options** are available for all LEICA MobileMatriX products mentioned above. The following options are available:
  - **TPS Option**: supports Leica Total Stations.
  - **GPS Option**: supports Leica GPS sensors as well as any other NMEA compliant GPS sensor.
  - **GPS Real Time Processing Option**: supports LEICA SmartAntenna.
  - **Level Option**: supports Leica and 3rd party digital levels.
  - **Stakeout Option**: used to stakeout points in the field.
  - **Layout Option**: used to layout a map and print it.

- **Georeferencing Option**: used to support raster images as background.

1.5 KEY FEATURES

- **Field-to-Finish**
  LEICA MobileMatriX is a field system providing all functionality a field crew needs to finish work in the field. Background maps (e.g. orthophotos, raster images) combined with immediate map display and labeling of the field measurements gives feedback and control about correctness of measurements and avoids the need of expensive re-measuring. Layout functionality including symbology, legends and north arrows allows creation of complete maps out in the field.

- **Unrivaled method of data capturing**
  A measured point can have multiple thematic meaning, especially if features or one of its vertices builds a border to another thematic type (e.g. a hydrant marks the border between two parcels and a street). Multiple feature editing provides a unique way to capture/edit geometry and attributes of one or more features with one measurement. Pending feature editing technology allows direct editing of already existing features.

- **GIS Functionality in the field**
  Pan, zoom, map rotation, bookmarks, etc. are standard functionality of any software visualizing spatial information. ArcGIS additionally allows real world display (rendering of symbols and labels), joining data from different data sources to perform complex spatial data queries and analysis, geoprocessing (only with LEICA MobileMatriX on ArcGIS), customization of user interface and functionality, and much more functionality.

- **Survey Data Management**
  All measurements and feature attributes captured are directly stored in the ArcGIS Geodatabase. Multiple coordinates (with quality information) can be computed for one survey point displayed at the position of the mean or a user defined coordinate. Measuring features produces a survey point that is coincident with a feature or one of its vertices. The relation between survey point and linked survey feature is a loose coupling indicated with a link line. Dependencies between computations, survey points, and measurements are stored and can be traced easily; later corrections are propagated automatically by the *Computation Network Analyst*.

- **Sensor Management**
  LEICA MobileMatriX supports a bi-directional connection to almost all Leica TPS and GPS sensors; 3rd party GPS instruments are supported using the NMEA interface. Connection to sensors can be established either with cable or wireless communication (Bluetooth® or radio connection).

- **Survey and COGO Computations with Reporting**
  Computations calculate new coordinates for survey points from measurements and known reference points. LEICA MobileMatriX supports survey computations for TPS (Tacheometry, Resection, Free Station, Survey Traverse, and Stakeout) and COGO computations (e.g. basic, curve, intersections, and traverse computations). Documentation of TPS computations is created by an XML reporting engine; content and layout of the reports can be customized with style sheets.

- **Customization: Extensible with any COM compliant programming language**
  Any COM (Component Object Model) or .NET compliant programming language can be used to customize LEICA MobileMatriX to the specific needs of the client in both architecture and functionality. The innovative software architecture of ArcGIS is delivered as a completely open solu-

tion for developers. LEICA MobileMatriX has been engineered to these standards and is therefore fully customizable by end users and developers.

2 Technology and Concept

All concepts discussed in this chapter apply to LEICA MobileMatriX on ArcGIS Edition and LEICA MobileMatriX Standard and Professional Edition. The products only differ in architectural approach but not in technical or usability concepts.

2.1 LEICA MobileMatriX Architecture

LEICA MobileMatriX Editions are based on the latest ArcGIS Technology from ESRI Inc., Redlands, CA and are designed to provide survey-specific functionality. This solution extends the ArcGIS 9 Geodatabase adding a survey database for storage of survey data from field observations and a measurement network that maintains links between the stored measurements and surveyed points. Survey points are created and updated from measurements and predefined survey points through a set of computations and can be linked to GIS features.

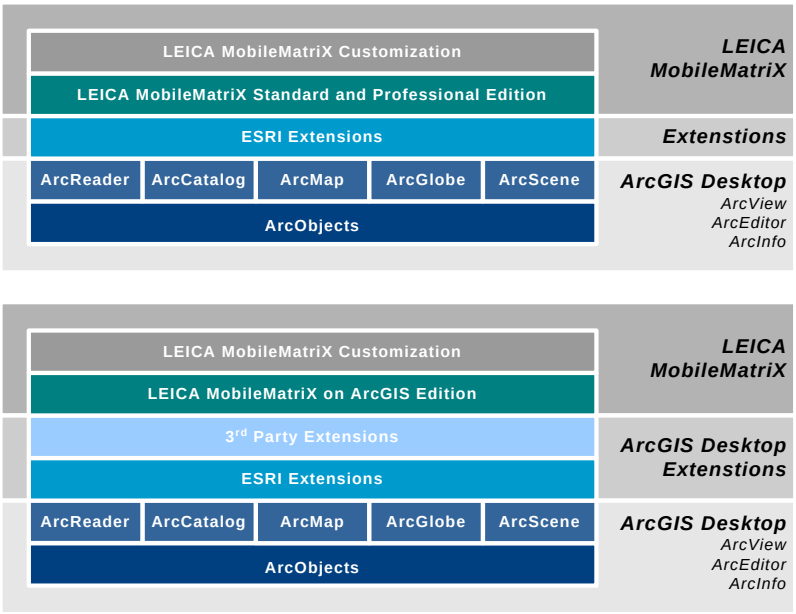


Figure 2.1: Architecture of LEICA MobileMatriX Standard and Professional Edition (upper) and LEICA MobileMatriX on ArcGIS Edition are based on the same ESRI ArcObjects components and allow enhancements and customization.

LEICA MobileMatriX is extendable to suit individual requirements through customization using any COM compliant language (e.g. Visual C++ 6.0, Visual Basic 6.0, or Delphi) or a programming language supporting the Microsoft .NET framework (e.g.: C# or VisualBasic.NET). ESRI ArcObjects components and LEICA MobileMatriX components can be used and extended with both technologies.

The workflow is ideally suited for work in the field with a TabletPC. It provides interactive graphic visualization and processing of all survey information. LEICA MobileMatriX has customized the functionality of ArcGIS Desktop 9 and designed it for the specific needs for working in the field.

2.2 ESRI Geodatabase and Surveying

The ArcGIS Geodatabase is an ESRI data storage format that allows persisting different geographic features and attributes within an RDBMS (relational database management system). For LEICA MobileMatriX, the Geodatabase has been extended to store survey points, measurement, and survey computations. Surveying information is hosted in survey datasets, survey projects, survey classes, and survey objects.

2.2.1 Survey Dataset

LEICA MobileMatriX introduces a new type of geographic dataset to the ArcGIS Geodatabase called the survey dataset. A survey dataset contains records for survey measurements, computations, and points. A survey dataset defines and manages the coordinates for a set of survey points. These survey points can be used to locate features in related feature classes. A survey dataset contains information for one or more survey projects and is characterized by its coordinate system and spatial extent.

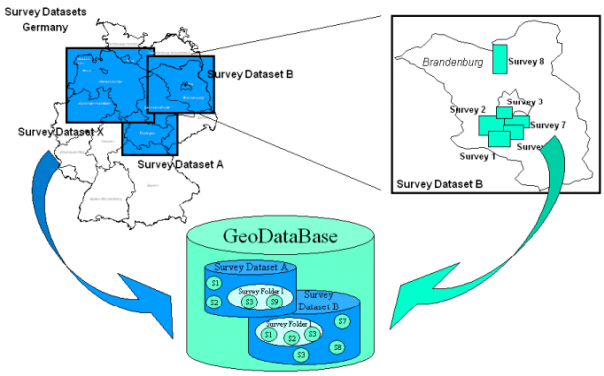


Figure 2.2: Survey Dataset and Survey Project – an example.

2.2.2 Surveying in GIS: Projects, Classes and Features

Survey Project

The survey dataset contains information gathered as a result of one or more survey projects. Survey projects are used to organize, manage and view the information available in the survey dataset. Created for a particular task or purpose, survey projects could be used to represent a job. For example a property survey project, control network survey project or topographic survey project. The points established within survey projects can be associated with features stored in tables of the same ArcGIS Geodatabase.

Survey Classes: The Five Types

- **Coordinates**
  A coordinate defines a position on the earth's surface. Coordinate values only make sense to a user if information on the definition of the coordinate system is available. A survey point gives the location defined by the coordinate a name and makes it possible for the user to identify it.

- **Survey Point**
  A survey point collects coordinates that describe the same position on the earth's surface. One corner of a building can have multiple coordinates, e.g. one from a GPS campaign, one measured with TPS in 1987, and one measured in 2001. Three coordinates which describe the same corner with the same point name. Nevertheless, the values for the coordinates will be different - depending on the reference points, accuracy of the instrument/sensor, experience of the surveyor, and method used. The user decides which coordinate or coordinates (averaging) he wants to use. In LEICA MobileMatriX, it is no longer necessary to lose information by overwriting former results, they are all stored with the survey point and available whenever you need them.

- **Simple Measurements**
  Measurements are derived from field observations. For example, a slope distance observation from a TPS, a corresponding vertical angle and horizontal angle observation define a measurement. Alternatively, they may be entered directly from survey plats (e.g. bearing and distances associated with property boundaries). This set of observations that complement each other is

called a measurement. All observations have a degree of uncertainty and hence no measurement is perfect. It is the knowledge and experience of the surveyor to determine the reliability of measurements for example, through techniques that are dependent on the standard deviations of observations taken from field instruments and other sources.

- **Composite Measurements**
  A composite measurement is a group of simple measurements that are related and dependent on one or more other simple measurements in this group. A good example of a composite measurement is an instrument setup. It can be defined as a session of observations from an instrument occupying a survey point. Each setup is the composition of the set of simple measurements made during that setup.

- **Computations**
  Computations are a heterogeneous set of objects that are defined by rules and algorithms for deriving locations for new or pre-existing survey points. COGO constructions are computations used for creating or editing features. Every computation and its results are stored in the database, can be viewed in the survey explorer and visualized on the map.

The following diagram presents the dependencies between survey object types:

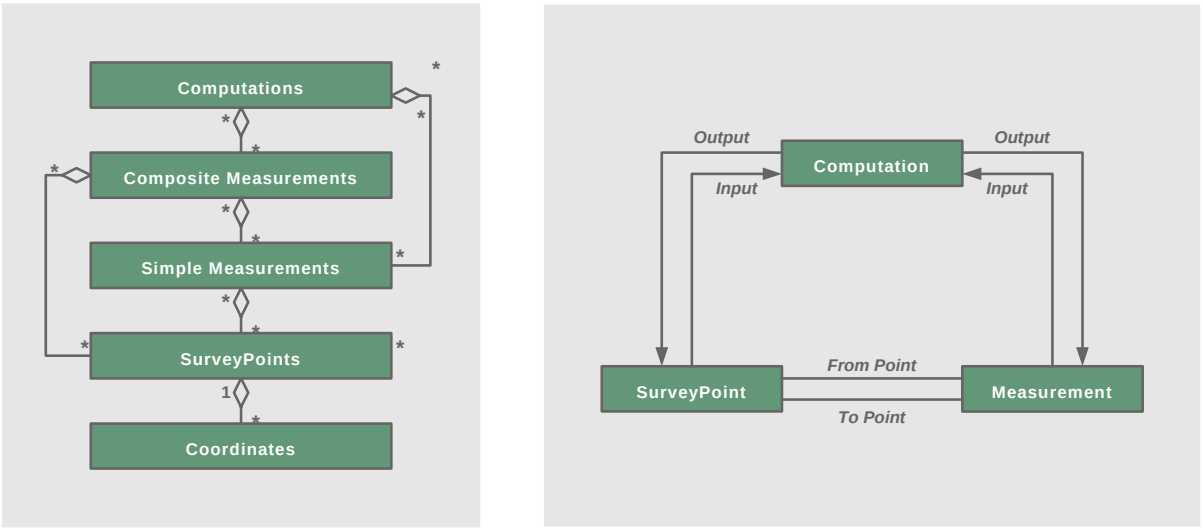


Figure 2.3: Dependencies between different types of survey objects (left) with extra focus on relations between computations, survey points and (simple and composite) measurements (right).

LEICA MobileMatriX supports the concept of multiple coordinates per survey point. For each coordinates location, quality information and origin (computed or imported) is stored in the ArcGIS Geodatabase. The user can decide if the position of the survey point is computed automatically (mean coordinate) form the associated coordinates or if a particular coordinate is used to set the location of the survey point. This mechanism provides on one hand an approved solution with an average (mean) coordinate and on the other all the flexibility a user needs to select the preferred coordinates manually. This eliminates losing old information and permits continuous navigation through computations.

Survey Features

When surveying, a survey feature will be created for each real-world object. LEICA MobileMatriX makes it possible to fill the gap between surveying and GIS by using survey points to define the vertices of features. This allows the user to link the existing feature data with the points measured in the field. Instead of deleting valuable thematic information and creating a completely new feature, the existing feature can be transformed to the accurate position measured in the field or new features can be surveyed while the thematic feature information is linked to the survey point.

By linking features to survey points it is possible to associate feature geometry with the accuracy defined for the survey points. This gives the user additional knowledge about the quality of features, whether they come from an old map that has been digitized or from a highly accurate GPS survey. With LEICA MobileMatriX, it is always possible to have information on feature source and quality.

Survey points are associated with measurements and computations and can be linked to features in the ArcGIS Geodatabase. These features are called survey features. Survey features should not be thought of as different to any other features. They are simply features that have become survey-aware and are created while a survey task is performed.

2.2.3 Data Management

Defining databases, datasets, feature classes, tables, relationships, format conversions, database connections, and many other data definition and administration tasks is usually done with ArcGIS Desktop's ArcCatalog. The *Data Manager* integrates this functionality seamless into LEICA MobileMatriX and enhances ArcCatalog with the ability to administrate survey databases, survey projects, survey classes, and their relationships to common existing feature classes.

The user interface of LEICA MobileMatriX makes the user's experience of creating and working with survey projects, survey classes, and feature classes a natural extension to commonly recognized methods used in survey offices. Handling and usability is strongly orientated to the well-known user interface of ArcGIS Desktop.

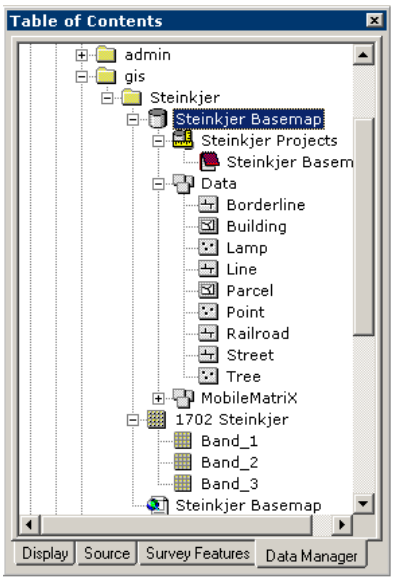


Figure 2.4: Data Manager as replacement for ArcCatalog.

2.2.4 Integration of Surveying and GIS: Feature Linking

Linking Features to Survey Points

Measuring features produces a survey point that is coincident with a feature or one of its vertices. If a survey point moves (due to more accurate measurements) the measured features of this survey point stay at their original position – repositioning of the features is not forced automatically. Instead, a link line indicates the relation between features and survey point. Several commands can be used to update the position of the measured features and set it to the location of its survey point.

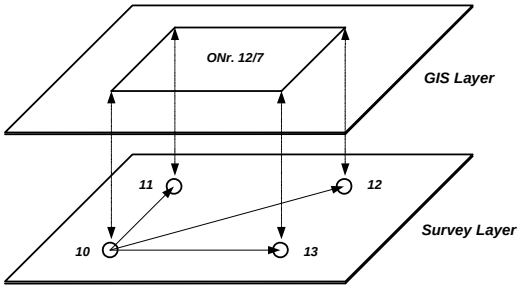


Figure 2.5: The link between survey and GIS data.

Figure 2.6: Viewing link lines in LEICA MobileMatriX.

Survey features are adapted by LEICA MobileMatriX to store additional information that is used to create links between feature vertices (nodes) and survey points. If a feature is "linked", a survey point and the geometry of a feature vertex (the XY position on the map) are associated with each other but are not necessarily coincident. In other words, a link does not mean that survey points and vertices of survey features are automatically presented at the same location in the map. If feature vertices are linked to survey points, the link is presented graphically on the map as a link-line and a symbol is used for the survey feature vertex.

Updating Lined Features

Typically, the goal is to have survey feature vertices and linked survey points sharing the same locations. The process of updating the map based on links is a GIS process for which LEICA MobileMatriX provides all the necessary information.

The final result of an update is that each survey feature geometry is altered to coincide with the geometry of the linked survey points.

Automatic updates of features are possible in LEICA MobileMatriX, but not always desired. The concept behind this field software is to allow the cartographic version of a map to remain intact, while simultaneously associating features in the map with measured survey points. This permits a high level of user control over feature updates.

Creating Cloned Survey Features

Creating a clone of the selected feature or features results in a new survey feature being created from each selected feature that has the same attribution as the cloned one, but no geometry. If a clone is required of an existing survey feature then the clone command can be used. If the ArcGIS Geodatabase requires that surveyed features have many items of attribution set it may be more convenient to perform a clone of a selected feature, or another survey feature.

2.2.5 Disconnected Editing

LEICA MobileMatriX provides tools for synchronizing the office database with the field database and vice versa. Many mobile users, such as a field survey crew, require similar functionality. They need to work independent from an organization's infrastructure and database connection, often for a longer period. When preparing for a particular work order or project, the relevant data would be transferred to a portable device, such as a TabletPC. This device would then be disconnected from the network, enabling the user to operate independently.

Mobile users may then continue to work with and modify the data even though they are disconnected from the network. When a connection to the network is re-established, any changes made to the data can be transferred to, and integrated with, data maintained in the central database.

ArcGIS Geodatabase disconnected editing allows organizations to disseminate their spatial data to other departments, associated agencies, or mobile workers and maintain the integrity and currency of that data. The disconnected editing functionality is provided by ESRI. As with checking out data, the check-in process involves an automated process.

This process begins by selecting all or only a specific set of features from multiple feature classes. All features used for working in the field are checked out from the Enterprise Geodatabase (ArcSDE) into a Personal Geodatabase represented by a Microsoft Access database file running on the field system (e.g. a TabletPC). Data capturing and feature editing in the field is performed in disconnected mode and completely offline: All changes are stored to the Personal Geodatabase. Afterwards fieldwork data has to be synchronized with the master database in the office. Special tools help to detect the changes of the data in the field and only check-in the differences between Personal and Enterprise Geodatabase.

The process of check-in/check-out is based on the Geodatabase versioning concept. Checking out a part of the Geodatabase creates a new version in the master database. A copy of this version, a Personal Geodatabase, is used for working in the field. When checking back in, changes are directly transferred to the corresponding version in the Enterprise Geodatabase: there is no version reconciliation at this point with the check-out version living in the Enterprise Geodatabase. If the check-out version for working in the field has been modified since the data was checked out, these changes are overwritten when checking in. The standard process of checking in allows to reconcile and post all changes of the check-out version with its parent version. It is up to the user to perform reconcile and post immediately or after some post-processing. After successful reconcile/post to the parent version all associated check-out information (e.g. list of datasets checked out) is removed both from the master database and the check-out database. Any versions created in the Enterprise Geodatabase are also removed. However, deleting the copy of the Personal Geodatabase that was checked out or any residual copies of the data once checked-in remains choice of the user or data administrator.

LEICA MobileMatriX Professional Edition includes disconnected editing of features. That means features can be checked out from an ArcSDE database to a Personal Geodatabase and edited while the field worker is disconnected, using the tools provided by LEICA MobileMatriX. Later the new and edited features can be checked in and reconciled with the master database. This process applies for features but not for survey objects, because they do not participate in the check-in/check-out process at the moment. That means the user is able to modify features in the check-out database, based on the links established between the features and the survey points, but while the features will be synchronized with the master database during check-in, survey objects will not. This does not mean that the link information or the survey information is lost, but it will not be visible in the master database. In order

to maintain link information later the user has to check out the features to the local database used in the field. Since this database still contains the original survey objects, the link information will be available again and the user can start using it in order to modify the features.

2.3 Survey Explorer and Map

A field-book is used to record the original survey measurements. Field book functionality is integrated into LEICA MobileMatriX and all measurements, setups, and additional information are stored in the database. LEICA MobileMatriX replaces the traditional field-book with a dialog called *Survey Explorer* that is used to display survey measurements (such as TPS and COGO), computations, and survey points. Additionally, the Survey Explorer is used to bring the content of the database to the user level by displaying the computations, their results, and provides the ability to navigate between different computations, survey points and measurements.

The Survey Explorer is based on detail and list views equipped with functionality for navigation between related survey objects. As an additional concept the Survey Explorer provides a look and feel most users are familiar with: back and forward navigation between pages is a concept originally from internet browser applications. The approach of "scrolling in a field-book" is easy to understand and efficient to use.

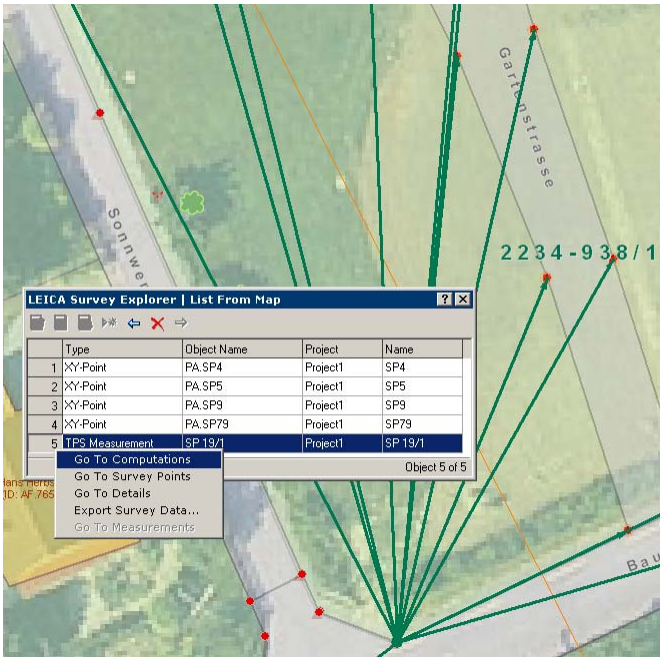


Figure 2.7: Survey Explorer displays selected or queried survey objects in list view and provides highlighting and navigation via context menu.

Much of today's field data is inventoried via paper forms, maps, and aerial photos. This increases the potential for poor quality service to clients, low productivity, long update processes in the office, redundancy, and difficult handling in bad weather conditions. In LEICA MobileMatriX, surveyors continue to take maps or orthophotos in the field, but in digital form, as background maps. Information about current location and completeness checks is simplified by symbols and cartographic elements.

Error information of computed points is calculated from reference points and measurements. Quality can be shown as standard deviation in tabular view or as error ellipse in the graphic view of the map. The results are computations including quality information that can be verified and reported. The surveyor can repeat or add measurements in the field to avoid poor quality of data detected in the office and time and money consuming re-measurements.

2.3.1 Map Navigation and Rotation

Map navigation (pan, bookmarks, etc.), and change of extent (zoom, last extent, etc.) shows data for specific locations with the resolution and scale needed for a particular task. Map rotation helps the surveyor to orientate himself in the field: he works in the same way as with paper maps and the traditional field book, except that labels of features and survey objects are always the right way up.

2.3.2 Map Layout

Finalizing maps is one of the surveyor's tasks that have either to be done directly in the field (after data capturing or editing) or later in the office. Map creation can easily be fulfilled with the layout functions supported by LEICA MobileMatriX, including predefined and customizable layout templates, or standard objects like legends, north arrows, and scale bars. An extensive range of drawing tools are available to modify the extents of the drawing as well as adding graphic images to create truly customized maps.

Standard ArcGIS functionality makes sure that feature rendering gives the user all possibilities of symbology; rendering of measurements and survey points is seamlessly integrated into the rendering framework providing functionality for labeling and complex symbols.

2.3.3 Sketch in the Map

Sketches are often used to add additional information to features or survey data, or to record temporary notes. For example:

- COGO information does not always have a physical source but may sometimes come from the implied knowledge of the user.
- Street edges may often be accepted in the field as having parallel edges.

With digital ink technology (available if working with TabletPC) the user can write field notes and sketches directly into the map. The sketches are stored with the map's document being available as personal notes for a specific user.

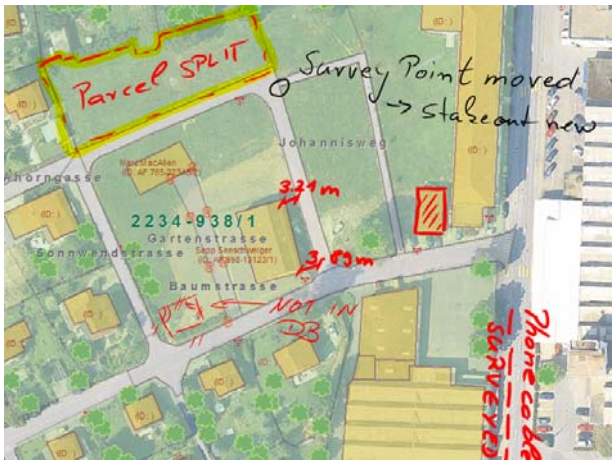


Figure 2.8: Notes and comments as additional information directly in the field book.

2.4 Multiple and Pending Feature Editing

2.4.1 Feature Geometry Editing

Creating multiple features or interpolation points of features (vertices) with just one measurement ensures economic field practices. A measurement triggered by a sensor either creates one or more new features or extends multiple existing features.

For example, a survey point could have multiple thematic meanings (a survey point could be the vertex of a building, a street and a parcel at the same time). When surveying, directly in the field a feature is created for each real-world object that is surveyed, which then avoids feature coding and additional office work. Such flexibility helps the user to perform complex-surveying actions, with immediate visual feedback for quality and completeness control, quickly and easily with the ability to undo and redo their last actions in the field.

Pending feature editing technology allows the user to directly edit already existing feature data (including their attributes). For example, if it is not possible to survey all 4 corners of a building at the same time, the field crew first could survey the visible corners of the building, and finish the feature later. At any time, the remaining corners of the building can be surveyed without losing any kind of information.

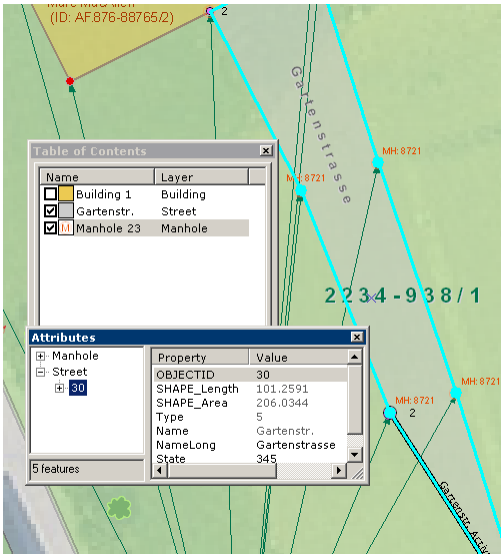


Figure 2.9: Multiple feature editing of street and manhole.

Creating more than one feature with just one measurement ensures economic field practices whereby one point is measured to extend/create multiple features. For example (see *Figure 2.10*), imagine that a survey point could have multiple thematic meanings – it could be the vertex of a building, a street and a manhole at the same time. Another easy method to survey a new feature is to sketch it and then measure its vertices. Such flexibility assists the user to perform complex-surveying actions, with immediate visual feedback for quality and completeness control, quickly and easily and the ability to undo and redo their last actions in the field. Expensive re-measuring is avoided by immediate quality and completeness control, when traditional evaluation of data reveals insufficient quality of measured data.

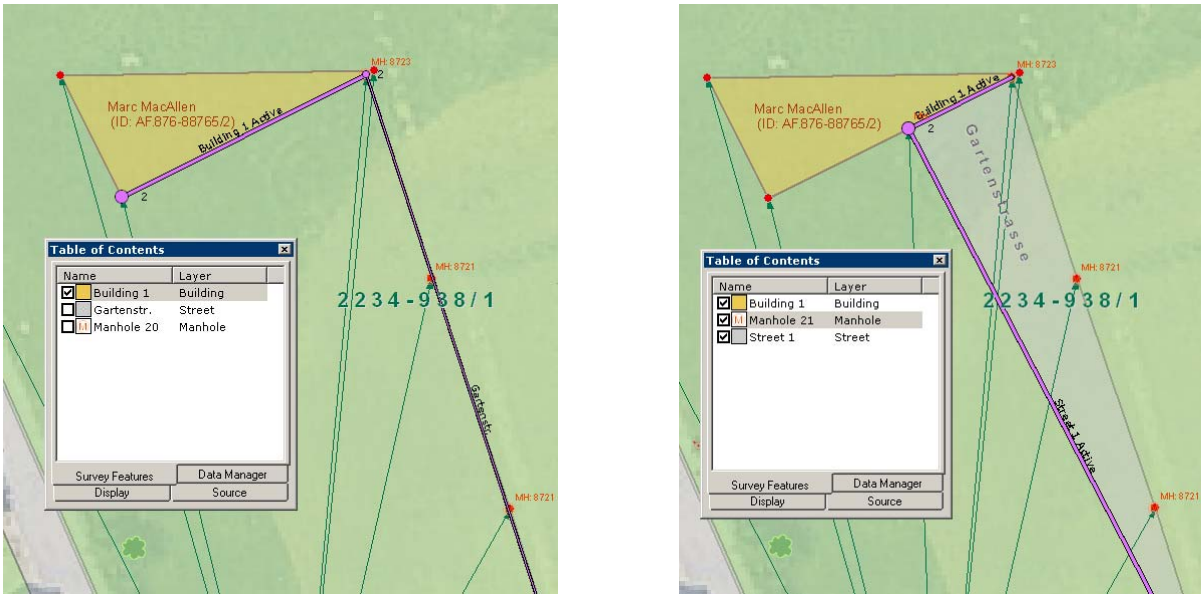


Figure 2.10: Before (left) and after (right) inserting a vertex into the parcel polygon: The insertion line indicates where the next vertex will be inserted.

2.4.2 Feature Attribute Editing

LEICA MobileMatriX enables survey crews to map surveys, collect spatial and feature data on the fly, simultaneously anywhere on the globe by integrating GPS/TPS with the power of ESRI ArcObjects mapping and data acquisition abilities. Field crews are able to quickly pick from a list of predefined attributes that are associated with a structure to enforce consistent and reliable data standards. Customizing feature attribute dialogs (see chapter *3: Customization*) to the specific needs of the user ensures efficient fieldwork and consistent data. Using window controls that are easy to handle with a pen combined with user logic based on approved workflows increases both efficiency of fieldwork and quality of captured data (see *Figure 2.11*).

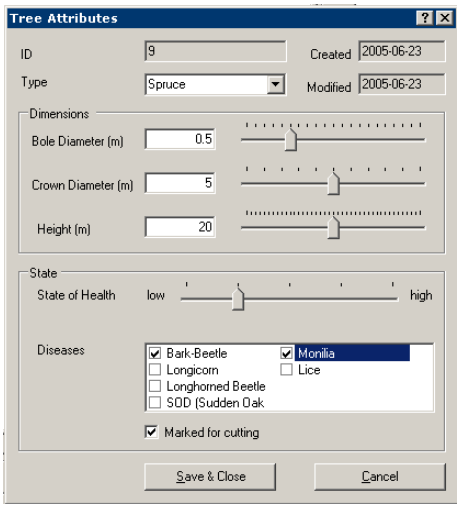


Figure 2.11: Customized dialog for editing tree attributes.

2.5 Survey and COGO Computations

All measurements taken in the field are automatically displayed in graphical and tabular form, and stored in the ArcGIS Geodatabase. Survey and COGO computations are also persisted in this database holding references to measurement, survey points, and computed coordinates.

2.5.1 TPS Computations

Available TPS computation methods for processing the measurements:

- Tacheometry
- Resection
- Free Station
- Survey Traverse
  (open and closed)
- Stakeout

All TPS computations provide the same look and feel in order to make work easier for the user. Information is presented on space-saving tabs differentiating between general, setup, measurements, computed points, and report.

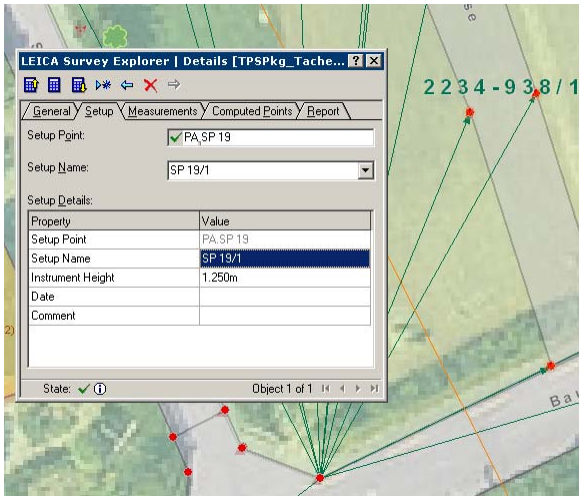


Figure 2.12: Example of a TPS computation (Tacheometry).

2.5.2 GNSS

When working with Leica's GPS1200 receivers and antennas, Leica MobileMatriX v2.1 now has the option to log raw GNSS data (including code and carrier phase measurements). This is available in addition to the GPS Real Time Processing Option. Using Leica Geo Office, raw data can be post-processed against other GNSS sources. This can be a second Leica GPS receiver, a reference station, or CORSs (Continually Operating Reference Stations) available throughout the whole world. One of the major advantages of the GNSS post-processing is that it is generally the most reliable and cheapest method of performing high-accurate GNSS surveys. To post-process survey data, it is necessary to have a post-processing software but the corrections are often available free of charge. Simple as that, GPS raw data is logged, then taken back to the office and processed. The measured features can then easily be transformed to new, corrected locations.

Real-time corrections for GNSS (RTK GNSS) provide major advantages on navigation and stake-out, the verification of spatial data directly in the field and effective data collection. But there are places in the world that don't have reliable real-time services, and in those regions the user requires better accuracy than can be achieved from navigated solutions alone. Second, not all field data collection tasks require data to be collected using RTK GNSS. Post-processing techniques are often essential to ensure that a feature's position can be defined to the required accuracy level. For example, a stormwater mapping project may require all data to have cm level accuracy. However, it may not be possible to have cm level accuracy in RTK all the time. By using raw data logging and post-processing techniques back in the office, field crews can focus on efficiently mapping as many stormwater structures as possible, without being concerned with real-time connections and accuracy results. Post-processing in the office will provide the required high levels of positional accuracy needed. It is also often required that raw data is logged for documentation tasks, even when receiving RTK corrections. Finally, post-processing allows you to re-process GNSS raw data several times. If post-processing the first time doesn't provide the expected results, you have the ability to re-process until you achieve the required level of accuracy.

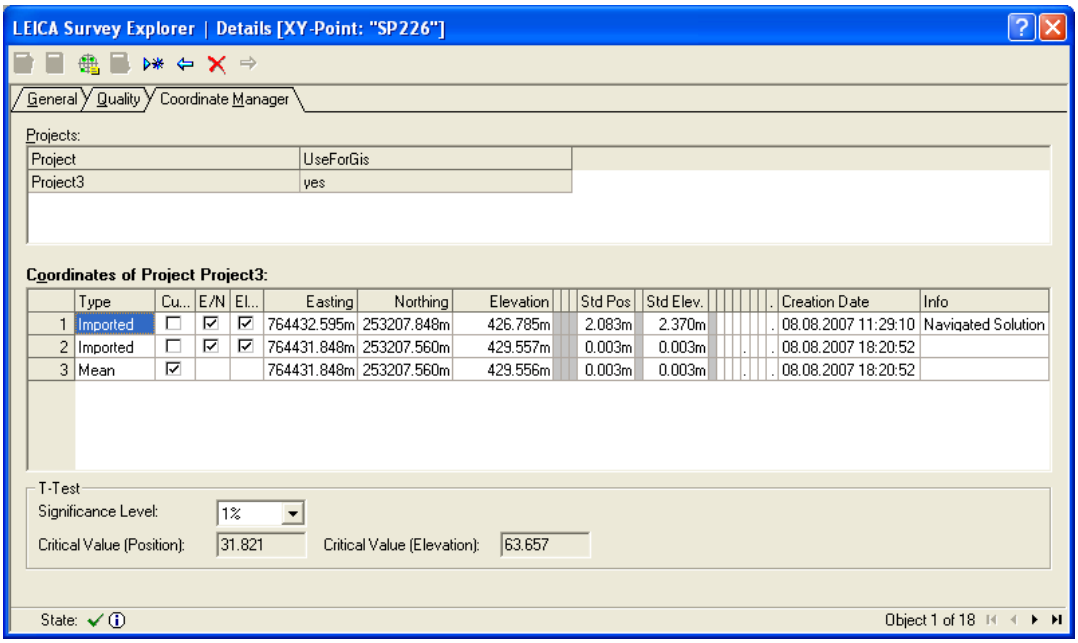
When you can use post-processing:

- Where reliability is the main concern
- When real time accuracy is not so important
- When real-time correction services are not available
- When you have to store GPS raw data for documentation needs

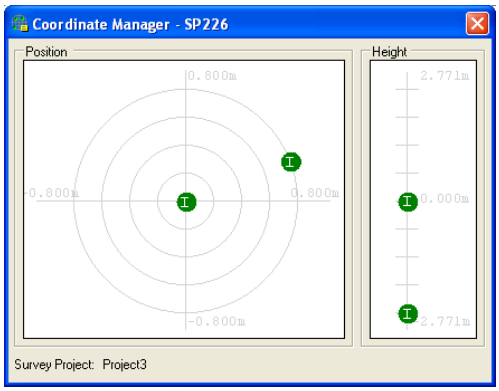
How to post-process GPS raw data?

For a post-processing application you can use Leica Geo Office (LGO). Please refer to LGO help to use the post-processing functionality.

After post-processing, the user can export the post-processed points (PointID matched with the points stored in MobileMatriX) in an ASCII file, which can then be imported in Leica MobileMatriX again. Leica MobileMatriX automatically averages the post-processed points with the existing points then creates an adjusted average.



The weighted mean is computed for position and elevation. Because of the big quality difference, the navigated coordinate doesn't affect the mean value. You can see this in the Coordinate Manager graphic view:



After the coordinates are averaged, the user can update/transform the uncorrected feature vertices to the corrected location.

The combination of LEICA MobileMatriX and the SmartAntenna ATX1230 (GG) & ATX900 (GG) is a light-weight, innovative GPS rover with RTK capability and the precision of Leica's high end GPS System 1200. Different RTK data formats are supported and the connection can be done as dial-in or via Internet (NTRIP). It is a cable free (Bluetooth®) solution that allows the user to collect and update GIS data directly in the field using the power of LEICA MobileMatriX.

The Bluetooth connection between the TabletPC and the SmartAntenna or the mobile phone is configured according to the used Bluetooth device and driver software. The configuration of the antenna height and the RTK connection is done in LEICA MobileMatriX and uses the GPS1200 PC Simulator. The

GPS processing is done by the SmartAntenna option (like the GTX1230 connected to the SmartAntenna does).

2.5.3 COGO Computations

COGO computations taking CAD functionality into the field:

- Basic computations: XY-Point, Delta XY, Direction/Distance and Deflection Angle
- Curve: Fillet Curve and Circular Curve
- Intersection computations
- COGO Traverse computation

Input of survey points, directions, distances, etc. is possible with both keyboard and stylus. The bold caption indicates the input target even if the dialog does not have input focus.

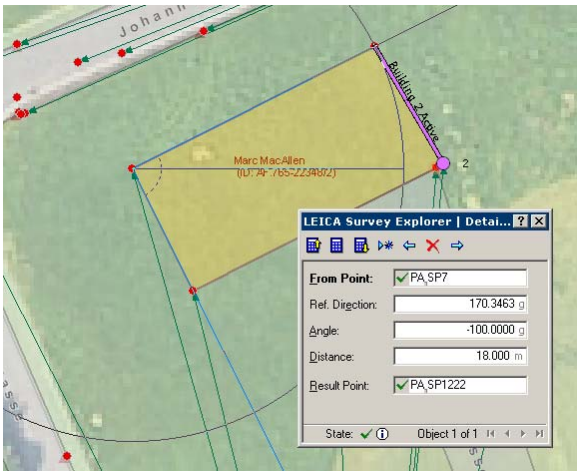


Figure 2.13: Example of a COGO computation (Deflection-Angle-Distance).

2.5.4 Computation Network Analyst

A key advantage of LEICA MobileMatriX is the dependency it creates and stores between computations, survey points, and measurements, which allows the user to easily trace the computation network. Imagine a surveyor realized that the coordinates typed in for datum point *A* are incorrect? Without LEICA MobileMatriX, the surveyor has to delete and re-create all the computations, which are related to point *A*. When using LEICA MobileMatriX correction of the wrong coordinate will update the affected datum point *A* and all computations depending on this survey point. The Computation Network Analyst calculates the order of dependencies and re-computes the dependent coordinates automatically. In this way a computation network can be easily kept up-to-date and hence save time and effort.

2.5.5 Height Modernization

The requirement to access information anywhere, anytime has never been stronger and will increase more and more within the next years. Professional users move towards mobile platforms to increase productivity through efficient information handling, resulting in cost reduction, as well as a fully integrated mobile workforces. Leica MobileMatriX, a mobile GIS - the natural expansion of the enterprise database into the field - allows the user to add points, measurements and features either using TPS (Total Stations), GPS (Global Positioning System), Level Instruments or other sensors (e.g. Laser Range Finder). Mobile GIS enables the workforce with tools and data they require – when and where they need it. Furthermore, since the software is graphically based, data quality and completeness can be checked immediately as data is acquired, which avoids expensive re-measurements when quality control activities in the office detect deficiencies. Using the connection to Level sensors field crews can measure accurate locations with GPS and in a second step they can update the less accurate height information with a level measured height. This "Height Modernization" is the start of the establish-

ment of accurate, reliable heights using GPS in conjunction with traditional and highly accurate Levelling information in a GIS.

The challenges of managing a rapidly growing GIS databases, the need to respond to Homeland Security and emergencies, Surveying and Cadastral agencies, Water and waste water supplier and Utility companies make it imperative that bigger organizations continue to develop and improve its geographic information infrastructure. One theme that will be covered more and more in the near future is to improve the height within a GIS. The so-called, Height Modernization provides a mechanism for significantly improving the accuracy of our geographic information and maps especially in the 3rd dimension. The Height Modernization functionalities within Leica MobileMatriX will greatly assist GIS users in managing critical issues, such as:

- Flood Hazard Mapping
- Cadastral Information Systems
- Utility companies

This "Height Modernization" is the start of the establishment of accurate, reliable heights using GPS in conjunction with traditional and highly accurate Levelling information in a GIS. Accurate and consistent height information serves as the basis for

- Improved transportation mapping systems,
- Sea level raise estimations,
- Floodplain, flood area and river basins mapping,
- Homeland Security and emergency prevention
- Storm surge modeling,
- Resource management,
- Regional and urban planning
- Erosion mapping
- Command & Control in military and public safety applications

The primary goal of the Height Modernization is to utilize GNSS (Global Navigation Satellite System) technology together with Level instruments and to finally support and improve all mapping, surveying and engineering activities.

The Height Modernization functionalities in Leica MobileMatriX will:

- Provide a more accurate, consistent, and improved accuracy for GIS databases and mapping
- Enable reliable sharing of spatial information between organizations and reduce unnecessary duplication of data while working with different sensors. In the past GPS, TPS and Level measurements have to be analyzed in different software packages.
- The combination results in lower the costs of surveying, and mapping throughout the whole workflow and data analysis chain

The overarching benefit of the Height Modernization functionality is that it will provide an accurate and consistent spatial framework for all mapping and surveying activities. Furthermore, it will dramatically improve the spatial infrastructure of the entire database. The importance of a robust and reliable spatial data is the consistent thread that runs through all the following examples:

- Height Modernization benefits Mapping of an entire water distribution system: the objective is to know the location of every component of the system at a level of accuracy that will allow them to quickly find that component (such as a valve), even if it is under water.
- Height Modernization benefits the measurement process of control points to establish a 3D geodetic network.
- Height Modernization benefits the accurate elevations, which are absolutely essential for e.g. flood hazard mapping: there is simply no other way to know where the water will go. In many cases, elevations must be carried over long distances for determining elevations at a particular project site where flood hazard mapping is needed. The traditional survey technique for transferring elevations – optical Levelling – is extremely post-processing-intensive, and expensive. Especially combining the level and GPS measurements finally in the enterprise GIS required many steps. This cost and workflow can be greatly reduced by using GPS and digital levels within Leica MobileMatriX with its Height Modernization functionalities.

2.6 Reporting

You can generate different reports of survey objects by just selecting an appropriate style that determines the general layout of a report. You are able to further influence the final report by adding your own header and footer and by selecting the attributes of a survey object you are interested in. It is also possible to change font, size, and color of these attributes.

The reporting component is based on XML/HTML. That means the survey objects to be reported are first written to an XML file and afterwards a style sheet (XSL) is used to generate an HTML file. The HTML file can either be saved or printed. There are several pre-installed style sheets available to report survey computations and survey points. These style sheets can be adopted to fulfill the users requirements, regarding layout or additional information.

Examples of reports include:

- Textual reports on computations
- Point and coordinate tables
- User-defined reports

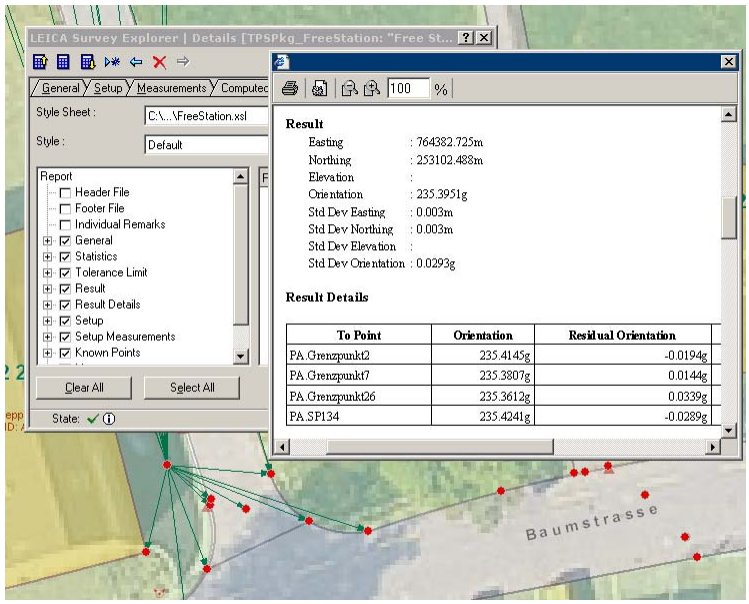


Figure 2.14: Reporting engine and print preview in LEICA MobileMatriX.

```
<!-- Write table -->
   <xsl:template name="WriteTable">
      <xsl:param name="NodeList"/>
      <xsl:param name="StartId"/>
      <xsl:param name="EndId"/>

      <xsl:variable name="SubSel" select="$Sel[@Id &gt;
         ber($StartId) and @Id &lt; number($EndId)]"/>
      <xsl:for-each select="$Sel[@Id=number($StartId)]">
         <BR/><DIV CLASS="TopicStyle" Id="{@Id}">
            <xsl:value-of select="@Text"/></DIV>
         <BR/>
      </xsl:for-each>
         <TABLE CLASS="FrameStyle" BORDER="1" width="100%"
            cellpadding="3" cellspacing="0">
            <TR>
               <!-- Table column header -->
               <xsl:for-each select='$SubSel'>
                  <TH><xsl:value-of select="@Text"/></TH>
               </xsl:for-each>
            </TR>
            <!-- Table row data -->
            <xsl:for-each select="$NodeList">
               <xsl:call-template name="WriteRow">
                  <xsl:with-param name="Rec" select="."/>
                  <xsl:with-param name="SubSel" select="$SubSel"/>
               </xsl:call-template>
            </xsl:for-each>
         </TABLE>
   </xsl:template>


<!-- Write single row into table -->
   <xsl:template name="WriteRow">
      <xsl:param name="Rec"/>
      <xsl:param name="SubSel"/>
```

Figure 2.15: Extract of XML style sheet for customizing survey report.

2.7 Communication and Data Exchange

2.7.1 Sensor Connection

LEICA MobileMatriX supports connection to almost all Leica TPS and GPS sensors. Third party GPS are supported using a NMEA interface. The following Leica TPS and GPS sensors are supported:

- LEICA TPS series 110C, 300, 400, 700, 800, TPS 1000, TPS 1100, and TPS 1200
- LEICA GPS GS5/5+, GS20, GS50, GPS 500, and GPS 1200
- LEICA SmartStation and LEICA SmartAntenna ATX 1230
- Other sensors will be supported on demand

Communication between sensor and TabletPC is realized by cable or wireless connection. Cable connection supports serial cable and USB; wireless connection is available for radio and Bluetooth®. After an initial setup of the communication settings, working with LEICA MobileMatriX is absolutely transparent to the communication method selected.

- Communication with Leica TPS
  All of the powerful tools associated with the Leica TPS instrument are also available in LEICA MobileMatriX including:

- ATR (Automated Target Recognition)
- PowerSearch
- Steering the TPS instrument using a virtual joystick
- Eccentric measurements
- Moving the instrument to a specific map location
- Flash the current horizontal angle
- And many more

Measurements are triggered on the TPS or directly in LEICA MobileMatriX. This functionality allows using LEICA MobileMatriX either at the instrument or at the pole for one-man surveying.

- Communication with Leica GPS
  The following setting can be displayed and edited in LEICA MobileMatriX:
  - Position/height and quality information
  - DOP values
  - Battery status
  - RTK connection
  - UTC time
  - Antenna height
  - And many more

  The current GPS location can be optionally displayed on the map, and hence provides real-time location information relative to mapped features. Additional quality information like float or fixed solution is stored with the computed coordinates.

- Communication with 3rd party sensors via NMEA
  NMEA, a standard GPS data format, provides position and quality information calculated by the connected GPS sensor.

- GPS Real Time Processing Option (LEICA SmartAntenna)
  The combination of LEICA MobileMatriX and the LEICA SmartAntenna ATX1230 is a lightweight, innovative GPS rover with RTK capability and the precision of Leica's high end GPS System 1200. It is a cable free (Bluetooth®) solution, which allows the user to collect and update GIS data directly in the field using the power of LEICA MobileMatriX.

  The Bluetooth® connection between the TabletPC and the LEICA SmartAntenna or the mobile phone is configured according to the used Bluetooth® device and driver software. The configuration of the RTK connection is done in LEICA MobileMatriX using the GPS1200 PC Simulator. The GPS processing is made by the LEICA SmartAntenna option (similar to the GTX1230 connected to the LEICA SmartAntenna does).

  GPS Real Time Processing Option (LEICA SmartAntenna)

- Level Option

  Using the Level Option in Leica MobileMatriX one can measure accurate locations with GPS and in a second step one can update the less accurate height information with a level measured height.
  Supported levels are Leica DNA, Leica Sprinter and Trimble DiNi 12T.

- Support of Laser Range Finder

With the interface of Laser Range Finder to Leica MobileMatriX a low-cost, highly productive method of in-field data collection is added to Leica MobileMatriX. In combination of a GPS and a Laser Range Finder the current position is always known and simple side shots can be taken to map coast lines, forests or any other feature. This functionality is already included in the Leica MobileMatriX Standard Edition

- Further sensors can be supported on demand.

Every measurement in the field provides an immediate feedback as the labeled measurement is displayed on the map. The surveyor checks correctness of the measurements and computations directly in the field, avoiding errors that would lead to expensive re-measuring.

2.7.2 Data Exchange

For data collected in the field by a surveyor, it is normally a long and complex path into a GIS. After data collection, the data is imported to an office software to execute the computations for the points. The resultant points are then exported to a CAD system where additional constructions are performed and finally the data is imported into the GIS. If the user detects a problem in his results, by checking the position of the created features in the GIS, he may have to rerun the whole series of events.

With LEICA MobileMatriX, all survey data measured in the field are automatically stored into the ArcGIS Geodatabase, eliminating the need for data conversion when moving data between field system and ArcGIS. To update the office database, simply use the synchronization mechanism (see chapter 2.2.5: *Disconnected Editing*) to transfer the data from office to field and vice versa.

To ensure maximum compatibility with all systems, LEICA MobileMatriX allows the user to interact with data from different sources, such as CAD files, shapefiles and raster data. Additionally, LEICA MobileMatriX provides interfaces from and to the most common TPS formats such as GSI (Geo Serial Interface) and ASCII. Such functionality provides the ability to process most data and uses the powerful LEICA MobileMatriX tools for data editing. Custom converters may be created in any COM or .NET compliant programming language. The powerful scripting language, Microsoft VBA (Visual Basic for Applications), offers a very convenient environment for this purpose.

3 CUSTOMIZATION

The innovative software architecture of ESRI ArcGIS is based on the Component Object Model (COM) standard and is delivered as a completely open solution for developers. LEICA MobileMatriX has been engineered to these standards and is therefore fully customizable by end-users and developers. Any COM (or Microsoft .NET) compliant programming language like C#, VisualBasic.NET, Visual Basic 6.0, Visual C++ 6.0, Delphi, etc. can be used to extend LEICA MobileMatriX.

Users and developers can further extend the data model to create custom measurements and computations. Basically, three levels of customization can be distinguished:

- End user customization
- VBA customization
- Developer customization

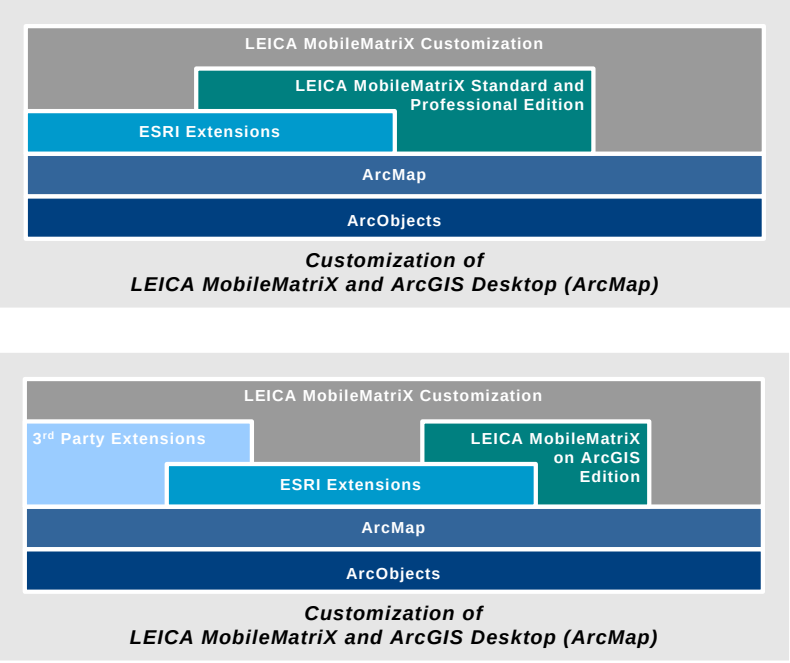


Figure 3.1: Architecture of LEICA MobileMatriX Standard and Professional Edition (above) and LEICA MobileMatriX on ArcGIS Edition (below): Possibilities and levels for customization.

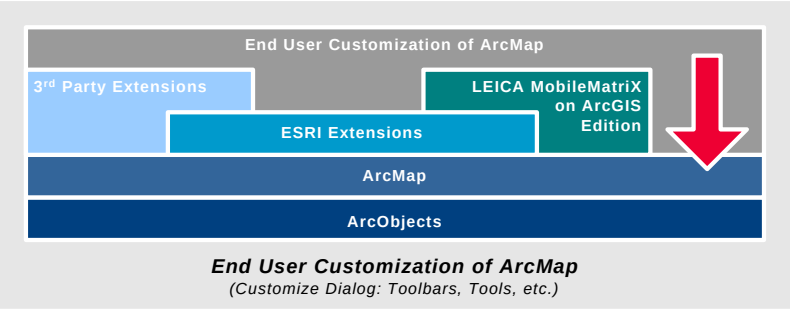
Regarding customization, some differences exist between LEICA MobileMatriX on ArcGIS and LEICA MobileMatriX Standard and Professional Edition. In Standard and Professional Edition, certain toolbars and commands are disabled due to OEM version of ArcView and ArcEditor. This limitations affect especially end user and VBA customization. Developer customization with COM or .NET compliant programming languages has no restrictions; the full set of ESRI ArcObjects is available for customization.

Customization	Example	LEICA MobileMatriX Standard / Professional Edition	LEICA MobileMatriX on ArcGIS Edition
End user	ArcMap Customize Dialog	Functionality according to ArcView/ArcEditor OEM version[1]	Full functionality according to ArcGIS Desktop product[2]
VBA scripts	ArcMap VBA environment	Only execution of VBA scripts	Editing and executing VBA scripts
Developer (COM, .NET)	COM DLL or .NET assembly	Full set of ArcObjects components available	Full set of ArcObjects components available

[1] In OEM versions not all functionality of ArcView or ArcEditor is enabled. Certain commands, tools, toolbars, e.g. are not available.
[2] Functionality available depends on ArcGIS Desktop product (ArcView, ArcEditor, or ArcInfo).

3.1 End User Customization

Like Microsoft Office applications, LEICA MobileMatriX provides the possibility to customize toolbars, menus, commands, tools and shortcuts in order to fulfill certain tasks more efficiently. Customization settings are stored in a map document (MXD) or map template file (MXT) and can be shared between users.



End User Customization of ArcMap
(Customize Dialog: Toolbars, Tools, etc.)

Figure 3.2: End user customization of LEICA MobileMatriX on ArcGIS Edition. Customization on this level works identical in LEICA MobileMatriX Standard and Professional Edition.

In LEICA MobileMatriX Standard and Professional Edition (based on an OEM version of ESRI ArcGIS Desktop 9.0) not all toolbars, menus, tools and commands are available. LEICA MobileMatriX on ArcGIS provides the full set of functions installed with ArcGIS Desktop Product ArcView, ArcEditor, or ArcInfo.

3.2 VBA Customization

Customization with Visual Basic for Applications (VBA) is persistent in a map document (MXD) or a map template (MXT). VBA customization is especially useful for automation of document specific, small task or simple user interfaces for data editing and evaluation. These map scripts can run without any restrictions in any LEICA MobileMatriX product as long as ArcObjects components are directly used or user interface elements (toolbars, menus, tools and commands) are available with the product.

LEICA MobileMatriX Standard and Profession Edition does not include the Visual Basic for Applications Editor, but VBA scripts written with the standard ArcGIS Desktop installation will also execute in LEICA MobileMatriX. This means that VBA scripts have to be developed in an standard ArcGIS Desktop environment, saved in a map template or map document and can then be deployed on any computer running LEICA MobileMatriX Standard or Profession Edition.

LEICA MobileMatriX on ArcGIS is based on an ArcGIS Desktop 9 product and provides full functionality regarding VBA editing and execution. This allows a scenario in which map documents including VBA scripts are created and tested in LEICA MobileMatriX on ArcGIS and deployed to systems with Standard or Professional Edition.

3.3 Developer Customization

All ArcGIS Desktop products are based on a conglomeration of COM components (DLLs) called *ArcObjects*. COM is a binary standard for communication between software components that allows the developer to use ArcObjects with every COM compliant programming language like Visual C++ 6.0, Visual Basic 6.0, or Delphi. Since Microsoft's .NET framework provides a *COM interop mechanism,* it is also possible to use any .NET programming language (e.g. C#, VisualBasic.NET) for ArcObjects or LEICA MobileMatriX customization. ESRI delivers together with ArcGIS a completely open platform for developers to enhance existing desktop applications or build any kind of application from scratch.

In order to support developers with information about ArcObjects ESRI offers an *ArcObjects Developer Kit* providing professional developer help, object model diagrams, white papers, tutorials and many examples in different programming languages. Additional developer resources can be found on the ESRI web sites http://support.esri.com and http://edn.esri.com.

3.3.1 ESRI ArcObjects

In most cases, customization of LEICA MobileMatriX refers to adaptations of GIS functionality. ArcGIS Desktop provides a huge range of objects and events making it easy to integrate new or altered functionality seamlessly into LEICA MobileMatriX. Examples for developer customization at ArcObjects level are:

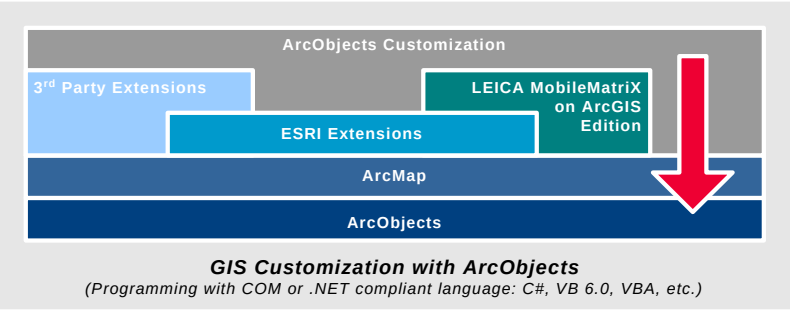


Figure 3.3: Developer customization in LEICA MobileMatriX on ArcGIS Edition: Direct access of ESRI ArcObjects components.

- Individual dialog window for attribute collection.
- Automatic consistency check and validation after editing.
- Logging of all modifications and deletions.
- Automated update of "last modified" field.
- Topology checks.

There is no difference to any other kind of ArcGIS Desktop customization described in the *ArcObjects Developer Kit*.

3.3.2 MobileMatriX

LEICA MobileMatriX is based on ArcObjects; customizing (mobile) surveying functionality follows the same rules and concepts as working directly with ArcObjects. However, integration of surveying functionality into ArcGIS needs additional knowledge about the concept of survey projects, survey classes and survey objects. LEICA MobileMatriX offers the possibility to create new types of measurements and computations that are seamlessly integrated into the existing framework. The following list is an excerpt of potential surveying related customization:

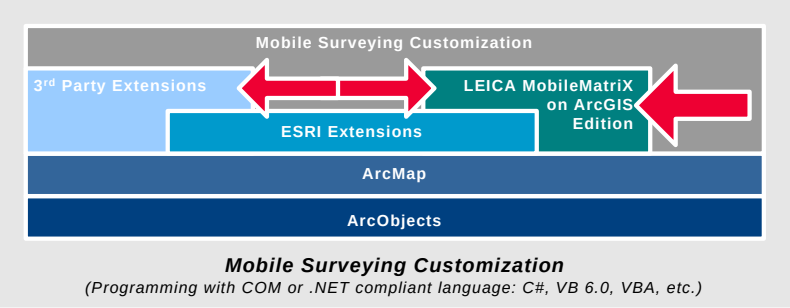


Figure 3.4: Developer customization integrates 3rd party extensions or accesses mobile surveying components of LEICA MobileMatriX on ArcGIS Edition.

- Additional COGO tools
- Additional or modified TPS computations
- Enhance the survey data model with additional attributes to the existing survey objects
- Access the raw measurements from a GPS or TPS sensor
- Additional survey data converters to exchange survey data
- Development of a surveying package from scratch (e.g. levels) including special data model, computation objects, renderers, etc.

3.3.3 Developer Customization Example

Data captured in the field is usually time-consuming. Multiple and pending feature editing helps to shorten the distances a field worker has to walk in order to fulfill his tasks. Measuring multiple features at once and capturing attribute data for all these features makes field surveying much more efficient.

In LEICA MobileMatriX data collection, maintenance workflows and underlying data structure are designed in a uniform way that satisfies the requirements of all customers and allows data exchange of measurements, survey points and computations. However, usually, this is the only common base, customers using LEICA MobileMatriX, have. Most GIS users have predetermined specific data structures, rules, and workflows that fulfill their requirements. Capturing feature attributes in such highly specialized environments must be adjusted to data structures and workflow. In order to raise the efficiency of field surveying and data capturing to the highest level possible, the user interface for entering feature attributes must be customized to data and workflow.

ArcObjects framework offers many possibilities for customization of feature editing:

- *Extending the standard attribute dialog*
  In order to make attribute editing as easy as possible ArcObjects allows the implementation of a custom object (feature inspector for each feature class) supporting predefined interfaces. If this object is registered as a class extension for the corresponding feature class the user will be able to work with a customized view in the attribute dialog. Designing an efficient user interface and workflow is totally up to the user and the developer.

- *Dockable window*
  Implementing a dockable window is another possibility for hooking a customized user interface into LEICA MobileMatriX. Dockable windows are standard customizations in ArcObjects providing the possibility to have a floating or docked window within the framework. Initialization and startup of the window can be triggered by an ArcObjects event or by a command button.

- *Standalone dialog*
  Implementing a standalone dialog for editing attributes is the easiest and most flexible way. There are primarily two approaches to integrate a standalone dialog into LEICA MobileMatriX:
  - Explicit pop up of custom dialog by command button and
  - Hooking into an ArcObjects event and pop up custom dialog automatically.

  Both approaches offer unlimited flexibility regarding user interface, navigation and workflow.

The following example is based on a standalone dialog invoked by an editor event. The implementation is straightforward and should illustrate how simple it is to build a custom attribute dialog. In order to accentuate the importance of an easy-to-use attribute dialog for working in the field, the main focus was on a user interface suitable for data input via pen. The sample dialog contains only controls that can be easily operated with a pen: Attributes and values of slider controls, combo-, list- and, check boxes can be set by a few simple clicks or drag&drop. Using primarily text input controls, like in the standard attribute dialog, would complicate attribute capturing in the field.

A small ArcGIS Desktop extension connects to the editor and its *IEditorEvents* event interface for being informed when a new feature was created (*IEditorEvents.OnCreateFeature*). This initialization is done within the *IExtension.Startup* method:

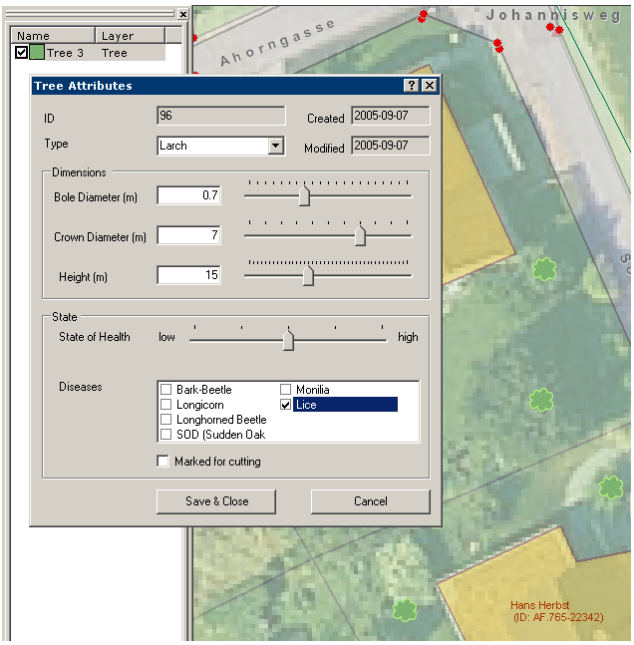


Figure 3.5: Developer customization: standalone attribute dialog hooking into ArcGIS Desktop event.

```
public void Startup(ref object initializationData)
{
    try
    {
        // ...
        UID uid = new UIDClass();
        uid.Value = "esriEditor.Editor";
        IExtensionManager appExtMgr = initializationData as IExtensionManager;
        this.editor = appExtMgr.FindExtension(uid) as IEditor;
        IEditEvents_Event editorEvents = this.editor as IEditEvents_Event;

        if (this.editor == null || editorEvents == null)
            throw new Exception("Editor not found.");

        this.evhEditor_OnCreateFeature =
            new IEditEvents_OnCreateFeatureEventHandler(EditorEvents_OnCreateFeature);
        editorEvents.OnCreateFeature += this.evhEditor_OnCreateFeature;
    }
    catch (Exception exc)
    {
        // ...
    }
}
```

Figure 3.6: Initialization of extension and connection to editor events.

Within the editor event itself, the type of the passed object (feature) must be checked first in order to provide a mapping to the appropriate user interface. In this example, only features of type `Tree` are handled; in real world, a particular user interface (dialog) would be selected according to the feature

type. In the next step, the values of the passed feature are readout and used for initialization of the dialog (for simplicity checks for reading feature values are omitted). After pop up of the dialog and entering feature values the modified attributes are persisted to the feature. This task is enclosed by an edit in order to support undo functionality.

```
public void EditorEvents_OnCreateFeature(IObject obj)
{
    // Get FeatureClass of object: we only handle trees
    IDataset fcDs = obj.Class as IDataset;
    IFeatureClass fc = obj.Class as IFeatureClass;
    if (fcDs == null || fc == null) return;

    if (fcDs.Name.CompareTo("Tree") != 0) return;

    // create dialog and set values for controls
    TreeAttributeDlg dlgTreeAttr = new TreeAttributeDlg();
    dlgTreeAttr.iID = obj.OID;
    dlgTreeAttr.iType = (int) obj.get_Value(2);
    dlgTreeAttr.dBoleDiameter = (double) obj.get_Value(3);
    // ...
    dlgTreeAttr.dtModified = (DateTime) obj.get_Value(10);
    dlgTreeAttr.InitCtrls();

    if (dlgTreeAttr.ShowDialog() == DialogResult.OK)
    {
        // start edit operation and set values to feature
        this.editor.StartOperation();
        try
        {
            obj.set_Value(2, dlgTreeAttr.iType);
            obj.set_Value(3, dlgTreeAttr.dBoleDiameter);
            // ...
            obj.set_Value(10, DateTime.Today);

            obj.Store();
            this.editor.StopOperation("Update Tree Attributes");
        }
        catch(Exception exc)
        {
            this.editor.AbortOperation();
        }
    }
}
```

Figure 3.7: Initialization of dialog controls and update of feature attributes within an edit operation.

Examples for customizing standard attribution dialog (feature inspector) or creating a dockable window can be found in the developer help of the ArcGIS Desktop Developer Kit or on http://edn.esri.com.

4 Conclusion

The main task of traditional field crews was to measure new points and assign codes to the points measured. Conversion and post-processing of measured geometries as well as mapping of codes to attribute values of features was done in the office. That is also the place where the first checks for completeness and correctness of measurements can be made.

With LEICA MobileMatriX, all these tasks can be done in the field with no additional effort compared to a traditional field crew. Instead of assigning a numeric code to a measured point the LEICA MobileMatriX field worker directly attaches attributes (from a list of predefined values) to the newly created features. Detailed background information combined with meaningful data layers, real world styles, and labels allow immediate orientation and completeness control in the field without any additional work.

With the mobile GIS approach, field crews are enabled to use geographic data in the field on mobile devices (TabletPC). Survey crews and GIS professionals have at all times all survey and feature data available in the field and can manage points, coordinates and surveyed features directly with an immediate quality and completeness control in the field. With the streamlined workflow of mobile GIS, emergency workers, inspectors, maintenance teams, utility crews, and many other field workers have real-time access to the enterprise data they require to do their job.

Mobile GIS integrates three main components:

- Global Positioning System (GPS) and/or any other sensor for location positioning,
- (Rugged) TabletPC, and
- GIS software.

The combination of these technologies makes the enterprise database directly accessible to field crews - whenever it is required.

Leica Geosystems has years of experience in the surveying market and as a successful worldwide surveying company can provide their customers a solution for extending their relevant office systems into the field including GIS and CAD. With any COM compliant language, LEICA MobileMatriX can be customized to meet the specific needs of the client, in both architecture and functionality. Leica Geosystems has developed a field software that allows companies to improve their efficiency out in the field. This saves time and money by improving the quality of data directly in the field, improving customer service and workflow and by increasing the field crew's productivity and efficiency. LEICA MobileMatriX addresses all the needs for a professional field workflow: controlling sensors, editing, collecting, visualization and mapping tasks.

LEICA MobileMatriX provides a technology that meets what surveyors expect from both GIS and field software. The system offers the capabilities expected from any good surveying software with the addition of quality information to enhance the decision making process.

A trend in the future could be smart surveying. There the field system should provide an easy to use workflow in order to support not only surveyors or GIS data collectors but also workers at construction sites, in forests. Engineering companies will work in the field with a software that can update the office database and maintain, over a long period, the quality of their data. This workflow should be free of surveying terms, the system should automatically detect the incoming measurements and uses

them to compute the location of features and other spatial information. The immediate quality control will become in future more and more a term of high importance.

Leica Geosystems will continue being the market and innovation leader for the surveying and GIS industry and will develop LEICA MobileMatriX continuously to provide the perfect field capturing and maintenance solution for their customers.

5 System Requirements

5.1 Hardware

Minimum system requirements for LEICA MobileMatriX:

- Processor: Pentium® - 1 GHz minimum
- RAM: 1 GB minimum
- CD-ROM drive (external)
- USB and/or RS232 interface
- 2 internal Bluetooth ports when working with RTK Option

5.2 Operating System

Minimum software requirements for LEICA MobileMatriX:

- Operating systems:
  Microsoft Windows XP or
  Microsoft Windows XP TabletPC Edition or
  Microsoft Windows 2000 (Service Pack 3)
- Microsoft .NET 2.0 Runtime
- Microsoft Internet Explorer 6.0 (or higher)
- Bluetooth® (using Real-Time Processing Option with mobile phone requires support of two Bluetooth® devices)

6 GLOSSARY

Abbreviation / Term	Description
ATR	Automated Target Recognition. Function of Leica TPS to target a prism automatically.
ArcGIS Geodatabase	Relational database model for storing spatial data. *Personal Geodatabase*: Microsoft Access File. *Enterprise Geodatabase*: ArcSDE gateway for enterprise RDBMS like Oracle, SQL Server, Informix, and DB2.
ArcObjects	Software components (COM DLLs) all ESRI products are built upon.
COM	Component Object Model Technology of Microsoft
COGO	Coordinate Geometry
DLL	Dynamic Link Libraries are loaded dynamically by applications like ArcMap, ArcCatalog, or LEICA MobileMatriX.
DOP Values	Dilution of Precision. Quality information about GPS measurements including geometry and time. DOP values are based on 2D (HDOP), height (VDOP), 3D (PDOP), or 3D and time (GDOP).
Eccentric Measurements	The stored point has an eccentricity in one or more directions to the centre of the prism (hidden point).
GPS	Global Positioning System
GSI	Geo Serial Interface
MXD / MXT	Map document / map template of ArcGIS Desktop's ArcMap. An MXT is a template for map documents containing layout and symbology information.
NMEA data	Data format of the National Marine Electronics Association (NMEA). NMEA is a standard that defines an electrical interface and data protocol used by GPS receivers to transmit data originally used between marine instrumentation.
Orthophoto	An orthophoto is simply a photomap on which true distances can be measured. It is an accurate representation of the earth's surface.
PocketPC	Small handheld device mainly used as personal organizer.
PowerSearch	Function of Leica TPS to detect prisms in range automatically.
RDBMS	Relational Database Management System
RS232	Serial cable interface to PC or TabletPC
RTK	Real Time Kinematic. GPS measurement method using real time correction data from reference stations to improve the accuracy up to centimetre level. To achieve RTK accuracies, reference/base station and a communications link to mobile carrier-phase capable receivers is required.
SmartAntenna	LEICA ATX1230 GPS antenna with integrated measurement engine and Bluetooth® module.

TabletPC	A standard defined by Microsoft for mobile computers that are pen operated (without keyboard). Can be used in- or outdoor (rugged, special display)
TPS	Total Positioning System
USB	Universal Serial Bus
VBA	Microsoft's Visual Basic for Applications
XML / XSD / XSL	XML files contain information in a specific format defined by XSD (XML Schema Definition) files. XSL (XML Stylesheet Language) files provide formatting for data contained in an XML file.

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