Industrial Energy Efficient Retrofitting of Resident Buildings in Cold Climates

D4.1
Guidelines to Preliminaries/Survey

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Executive Summary

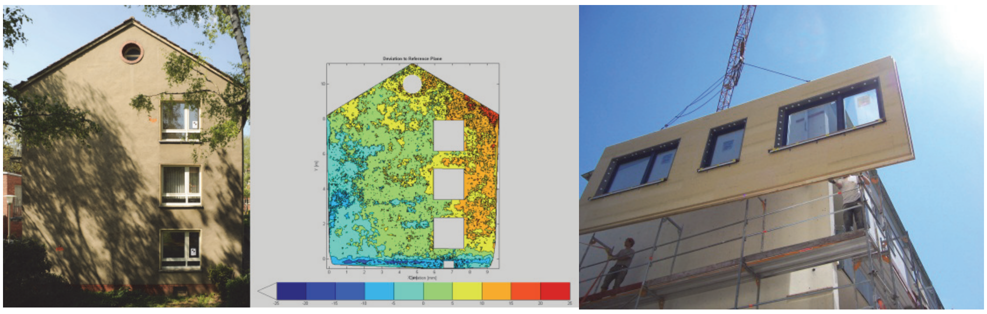
A comprehensive building survey as well as the analysis of the condition of the existing structure of the building to be retrofitted is an essential precondition for a successful planning, construction and life phase of a retrofit project. The planners of the process need full control over all requirements for energy efficiency. Additional a comprehensive knowledge on the construction and material is needed, as it is present in the existing building.

Starting with the explanation of the condition of survey and planning as the intrinsic property of prefabricated solutions the text describes the requirements for knowledge based retrofit processes from survey, construction planning to production and assembly.

A complete condition analysis of the existing building structure as well as building materials is a key factor in building modernisation and of great importance to create as much knowledge as possible in the early stage of the project. A checklist exemplifies different tasks and points out the responsibility of planners and engineers.

A fully featured 3D model for planning and production is needed otherwise industrialised retrofitting based on prefabrication is highly risky. The first crucial step in industrialised retrofit for energy efficiency is to translate built reality into the planning tools. The 3D model develops in different steps. It starts with the application of specific surveying methods to develop a 3D image from the existing object. Based on this data surveyors or trained architects or engineers have to develop the building information model. It is a transformation of real 3D data into usable planning data. The abstract gives an overview of current surveying methods and describes different approaches in building measurement based on Tacheometry, 3D Laser Scan and Photogrammetry.

Based on the demonstration project Grüntenstraße, Augsburg Germany the experience of the surveying and planning process is explained and gives an overview of features and guidelines of a comprehensive digital survey.



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1 Survey and Planning

1.1 The Process and its Control

Aim: improvement of a comprehensive retrofitting process on the basis of a frictionless workflow chain from survey, off- site production to on-site assembly

Scope: the comprehensive retrofitting process on the basis of a frictionless workflow chain from survey, off- site production to on-site assembly.

Objective: key issues are the optimisation and standardisation of the digital workflow throughout the whole process chain, the application of replicable retrofit solutions on an industrial level and coherent assembly methods.

Objectives of the project = advancements / innovation in technology and construction.

The preliminaries in technology and construction are based on a holistic retrofit for energy efficiency concept, the central objective of E2ReBuild. The chosen methods and technologies are based on technical requirement as well as the analysis and findings in work package 3 (WP3).

A proper retrofit process needs full control over all requirements for energy efficiency. Additional it needs the full control on the construction and material, as it is present in the existing building. The documentation of the state of the art of a building is mostly lacking a lot of information due to its absence, incompleteness or obsolete

The most important systems for energy efficiency retrofit are the outer leaf of the building including the windows, the heating system, ventilation system. By improvement of all systems a reduction of energy consumption of a factor 10 with an improvement of user comfort at the same time is possible.

The innovations in technology and construction are targeting on an increased use of prefabricated components for retrofit. The economic gains from the reduction of on-site works are implicated by the reduction of unplanned and therefore fault impeding processes. Finally the off-site production in industrialised processes increases productivity.

The construction industry is changing from an only material and craftsmanship based industry to a knowledge-based sector. It aims at the generation of higher value by minimizing the need of resources. Especially the planning process and the operation are getting more sophisticated and have to integrate lots of knowledge. The construction works are still based on craftsmanship but gradually changing. Workers need better knowledge of construction systems and they have to deal with CAM tools in manufacturing or with survey tools on-site for quality assurance.

1.1.1 Retrofit Process

The retrofit process can be conducted from the basic construction process, but with the simple difference that the object of interest already exists and has to be integrated in the process of preliminary strategy definition for the design and the following design and production phases. The proposed process steps are based on:

- Experience in several research projects
- ISO 12006-2:2001 standard definition of the design and construction process [1]
- Case studies and demonstration projects.

The main process steps are the pre-design phase, design phase and the construction phase. The post-construction or operation phase of the building, as well as the end-of-life (EoL) are not central parts of

E2ReBuild and therefore only it will be referred to them. The impact of decisions in preceding phases for service life and EoL are pointed out in order to keep the development in parallel with the EC politics towards a more sustainable economy.

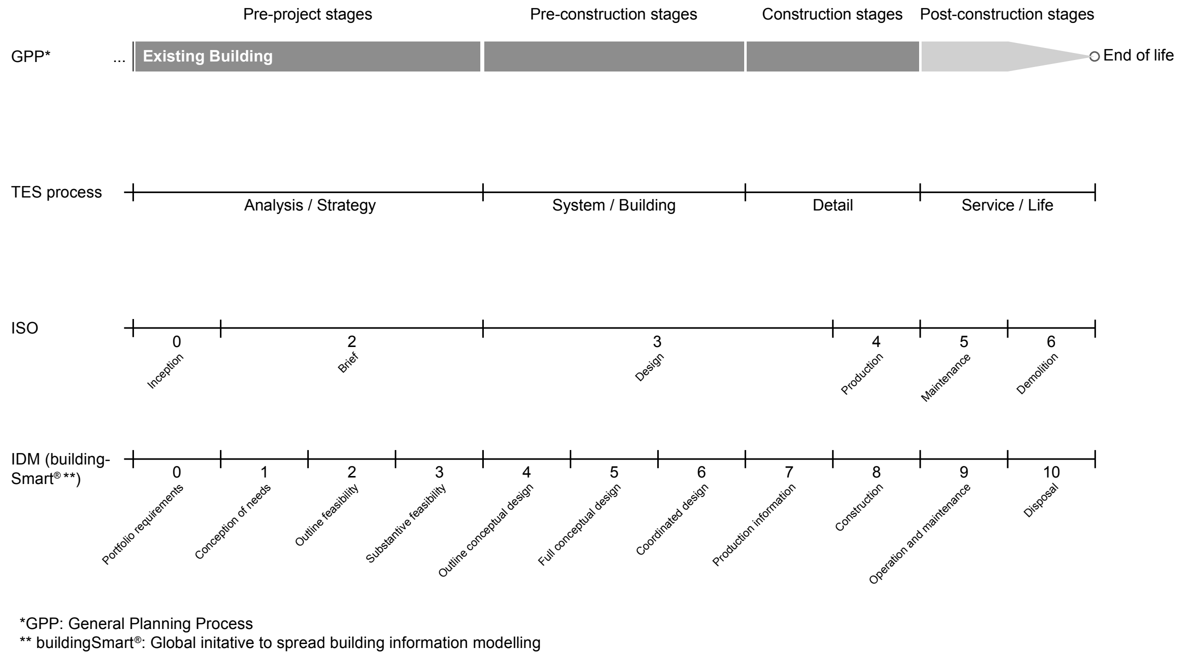

Figure 1 Retrofitting process with prefabricated timber based elements (Le Roux, Ott).

1.2 Prefab needs Survey

The following production planning process description should explain the background and the necessity of a comprehensive survey of the existing building, because of the already defined physical preconditions of the retrofit object.

The paradigm of modern prefabrication in the construction sector is based on a full-featured virtual model of the new building or the new components used. A very good example is shown in the timber construction sector in central Europe, mostly in Germany, Austria and Switzerland. The manufacturer, digitally plans the timber-framed or cross-laminated wall components, including all sub-components, which have to be integrated during or after the production or assembly. Each single part is modelled in 3D, with material properties information and part number. During or after the preparation of the complete production plans a full bill of materials (BOM) is automatically generated for the ordering process of the raw materials and sub-components, e.g. windows.

In order to enable a high level of prefabrication, the geometry of the building, functional properties and constructional issues have to be surveyed.

Buildings differ in geometry, use, components and materiality even when they are made from the same construction system. Also when the structural elements are be identical, the buildings can differ in geometry, due to different site shape, foundation properties or façade appearance etc.

The individual character of a building is most often expressed in the façade. In consequence it is one of the most complex tectonic parts of a building, consisting of structural elements (exterior walls, columns, ceiling edges etc.), functional elements (windows, shading etc.) and technical equipment (piping, ventilation, etc.). The hierarchy of the surveying process is split according the needs of data acquisition and post-processing for digital planning. Starting from the state of the art of the existing building the first step is the digital acquisition of the geometric dimensions of the façade and, when necessary, of the interior floor plan. This step is accompanied by a survey of e.g. wall compositions and used materials. The first rough result is the basis for feasibility studies. It already can be used in a building information model (BIM) but at least it has to be available in digital 3D data as a common basis for future design phases and production planning.

The existing information about a building goes back to its approval phase, in some cases also to its construction phase. The documentation of the actual built situation ("as-built") as well as alterations made during the lifecycle of a building ("as maintained") is seldom or only partly available. Only in rare cases will existing drawings of buildings represent the as-built / as-maintained condition.

A blueprint of the state of an existing building is an essential requirement for a customised production of fitting retrofit components.

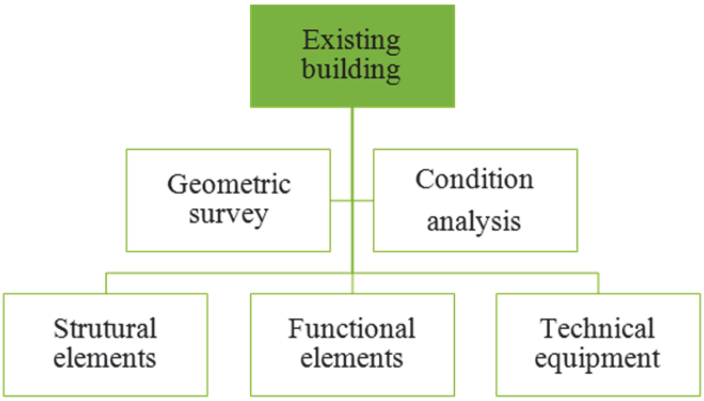

Figure 2 Hierarchy of the holistic survey (Ott).

1.2.1 Information and Knowledge

The survey provides the initial information for planning and production of prefabricated components. Survey provides a virtual information model of the existing building for the adaption of retrofit components, the interaction of elements with the existing structure, their assembly on-site and last but not least their maintenance. The construction industry is already on the path of building information modelling. The combination of geometric representation of building components or objects with semantic and topologic information happens on this trail.

The described information is needed for:

- Feasibility study
  - Energy simulation
  - Architectural design
  - Cost estimation
- Comprehensive Model
  - Structural analysis
  - HVAC integration
  - Energy and information supply
  - Quantity surveying
  - Tendering
- Production Model
  - Production & Assembly planning
  - Sizing of components
  - Commissioning process (Bill of Materials: BOM)

- Positioning (back to reality) & Assembly preparation
- Quality control

- Facilitation of Life Cycle (not part of E2ReBuild)
  - Maintenance
  - Demolition planning
  - Reuse and Recycling.

The initial survey for the feasibility study has to provide both kinds of information, the geometric data and the semantic information. These inputs have to be integrated in pre-design stage decision tools like the '*Retrofit Advisor*' [2] or some energy calculation tools or even in a building information modelling software. In a first step a preliminary assumption of materiality of the existing building has to be acquired for the information model. Digital remote sensing survey methods provide 3D images in this phase. The fastest and most economical method for this task is the photogrammetry. All the methods as well as the photogrammetry are introduced and explained later on in this report.

The second step analyses and describes the content of the information model on basis of the geometric data and the semantic information by:

- Identification (of structures and components)
- Indication (of positions and joints)
- Structuring (of levels of detail)
- Classification (of material properties)
- Evaluation (of qualities and state of constructions)
- Connotation (of faults and damages).

The process of analysing and describing has to be done by a trained expert who inspects the 3D image visually and when necessary do also a physically inspection of unknown issues on the real object.

1.2.2 Survey Requirements in Retrofit Process

The requirements for the survey in a retrofit project can be separated in three main sections:

- Feasibility study
- Comprehensive model
- Production model

The task is to integrate the information from the different sources and to improve the building information model continually during all phases. This will guarantee the most economic approach, the best quality control and a sustainable retrofitting process based on an integrated concept.

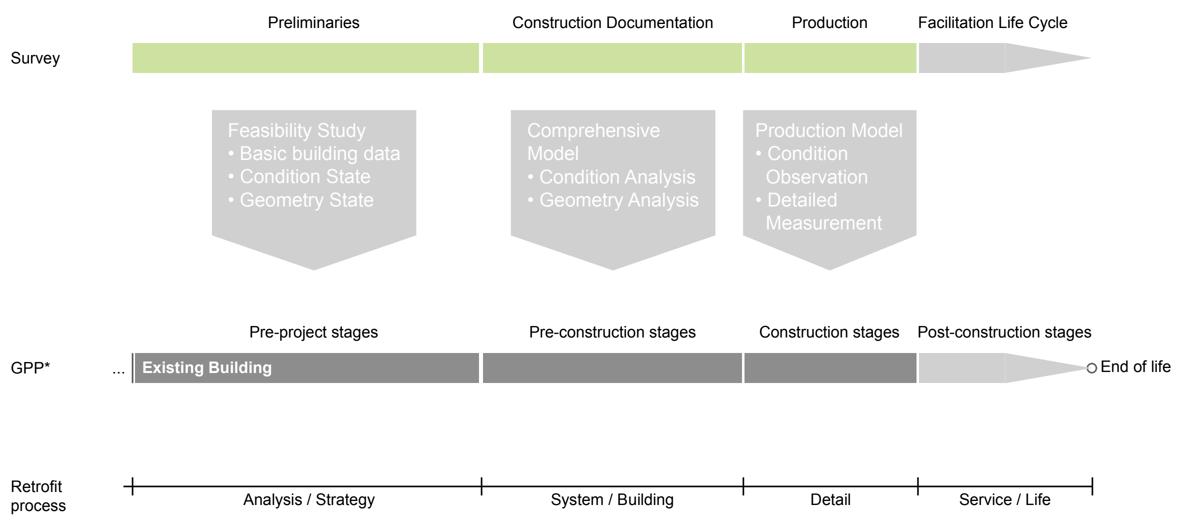

Figure 3 Surveying in Retrofit Process (Ott).

1.2.2.1 Requirements for Pre-project Stages

In the pre-design phase the task is the strategy definition for energy efficiency measures for the existing building. The survey provides necessary information about the found basic conditions and geometry and other data of the building, e.g. from existing plans and comparison with a rough measurement based on e.g. photogrammetry. These findings could be used also in other work packages and tasks, e.g. T3.5 *Retrofit Advisor*.

1.2.2.2 Requirements of the Pre-construction Stages

The design phase is based on the fundamental and strategic findings of the preceding phase and more detailed data and comprehensive information. The requirements for the additional survey and inspection are a detailed condition analysis with a sequential analysis of the construction materials, joints and structures. The overall geometric data has to be enhanced, e.g. with simplified methods from geo-informatics like 2D- or 3D-photogrammetry or 3D-laserscanning. There are tools available which help to automatically recognise and extract topologic data like windows from the raw data cloud. Such automated software, e.g. EOS, Photomodeler Scanner® Additionally the geometry of the examined joints has to be acquired and documented. The integration into a common model for all planners is the central task for the surveyor or the architects, engineers and consultants who are responsible for the project management or certain tasks in the design process. Further data is needed for energy and environmental calculation, e.g. heat bridge data, toxic substances, infected materials, demolition data, etc.

1.2.2.3 Requirements of the Construction Stages

The construction phase is the next and final step of the improvement of the information model for the retrofitting process. The basis is the comprehensive model and its further development into a production model, e.g. the SEMA® [3] CAD/CAM model for the timber constructions used in the demonstration Augsburg, Germany.

The requirement for this production model was a detailed survey of the façade geometry of the whole building based on the method of tacheometry. The contractor or manufacturer, who was responsible for the building envelope, did his own detailed survey in order to get the full information from the existing construction. This allows him to prefabricate all elements including all windows and façade claddings and to assemble digitally customised façades for the demonstration project.

With the data of the final production model there is an opportunity to provide the client also with comprehensive service and maintenance information for the operation of the building.

2 Façade Survey

2.1 Condition Analysis

A comprehensive condition analysis of the existing building structure is a key factor in building modernisation and of great importance to create as much knowledge as possible in the early stage of the project. The implementation of prefabricated solutions in building modernisation requires besides a highly precise survey thorough knowledge of the construction, especially:

- Condition of existing construction and load bearing parts
- Material properties (density etc.)
- Building envelope (R/U-values etc.)
- Thermal bridges (construction, geometry)
- Contamination
- Fire safety
- Noise protection
- Accessibility
- Allocation of spaces and organisation of floorplansfloor plans
- Condition of building services

The analysis is carried out by a team of architects, engineers for structure and building services other experts (e.g. laboratory for material testing). This service extends a regular planning process for a new building (planning, approval, site management, cost control) and has to be remunerated.

Depending on the retrofit concept and the measures taken in the later building phase, different analysis methods can be applied:

- Visual check
- Partial demolition of layers (e.g. membrane on flat roof)
- Calculation (e.g. load bearing properties)
- Laboratory testing
- Thermal imaging to detect heat bridges
- Measurement on site (e.g. noise property of building elements)
- Simulation

Figure 4 Thermal image, open roof membrane (wet insulation), window shutter

Experiences made in recent retrofit projects prove weak conditions revealed during the construction phase causing higher cost and delay of processes. Exemplary are partition walls ending at the bottom edge of suspended ceilings, leaving large spaces which do not meet today's fire safety regulations, ventilation ducts without barriers penetrating fire walls or asbestos contaminated fibre cement plates found in wall construction.

The consequences of a missing comprehensive analysis at the beginning of the planning stage result in surprises during the construction phase causing:

- Unpredictable costs
- Extension of construction processes
- Less flexibility in developing alternative solutions

Following checklist describes the tasks of a comprehensive building analysis as a planning basis in a retrofit project[1].

Arch.	Architect
Eng.	Engineer (statics)
HVAC	Engineer for HVAC and building services

		Arch.	Eng.	HVAC	other
A 1	**Condition of construction**				
1.1	Check and compare existing plans	x	x	x	
1.2	Check static calculation		x		
1.3	Construction elements / weak parts	x	x		
1.4	Materials - U-values		x		
1.5	Materials – contamination*		x		laboratory
1.6	Materials - condition and testing		x		laboratory
1.7	Roof structure - loads and weak parts		x		
1.8	Roof structure - static and load reserves		x		
1.9	Fire safety – organizational*	x	x		
1.10	Fire safety - construction and building services*		x	x	
1.11	Noise protection*		x		
1.12	Accessibility*	x			
A 2	**Building envelope**				
2.1	Facade structure, loads		x		manufacturer
2.2	Facade layering & composition R/U-values etc.*		x		
2.3	Windows R/U-values, airtightness, age		x	x	
2.4	Thermal bridges (construction, geometry)		x	x	

[1] The checklist has been developed on the basis of a questionnaire of the 7 demonstration projects of E2ReBuild .

2.5	Roof - layers		x		
2.6	Heat protection in summer*		x		
2.7	Specification for thermal imaging*		x		
A 3	**Space and Use**				
3.1	space allocation plan (as is)	x			
3.2	Check and compare with existing regulations	x	x		
A 4	**Survey of building services**				
4.1	Heating			x	
4.2	Air condition			x	
4.3	Warm water			x	
4.4	Sewage			x	
4.5	Cooling			x	
4.6	Elevators			x	
4.7	Electricity			x	
4.8	Light			x	
A 5	**Certification**				
5.1	Energy consumption (e.g. DIN V 18599)*	x	x	x	x

Table 1 Check list of tasks and responsibilities of condition analysis.

* Depending on the competence of the design team as well as legal regulations the task can be supported or executed by additional experts or code inspectors.

2.2 State of the Art in Surveying

A fully featured 3D model for planning and production is needed otherwise industrialised retrofitting based on prefabrication is highly risky. The first crucial step in industrialised retrofit for energy efficiency is to bring the reality into the planning tools. The 3D model develops in different steps. It starts with the application of specific surveying methods to develop a 3D image from the existing object. Based on this data surveyors or trained architects or engineers have to develop the building information model. It is a transformation of real 3D data into usable planning data. A necessary step, because the data of a full surveying 3D model cannot be handled by design architects. A recommendation is a 3D model based on horizontal sections each 500 mm combined with the orthophotos of the façades.

- Digital workflow
- 3D model integrity
- Precision of geometry
- Geo-reference of information
- Visual documentation
- Façade planning features (digital elevation models of façade surfaces)
- Economic methods and tools

- Technical feasibility
- Open and interchangeable data structures
- Meta information on objects
- Abstraction layers (wireframe models)
- Reusability of data

The second step is the constant use and improvement of the 3D data, if further surveying campaigns are done, and of the building information model (BIM) in the entire process of a retrofit; up to the final documentation or even beyond this for maintenance and service contracts.

Opportunities based on new developments:

- Drones (Hexacopter or MAC2) → higher buildings and shaded areas,
- 3D-pointclouds from multi-image photogrammetry (e.g. Topcon, *Imagemaster*; Menci, *ZScan* [4]; EOS, *Photomodeler Scanner*) → high definition point cloud calculation/creation.
- Photogrammetric method → semi-automated and automated post processing with image matching methods [5].
- 3D-camera (FORBau [6]; B. Strackenbrock, DLR) → high depth precision and fast image acquisition.
- Object oriented CAAD or BIM software and CAD/CAM systems allow the combination of geometric, topologic and contextual information about objects with the integration of point clouds.

2.2.1 Terrestrial Surveying Methods

We talk about terrestrial surveying methods, when the instruments used for measuring and the process of data acquisition takes place on a defined location of the terrestrial surface. A second issue that makes an important difference to the non-terrestrial methods are the distances between the object and the instruments. The terrestrial methods are all close-range methods and are located within viewable distance from the object. Therefore these methods are often called close-range surveying methods. They are based on unmanned micro aerial vehicles. The measuring method is also in the close-range of the object, but it has the advantage, that larger and higher objects can be acquired more efficient in much shorter time. However the biggest advantage is the realisation of image acquisition perspectives, which are not possible with terrestrial laser scanning or tacheometry. The Swiss CCEM-retrofit project [7] also experimented with the use of micro aerial vehicles for surveying.

2.2.1.1 General Conditions and Requirements

Since exact documentation of the existing state may be wholly or partially be missing and the reliability of the existing sources may be doubtful, most retrofit processes will require a complete and detailed survey of the existing state. This is described as the first phase of RE by Raja et al. (2008) [8], with the slight difference that he focuses only on scanning methods. All modern measuring methods create polar coordinates from the measured object therefore you can simplify data acquisition in a scanning process. In principle RE starts with the acquisition of polar coordinate geometry from an object. The second and third phase of RE are described as the point processing and the application geometric model development. In point processing, combination of data of different states or points of view during measuring and the cleaning of inferences or superimpositions takes place. Finally the application geometric model development is the most complicated and time-consuming act. There are routines for semi-automated data analysis, manipulation and modelling but it is limited to a certain degree. In TES EnergyFaçade for example CAPLAN, a surveyor software tool, was used for semi-automated digital surface modelling.[2] Raja et al. pointed out that the derivation of surface models from raw data is a subjective process. As a consequence, the preservation of data accuracy and reduction of cost intensive remodelling demands other strategies. A result of this is the development of the new façade elements inside the geometric point cloud model after point processing. An exact remodelling of reality is obsolete because the new parts are constructed inside point clouds instead of models, derived from point clouds.

In addition to hand measurements by measuring tape, hand-held laser distance meters, etc., there are three approaches in 3D measuring technology that are applicable to building survey. The first is based on traditional methods in geodetic land survey, the second is based on photographs, and the third is based on laser light:

2.2.1.2 Tacheometry ("Terrestrial Point Scan", TPS)

Tacheometry is a system of rapid surveying, by which the positions of single points on object surfaces are determined from horizontal and vertical angles together with the distance. The original tacheometer was a theodolite where the distance was obtained from readings on a levelling rod. The instrument used today is a "totalstation", where the angles are read electronically, the reflector-less, automatic distance measuring is based on laser light, and the co-ordinates can be computed instantly. The co-ordinates of the surveyed points are then downloaded to a computer, and application software computes the results to create a 3D CAD model.

In consequence all the discreet points on a façade are measured very efficiently. Discreet points are unique, single points that can be described precisely by a definite coordinate. It requires more effort to acquire enough co-ordinates in areas on the façade surface for unevenness analysis. This method is very suitable to combine records on the inside of the building with the façade survey.

2.2.1.3 Photogrammetry

Photogrammetry (PG) can be defined as „the art, science and technique of determining geometric and other properties of objects by measurements and observations on photographs of those objects". The techniques of photogrammetry date back to the mid-19th century. For more than a century it has been used mostly for mapmaking and surveying, based on aerial photography. The use of close-range (terrestrial) photogrammetry has increased over the last decades, a progress made possible by the development in technology, especially in the information technology. The introduction of digital cameras in the 1990s dramatically changed the possibilities of photogrammetry. Digital cameras and dedicated software for the analysis of photos to create 3D images has introduced the era of digital photogrammetry.

When photogrammetry is applied to 3D building survey, the building is photographed in such a way that each and every detail (part of the surface) is imaged in at least two photos. 3D co-ordinates of points on the building are computed based on co-ordinates of their imaged points, measured in two or more photos. For some purposes where the object is close to planar, and where a high accuracy is not required, results can also be obtained from single photo measurements. Large and complex objects are recorded on a number of images that are stitched together, see 3.1.2.2.

In fact photogrammetry is a very robust method, because it is insensitive to rough conditions like shocks or vibrations. The amount of data generated guarantees a high level of detail and data integrity

[2] CAAD tools often support digital surface modelling but only for the plane level and not for elevations.

is ensured. There is a lack of analysis possibilities for the façade topography due to a small deviation in the depth of façades in the range of 1 – 5 cm, as is usual for most façades. This method is also more difficult to use when combining inside views and outside elevations of a building.

2.2.1.4 3D Laser Scanning ("Terrestrial Laser Scanning", TLS)

3D laser scanning describes the three-dimensional measurement of the surface of an object through the analysis of the reflected light from a laser beam which is scanned over the object surface in [9].

There are different measurement principles for laser scanners. Laser scanners relevant for buildings use the "time-of-flight" principle (TOF). The distance is measured by measuring the time from emitting to detecting the return of a laser pulse. Mirrors or a rotating head are used to control horizontal and vertical angles of the laser light. TLS can collect large numbers of points, called "point clouds" in a short time, from a few thousands to several hundreds of thousand points per second. The problem with TLS lies in the post-processing of the point cloud. The analysis of point cloud data and converting them into useful information, e.g. in a 3D CAD model, is a major challenge. It is basically on the same level as photogrammetry but more abstract, because there is no image of the reality. The intensity value of reflected light from the measured point can help to improve the visual experience.

The relation between actual scan time and time for post-processing varies from 1:1 to 1:50, depending on the detail of the desired output.[3] There are also values of experience from pilot projects, done in TES EnergyFaçade research project, showing that the post-processing of façades can be achieved with ratios between 1:8 and 1:10 depending on the regularity of the object. In the case of an ordinary modern three-storey building 30 x 60 m, in plan, the probable scan time would be 10 hours estimated by a surveyor. The development of a basic 3D geometric model without mouldings and other architectural features would take 10 to 20 hours, depending on the number of windows. To date no automatic method exists for the creation of a 3D CAD model from a point cloud. Post-processing of 3D imaging data and the generation of 2D drawings and 3D models from this data are time intensive tasks and require specific experience. This technology allows the documentation of scanned areas together with pictures, taken with integrated cameras, and provides better spatial impressions and realistic textures. Each scanner company has its own proprietary software solution for data gathering and post-processing.

In addition to façade survey this method has a high capability of speed and level of detail, interior integration and the analysis of surfaces. Today's major issues are the cost for the application and the time factor for post-processing / 3D-modeling. A useful post processing approach is described in the project CCEM-Nachhaltige Wohnbauerneureung [10]. Horizontal sections through point cloud data every 500 mm generate a layered model of the exterior façade volume. It is used for further planning and design steps of architects and engineers. The amount of data is reduced dramatically compared to a point cloud. Together with a normalized topography image of each façade elevation in false colours, the elements can be planned properly.

[3] These relationship of 1:1 to 1:50 between scan time and post-processing was suggested by laser scanning experts during a workshop that was organised at the NTNU in Trondheim in September 2008 as a part of the TES EnergyFaçade project: "3D Laser-Scanning and Photogrammetry for BIM".

2.2.2 Comparison 3D Geometric Survey

The key performance criteria that need to be considered with respect to the application requirements and constraints are according to El-Hakim and Beraldin (2007, 261) in [11]:

Geometric fidelity of the final model (the accuracy or uncertainty)

Generated level of detail (spatial resolution)

For the TES process there are a few other aspects of relevance:

1. Integration of interior (preparation of the window sill and reveals)
2. Topography analysis method

The evaluation of the three methods tacheometry, photogrammetry and 3D-laserscanning resulted in a preliminary vote for 3D-laserscanning and tacheometry. There was a slight advantage for the method of tacheometry due to the fact that it is easier to adopt and cheaper to afford for construction companies. Additionally a lot of practitioners have used a manually operated tacheometer or even its modern version with automated angle and distance measuring, so called totalstation. The 3D-laserscanning offers advantages in the precision and detail level in respect to surface topography analysis. The automated scan method enables to gather a bigger detail level from all over the facade within a minimum span of time and there are functional topography analysis tools already available in the 3D-laserscanning software. Photogrammetry is the third digitally based and remote sensing method that is especially useful for the early project stages. The equipment is only a digital camera for the site work and a multi-image 3D photogrammetry software for the image registration, matching and bundle block correction. In a final processing step, after the calculation of the former site camera positions, the scale and the dimensions has to be corrected according to real measuring points from the site.

	(Hand-measuring+)	Photogrammetry 2D/3D	Tacheometry	Laser scanning
Target points	discreet point	2D: every point3D: only discreet	discreet point	non-discreet
Measuring possibilities	limited to distances	2D: distances and angles in plane3D: distances and angles	distances and angles	distances and angels
Technique	manually	remote sensing (indirect daylight)	remote sensing (TOF*)	remote sensing (TOF*)
Work on site	location dependent	location independent	location independent	location independent
Installation	not relevant	not relevant	firm, without vibrations	firm, without vibrations
Limitation	related to reference point	visibility, 2D: measuring in plane 3D: real spatial measuring	visible, free 3D point selection	visible, free 3D scan area selection
Data	distances and dimensions	congruent image and coordinates	polar coordinates	intensities and polar coordinates
Process	straight forward record	imaging and 2D/3D measuring	imaging and 3D modelling	imaging and 3D modelling
Time factor imaging / modeling	high / low	low / medium - high	high / medium	low / high - very high
1st level model	2D sketch or plan document	2D: rectified image 3D: coordinates (image)	co-ordinates of discreet points (polar / cartesian)	co-ordinates in point clouds, with intensities
2nd level model		3D: **B-rep	lines (connecting co-ordinates)	3D: B-rep
3rd level model		3D: volume	3D: volume	3D: volume
*TOF: distance measuring method of ‘time of flight’ of the laser light. **B-rep: boundary representation (polyline?)				
+Hand measuring for completeness of comparison of measuring methods.				

Table 2 Comparison of measuring methods for façade surveying tasks in [12].

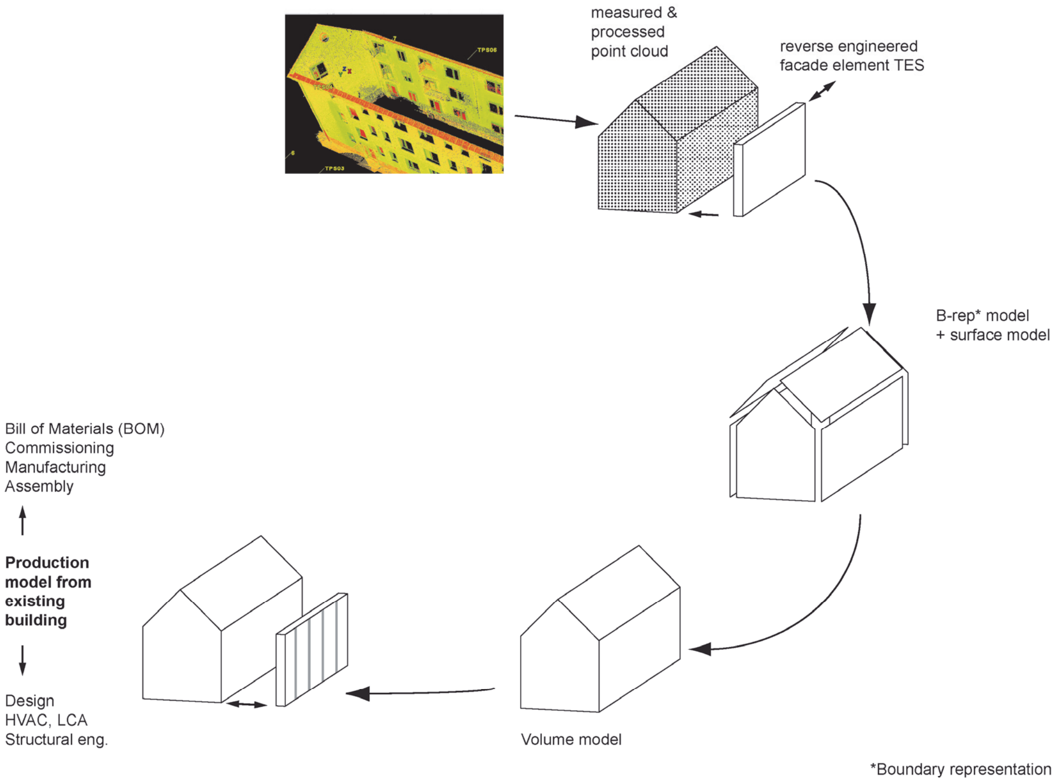

Figure 5 Data acquisition and preceding steps of object classification in information integration process (Ott).

In most retrofit projects it is likely that a combination of the three above-mentioned methods will be necessary in order to develop accurate, cost-effective, timely and comprehensive as-built/as-maintained information in the form of a 3D model. Modern methods or surveying techniques can be adopted by construction professionals as well. However, as a general rule the services of professionals within the field of 3D surveying will be required for the use of any of these 3D measuring technologies.

	Photogrammetry	Tacheometry	3D-Laserscanning
Geometric fidelity	+	++	++
Level of detail	++	o	+
Model completeness	+	o	++
Interference	+	o*	o*
Interior integration	o	++	++
Analysis	o	+	++
* devaluation because of sensitivity due to vibrations and problems with invisible, shaded points.			

Table 3 Eligibility of modern survey methods in [12]

The advantages of 3D photogrammetry are the robustness of the method and the combination of visually usable results with 3D data of the object. The disadvantage is the missing precision for the depth recognition of discrete points like window edges and in consequence the inaccuracy of surface analysis of the building envelope. The fast development and improvement of methods and tools for photogrammetry are good indicators, that the technology will provide more precise data in the near future. Therefore there is an outlook on the use of photogrammetry in combination with airborne surveying methods.

2.2.3 Airborne Surveying Methods Outlook

Inspired by the CCEM retrofit project and the obliging offer to cooperate with the research institute of the TU Munich, the Chair of Geodesy, Univ.-Prof. T. A. Wunderlich, allows to get experience of the use of MAV technology in the field of façade surveys [13]. He cooperated with the Austrian surveying company *Stix Donauer Neuner*, who have developed a prototype of a cheap and flexible MAV system, with a good performance index for façade survey tasks. The unexpected possibility and short dated experimental flight do not allow presenting all results within this deliverable. Therefore only the method, the technology and its advantages are introduced. The results and the comparison of this method with the terrestrial survey of façades and buildings will be presented at a later stage.

2.2.3.1 High Buildings

The typical equipment for surveys up the first storey is scaffolding or lifting devices. This equipment interferes with the view to the object or it has vibrations. 3D-laserscanners are sensitive to vibrations and need absolutely firm positioning.

Digital cameras used for photogrammetry should take photos from a variety of different positions. Therefore the use in densely populated areas with neighbouring houses is possible, but it results in a high effort changing camera position.

The use of drones for façade surveying is an interesting application for unmanned aerial vehicles equipped with cameras and positioning systems.

2.2.3.2 Drone Systems used for Photogrammetry

Micro drone systems or unmanned aerial vehicles (UAV) are known since almost one hundred years and are mostly used in military services. They can either carryor different devices e.g. cameras. Due to miniaturisation not only in electronics, also in electrics and mechanics, e.g. high-efficient motors, gyroscope and velocity-sensors, these parts get affordable and available for model aircrafts. The application of micro aerial vehicles (MAV) for remote-sensing devices is quite young in close range surveying; nevertheless there is a lot of experience with aerial surveying. These MAV can be used to take photos of buildings from higher levels in order to acquire the shaded parts of the façade. The speed of acquisition of large buildings is reasonable higher than with terrestrial based systems.

The MAV have limited action radius and airtime and can be used within the aviation regulations for flying models. Within these rules they can be used at any time without extra permission.

Exemplary micro aerial vehicle, the MAC^2 (Hexa- / Octocopter):

- Six (eight) propellers depending on system configuration
- 1500 grams of load capacity
- up to 1000 meters of action radius (limited by aviation rules)
- 17 minutes maximum flight time only at good weather conditions (dry, mild, without burst)
- manual flight control as well as automated flight control based on GPS (only take-off and landing requires manual control → regulation issue)
- light-weight and easy system with transport in one box (ca. 700x500x500)

- self-stabilizing by integrated control software
- self-positioning with the GPS

Figure 6 MAC2 equipment fits into two boxes (Ott).

Figure 7 MAC2 from cooperation Stix-Neuner-Donauer from Austria, a MAV with six propellers (Ott).

Figure 8 MAC^2 flight on southern façade (Ott).

Figure 9 Operation needs only limited space (Ott).

The miniaturisation has several practical advantages. The progress in development of small flight equipment for surveying is very fast and especially the low-cost sector gains from lots of open source projects and joint efforts of an interested community. The availability of cheap and miniaturised components helps to manufacture and improve a large number of prototypes. The ultra-lightweight and minimized construction saves material and investment costs. Additionally it enables the ad-hoc use without complicated flight permission procedures. Furthermore the transport and the storage of such lightweight und compact solutions are of big advantage. The usage in densely populated areas is easier and less risky. The operation in narrow areas, e.g. tunnels or shafts, which are complicated to navigate, is a specialty of MAV.

2.2.3.3 3D Photogrammetry

As described above, the Photogrammetry is a very fast and economic method that develops rapidly. Therefore lots of solutions are available to transfer into the construction sector.

The robustness of the method and the devices predestines it for daily rough construction site work. Handling and application of the image acquisition is used to everyone who has a digital camera. Additional effort is needed to acquire images from different directions on the façade of the building. Digital cameras are optimal for the use with MAV. They are light, they can be equipped with wireless data connection or they can store data on flash storage devices. Photogrammetry also needs defined and robust internal camera orientation. These orientation parameters can be calculated and the camera is calibrated afterwards with most photogrammetry software.

The core of 3D photogrammetry is the bundle adjustment of images. A bundle adjustment is a complex algorithm that optimizes all the data acquired (camera information, user and system photo markings, etc.) to indicate the original positions and angles of the camera at time of exposure, and the positions of the 3D data points.

Bundle adjustment algorithm and code are needed for convergent close-range photogrammetric work. Bundle adjustment has to provide camera self-calibration and full error propagation. The first stage of bundle adjustment provides automated relative and absolute camera orientation.

Modelling jobs for façade survey made with MAVs require a large number of points to be marked, a process which is time consuming if the marks have to be made on the photographs manually, and which also makes performing complex surface measurement tasks less amenable to the photogrammetric method. Software algorithms can find, extract and mark dense grids of targets and then automatically reference or match these across photographs. In addition coded targets provide for robust automated marking and referencing in complex scenes.

Matching processes search out natural feature points in images, matches them between photos, and generates 3D xyz points automatically. It brings automation to the setup phase for projects without targets.

The end-users like engineers, architects and clients are requiring more and more realism from computer-generated scenes. One way to achieve high realism in 3D computer models is to use photographs to apply textures to the models. The resulting models then themselves look just like photographs, but can be manipulated in normal 3D computer graphic ways.

On the software and data handling side photogrammetry is a stable, fast and cheap method, which rapidly develops in the last years, especially by efforts of the motion picture and computer gaming industry (e.g. Microsoft Kinect®) and the geographic services available in the internet (Google Earth). There are several software solutions available, which derive point clouds from 3D-photogrammetry images. These point clouds can be used like 3D-Laserscanning point clouds. By the use of standard CAAD software with additional Plug-ins or within proprietary software packages it is possible to measure each point in 3D-images on the fly.

2.2.4 Reality versus Model: Accuracy / Tolerances

In order to describe the relationship between the model measurements and the true values different authors use different concepts, such as "accuracy" or "tolerance". For instance, the CCEM Retrofit Project uses the following definition:

"The required accuracy (1 σ) is around ± 4 mm in the window areas and ± 7 mm in the roof / façade area." in [14].

In addition to specifying the deliverables from the surveyor as to what should be scanned and modelled, the survey tender package should also include specifications of tolerances and minimum artefact size, which is the resolution of the scan. Minimum artefact size is the dimension of the smallest recognisable feature. Tighter tolerances and higher resolutions increase scan times and thus costs.

The GSA has defined a deliverable selection matrix in 4 levels according to expected resolution (minimum artefact size) and tolerances. At the most demanding level (level 4) the minimum artefact size is 13 x 13 mm with tolerance ± 3 mm (GSA, p. 5). The GSA (ibid.) defines "tolerance" as

"…the allowable dimensional deviation in the deliverable from truth (truth being a measurement obtained by some other means) in the specified co-ordinate frame. Some examples of tolerances are: 1) Point cloud: the distance between two points in a point cloud as compared to the true distance between the same two points in the actual scene should be less than or equal to the specified tolerance, 2) Plan: the difference between the length of a wall length in a 2D plan and the actual wall length should be less than the specified tolerance." in [14]

2.2.5 Economic Aspects

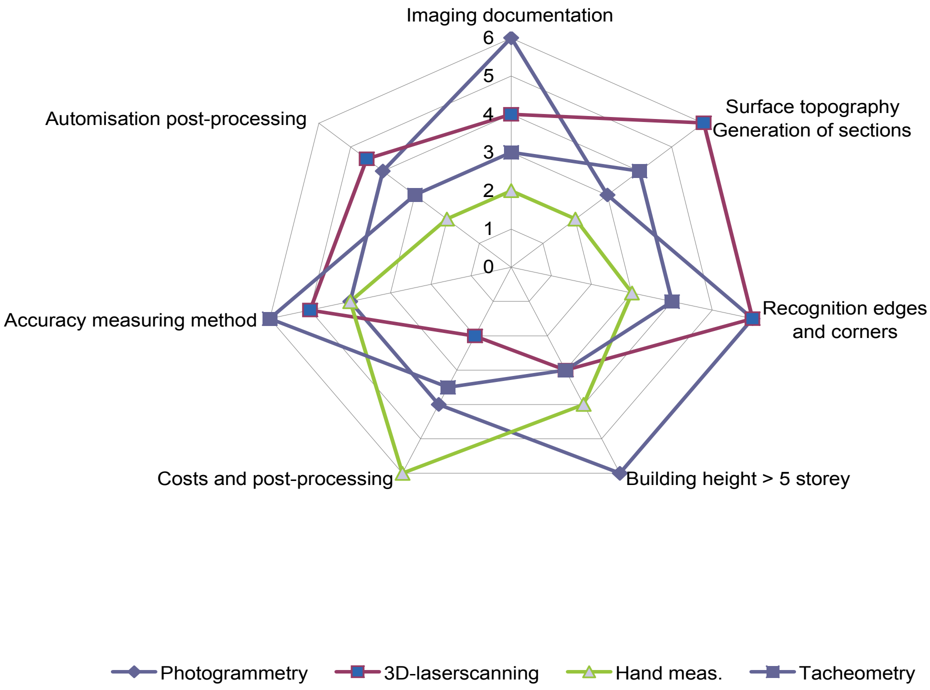

Figure 10 Economic criteria for survey method selection. The spider diagram illustrates the qualities of different surveying methods. The disadvantages of impact parameters are ranked with low values (according to Rauch).

Below are results of a field test of the appropriate measuring methods for façade surveying. The spider diagram is a result of the analysis of a survey campaign for a building in Rotlintstrasse, Frankfurt. Prof. T. A. Wunderlich, the chair of geodesy, and his staff supported the survey and provided a technical report, which was compiled by S. Rauch [15].

The graph recommends appropriate surveying solutions depending on the building's attributes. It is important to consider all attributes of the object and aspects of surveying in an individual project to avoid unpredictable results.

Two alternatives for economic survey contracting can be deduced:

First solution: As soon as feasibility studies recommend a TES EnergyFaçade, undertake an entire survey and a 3D model or 3D image. This implies that the planner is able to handle the data and has reverse engineering experience[4]. Alternatively a surveyor can also provide geometric models with correct data structures. If higher-level product models, in other words BIM models, are needed the support of experts in building construction is necessary. BIM models demand a high level of construction specific know-how, which is only available to architects and engineers in order to provide comprehensive survey information for the further design process.

The second solution will be more practical in today's construction industry. In a first step only a holistic hence not geometrically detailed investigation is done. This is the basis for design planning and tendering. A second step follows when the project is contracted. In this phase a detailed survey is subcontracted or undertaken by the general contractor.

[4] Specific software is e.g.: kubit PointCloud® an AutoCAD Plug-in; Rhinoceros 3D® by McNeel

Experience in several projects shows that intensive communication, at the very beginning, in the survey planning phase as well as in the post processing phase between the end user of the 3D model and the surveyor is essential for efficient and proper survey results.

2.3 Conclusions from Methods

1. High precision remote sensing is cost efficient and fulfills the requirements to use prefabrication in retrofitting.
2. Missing conventions for required 3D data of existing geometries and 3D models
3. Lack of 3D planning methods/BIM in architectural offices and especially in retrofitting
4. Mainly expert software systems available who can deal with 3D survey data
5. Automated tools for survey data processing are available

Conclusions:

1. Step wise use of methods (a. PG + b. TPS) or (c. TLS) and use of Hybrid surveying hardware
2. Survey consulting to define measurement result (Lastenheft = user requirement specification)
3. Forcing 3D methods + BIM in retrofitting
4. Software for broad market has to be developed

High precision remote sensing provides cost efficient methods for surveying the building stock. The acquired data is of very good quality and allows its use in prefabrication. In order to reach a good cost-benefit ratio a consulting from a surveyor is recommended.

Consequential the level of detail and the significant coordinates have to be identified on either side, surveyor and customer. This is a result of the missing conventions for required 3D data of existing geometries as well as the individuality of each building.

The lack of 3D planning methods and the usage of BIM in architectural offices in general and especially in retrofitting projects anticipate a continuous digital workflow up to now. A reason for such deficit is the restriction of the handling of survey data with expert software systems.

Cost control can be reached by a step-wise use of appropriate surveying methods. Digital technology allows this approach and guarantees consistency. There is also new hybrid survey hardware on the market, so called intelligent total station, integrating previously described measuring methods in one solution.

A user requirement specification is needed to define the content, the level of detail and the description of the 3D model.

Planners can intensify the use of 3D methods on behalf of their own interest to avoid mistakes and reduce costs. Furthermore the use of BIM tools in retrofit projects needs a deeper examination and capabilities should be enhanced on the survey side.

There are high requirements in terms of tolerances and content to prepare useful surveying results for industrialised retrofit. In consequence post processing the survey data into an abstract 3D wireframe is a costly and responsible task. The surveyor has high responsibility for this task and needs additional basic expert knowledge in construction as well as a close cooperation with the client.

Summing up the conclusions shows that applications of modern surveying methods combined with reverse engineering methods are important tools in industrialised modernisation projects. They can optimize the workflow and enhance the robustness of the retrofit method and facilitate the application of prefabrication in retrofit projects.

The most important issues which need further research and development:

- Surveying the shaded parts of façades with less effort and almost on a remote basis is still unsolved.
- Acquisition of indoor window reveals needs a high manual effort.
- Acquisitions of floor levels in all existing storeys are an additional effort.
- Workflows for visual control, marking and structured documentation are not available.
- Tools for data analysis in generic CAAD software are still missing (topography models of façades; collision detection)
- Controlled (manually + automatically) adaption of elements to uneven surfaces / collision points is difficult and manual work.

3 Digital Workflow

3.1 Experience of Demonstration - Grüntenstraße, Augsburg

The demonstration consists of a 3-storey and a 6-storey building. Both are solitaires and stand close to a big crossing of Grüntenstraße and Friedberger Straße. Apart from old high-grown trees there are no other high objects on the site.

The survey is tendered together with the services delivered by the carpenters.

The research activity contains also an additional photogrammetric survey that is complementary to the carpenter's own survey. The data acquisition will be done by the MAV as described above. The post processing and the 3D image generation is part of the cooperation with the TUM institute of geodesy and will be presented at a later stage of the project.

Additionally there is a preliminary photogrammetric survey done for the smaller building in Augsburg and only with one façade elevation, in order to get information about the process, the required steps and the use for the pre-stages and design stages.

Figure 11 North elevation of the smaller house in Augsburg demonstration (G&M).

Tasks for digital workflow evaluation:

- High resolution still images from both buildings are taken with an hexacopter platform in order to avoid shaded parts of the façade (time: 2,5 hours two persons)
- Discreet points for image orientation are acquired terrestrial with a totalstation
- Multi image photogrammetry and geo-referenced 3D model of two buildings
- Point cloud derivation from 3D-image
- Topography models of all façade surfaces
- Post processing of lower edges of the window reveals and edges of the top of the sill
- Control points of the most upper edges of the window opening.

- Comparison with the carpenter's survey data.
- Documentation of the entire process and analysis of economic aspects.

Figure 12 The site with the two rectangular blocks north of the road no. 2 Friedberger Str., courtesy Google Maps.

3.1.1 Field Survey Needs / Developments

The timber construction industry seeks easy to use and affordable solutions either as service or as in-house solution. Bigger companies with an own construction office often prefer the in-house solution with own measuring devices and trained staff. Therefore they need an economic and universal solution concerning the hardware and a post processing which can be customised to the companies' workflow. Finally the entire process should be easy to implement and learn, failure safe, resulting in good quality.

Aim: Improvement of the survey result with additional data and information needed for prefabrication.

Scope: Enhanced/holistic information is needed in design and planning process. Often it has to be improved during several site visits and lots of information are not related to geometric data or have to be added after site visit to a digital model.

Objective: (1) Holistic data acquisition on several information and detail levels, to avoid frequent site visits.

(2) A data format/structure and compilation (3D image) which allows non-experts in surveying to read, understand and use the data.

The second house in demonstration site Grüntenstrasse, Augsburg, is a 3-storey building with 12 apartments.

The volume of the building is a rectangular solid. The apartments are facing the north-south direction. The foundation structure has a cellar that comes out of the perimeter about 0,80 m. The main structure consists of load-bearing exterior walls made from masonry and concrete with a rendered outer surface. The ceilings are solid in-situ concrete slabs. The flat roof structure has the same construction as the floor slabs. The overall dimensions are about 20x10x12 meters. The northern façade is flat with window holes in it. On the southern façade deep loggias are cut out of the flat façade surface. The staircases are incorporated in the volume of the building.

The procedure for an enhanced survey consists of the measurement with the totalstation and the photography of the measured façade area from different perspectives. The data is handed over to photogrammetry software in order to calculate a 3D image. This 3D image has set the basis for certain, derived data sets, e.g. a point mesh of the façade surface.

3.1.2 Application of Surveying Methods

Hence the preferred method is mostly tacheometry, which has minimised amount of post processing. On the other hand site the time span of fieldwork is reasonably higher and, compared to the amount of data, more costly.

In case of this demonstration, the carpenter was able to develop his product model directly from the detailed survey because there is a connection or data transfer between his totalstation and the CAD/CAM software SEMA® used by the carpenter company.

3.1.2.1 Field Survey with Totalstation (G&M)

The digital survey of the Demonstration Project in Augsburg, Grüntenstrasse was performed after the architectural design phase, as a part of the work package of the carpentry contractor trade. Therefore, it was strongly focused on the construction of a production model for the prefabrication and on site erection of the new envelope.

For this purpose, the carpenter has developed its own method to integrate the digital survey and the information of the existing structure into its own workflow and CAD/CAM software. This simplified survey methodology is based on the development of an adequate interface between the production model and the totalstation. The combination of these two tools allows producing a reliable 3D model using the common drawing tools of the software SEMA®, based on the measurements provided by the totalstation.

The development of this simplified method has allowed the integration of a comprehensive amount of measurements and information obtained from the site, in the regular planning tools and production processes of the company.

The aim of the methodology is to integrate the different phases of the planning process into a single working model and planning team, which will be used from the Survey of the existing structure until the programming of the machinery in the production line.

The objective of this simplified surveying method is to build a comprehensive 3D model of the existing structure that will provide all the required information for the planning and production of the new envelope, focusing on the relevant information required for the design, discarding large amounts of details and information which is not useful later in the process.

3.1.2.1.1 Robotic Totalstation

Equipment: LEICA® VIVA TPS TS15+ CS10/15

Features:

- Tacheometer with integrated reflectorless distance measuring.

- Both manual and motor driven horizontal and vertical rotation.
- Integrated digital camera for imaging.
- Storage extension with different flash media and connections via USB or Bluetooth.
- Fully remote controllable with a handheld device.
- Extendable with additional geodetic devices like GPS receiver etc.

Technical Data: see Appendix A and [16].

Measuring point acquisition with totalstation (which ones, how many, time / work load for one / each façade, northern elevation Augsburg second house: 2,8 h).

3.1.2.1.2 Interface between Tachymeter and 3D Modelling

The Software Theo Online provides the interface between the LEICA® Viva and the software SEMA® through cable or BlueTooth® connections. It allows the 3D software to import und locate 3D points obtained with the totalstation, and use them as input commands for the common design tools, such as 3D walls, predefined windows and doors, 3D reference points with labels and notes, etc.

Figure 13 3D totalstation connected with notebook (G&M).

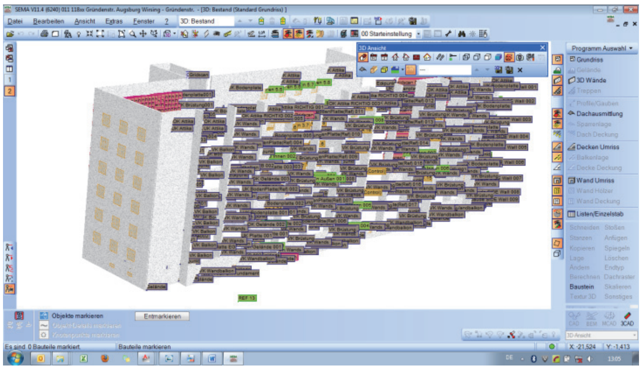

Figure 14 3D product model in SEMA, point data is acquired directly from the totalstation (G&M).

Simplified method: Production of a 3D Model at the construction site using totalstation measurements as a direct imput to CAD/CAM software used by the company.

The evaluation of the most determinant surfaces, shapes, edges or points is performed directly on site by the site surveyor, integrating the measurement and the post processing of the data in a single activity. These points are used to create a 3D object in the model which will represent the current location and positions of the existing objects for the planning and production process. The images above show the tachymeter and computer connected with each other while constructing the 3D model directly on site.

In comparison to other systems like 3D laser-scanning or tacheometry survey by specialists, a great deal of information which is discarded by the site surveyor is not included in the model. This method is not intended to obtain models of the existing buildings as detailed as possible, but to bring into the design process all the required information already selected by the evaluation of the site surveyor on site. Therefore, the scope of the survey is limited to the amount and degree of detail required by each individual case.

3.1.2.1.3 Measurements and Process

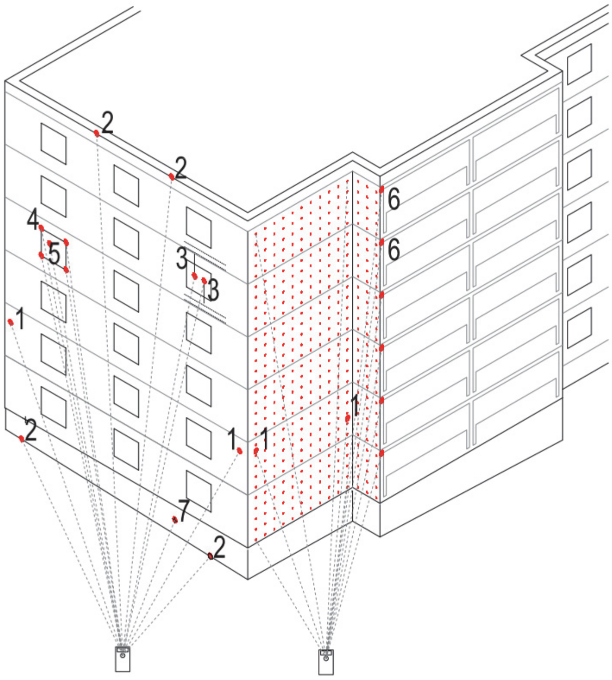

Figure 15 Measuring of discreet points left side and scan of surface area in defined step width of grid (G&M).

The points described in the image above show the most systematic and typical relevant measurements that had to be obtained for this project.

P 1. Referential plane: A wall tool sets a referential plane from start and end points obtained close to the edges of the facade. The wall is defined parallel to the vertical plane, feature which must be corrobotated with the grid scan or single points obtained from different levels.

P.2 Heights: The measurement of these points will determine the level of the highest edge of the building and the level of the terrain.

P 3. Level of the floor slabs (inside the building): Detailed explanation in Figure 15.

P 4. External dimension of the windows: The four corners of the openings are measured from the outside lo locate the windows on the facades.

P 5. Reference Window Point: to locate in the 3D model a reference from which the position of the internal sills and reveals are measured.

P 6. Edges: angles which are likely to have deformations in relation to the vertical axis are examined separately with single points.

P 7. Planes of the façade: 3D points have to be obtained where sections of the façade are on different planes than the reference wall.

Grid Scan: An automatic scan is recommended with a grid of approximately 50 x 50 cm, in order to identify deviations to the reference wall and to amend its position if necessary.

3.1.2.1.4 Integration of Indoor Survey

The levels of the floors and position of internal window reveals have to be obtained from the inside of the flats. Entering the flats can be a time consuming task due to the difficult coordination with the tenants needed.

The position of the windows of the new envelope is determined by the internal measures of the sills and reveals. The following diagram explains the points and measurements obtained to determine the position of the openings.

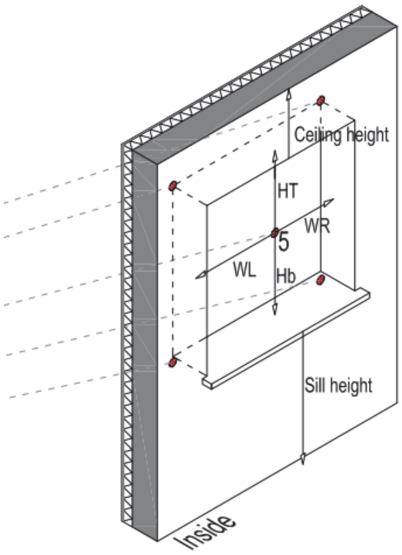

Figure 16 Measuring windows (G&M).

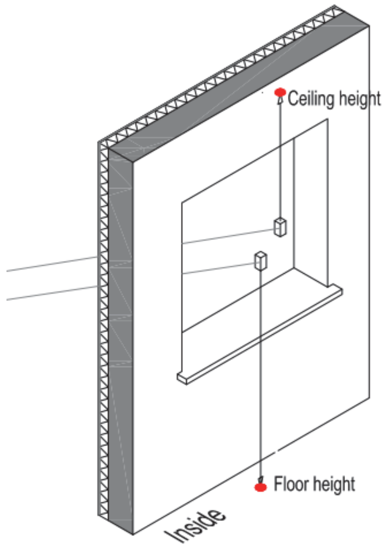

Figure 17 Measuring floor heights (G&M).

P5 Is a paper sticker pasted on the outside of the window, measured as a 3D point in the model. Measures Height Top and bottom, und width right and left (HT, HB, WL and WR) are then obtained by hand, and determine the exact position of the existing openings.

Using a prism (part of the tools included in the totalstation's equipment), the levels of the slabs are measured through the opened windows, obtaining points from the inside of the structure to determine the vertical position of the slabs.

3.1.2.1.5 Experience and Results

The simplified method has been implemented in five retrofit projects of the company and has proved applicability and benefits, but some improvements in terms of workflow are still required; minor imprecisions have occurred during the interpretation of the 3D model when the survey and the technical design of the prefabricated elements are done by different people.

	Results	Needs
Geometric fidelity	Enough precision for prefabrication. Minor imprecisions in the positioning of new windows on old openings due to integration of digital and hand measurement. Difficult evaluation of inclined edges, especially in the vertical edge.	Integrate the measurement of windows in the digital method. Enhance the use of the grid scan to modify the 3D virtual walls.
Level of detail	The level of detail is determined by the surveyor on site, and has been proven enough according to realised projects.	Include of limited cloud points as a minor part of the model where exhaustive details are needed.
Model completeness	The information from the existing building is not necessarily complete. Occasionally, additional measurements have been required during the planning phase which were discarded during the survey (common by changes in the architectural design)	Combination with Photogrammetry.
Interference	The interferences have been handled and have not compromised the results of the survey.	-
Interior integration	The measurement of the levels of the floors and ceilings is positively evaluated. The need of entering all flats has resulted time consuming.	Minimize the need to enter the flats.
Analysis	The integration of the post processing of the information in the measurement on site has presented very positive results. All information included in the Model is already analysed and processed.	-

Table 4 Overview on missing tools or software capability for fluent workflow

Still under development, the simplified method tested in the demonstration project in Augsburg has been proven to be applicable in the workflow of the industry with its existing capacities, and reliable for retrofit with prefabricated timber based elements

3.1.2.2 Field Survey with Photogrammetry

There was the same north orientated façade elevation selected for the application of the 3D photogrammetry than for the tacheometry. The main goal was a textured representative 3D model of the elevation for additional information together with the tacheometric measurement. The 3D image can also support the pre- and design stages of a retrofit project, without the need of a detailed survey.

Equipment: Canon EOS 500D

Features: 15.1 mega CMOS sensor, DiGiC 4 Image Processor, ISO 100-3200 (H1:6400, H2: 12800), Noise Reduction for high ISO speeds

Technical Data:

Optics: Tamron 18-270mm

Application and use: Zoom feature locked, Autofocus set to manual focus.

Software: EOS' PhotoModeler Scanner (PMS) software introduces an advanced correlation-based image scanner/matcher. This technology is capable of extracting accurate dense point clouds from textured surfaces without a laser and without any surface modification.

The workflow with digital camera and PMS:

- Images of the façade elevation in portrait and landscape format from different angles
- Image matching and bundle adjustment in 3D photogrammetry software
- Scaling with real dimension of characteristic length
- Optional orientation adjustment with 3D points from tacheometry
- Solution of the 3D image and densification of point mesh
- Export for use in CAAD systems.

The acquisition of a set of measured points together with the internal camera of the totalstation was tried in an additional step. The images of the integrated camera are centred to the laser beam and the target optic of the totalstation but also other measured points within the image can be used as reference point. The focal length of the totalstation's camera resulted in small image sizes that caused problems in photogrammetry due to minimum overlapping.

Data acquisition with Photomodeler Scanner (PMS) software: 17 images from different perspectives of the north elevation were taken. The camera was calibrated with the integrated routines of the software. Printed registration marks were used and placed on a façade. With several images of these registration marks from different angles and rolled camera perspective a basic set of images for calibration was done. The calibration settings of the internal orientation for a specific lens / camera combination are saved.

All images are selected for an automated matching project. Together with the camera calibration settings the camera position and perspective of the image are calculated. Additionally equal or matching points amongst the images are analysed and used for image orientation. Best matching images are selected; the remaining ones are excluded from further operation.

Figure 18 Image for photogrammetry (G&M).

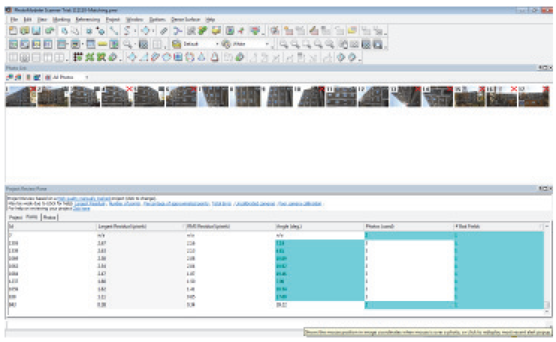

Figure 19 Selected images are adjusted and matched automatically within PMS (Ott).

After automatic image matching and processing, additional points can be added and referenced to corresponding points on other images. This is done by selection of a discreet point in a reference image and then the selection of the same point in another image; taken from another angle or perspective.

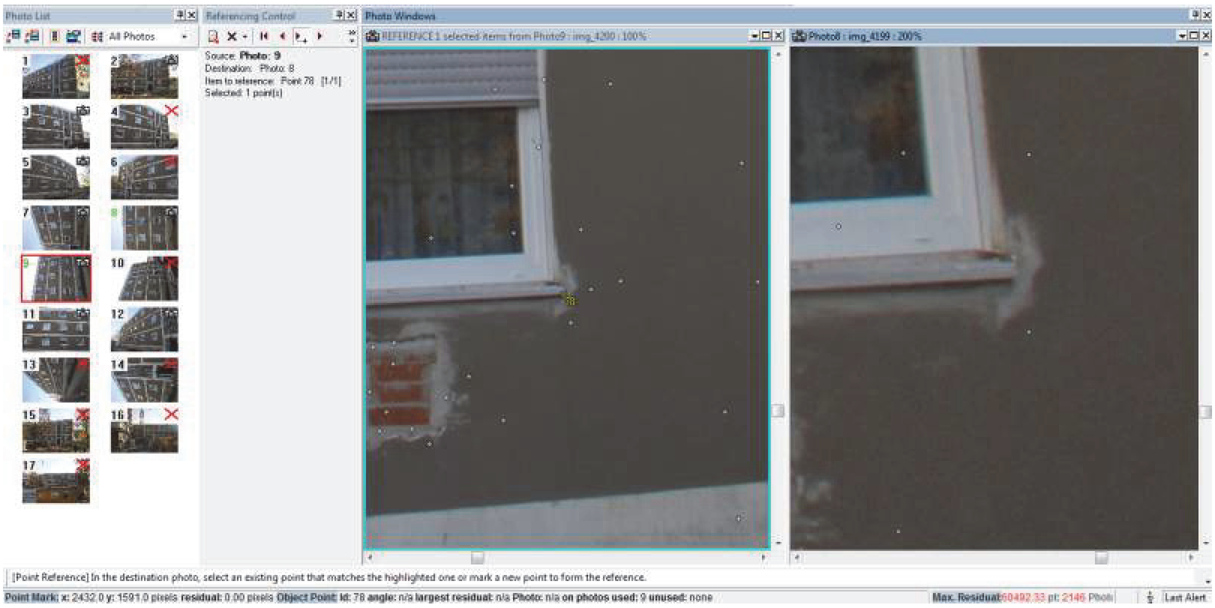

Figure 20 Manual matching of additional reference points in zoomed images (Ott).

The first mesh of points based on automated matching and bundle adjustment can be enhanced or refined. There is the possibility to calculate a fine mesh of control points with PMS. This mesh of single points can be seen in Figure 21. The dimensions of the points are not in real size, they are only texturized with the pixels of relating images for better visibility. The mesh of the model can be enhanced and the scale determined by additional measurement points from hand measurement or tacheometry. By assignment of at least four points of the images to their counterparts in the 3D tacheometry mesh a reorientation of the co-ordinate system is calculated.

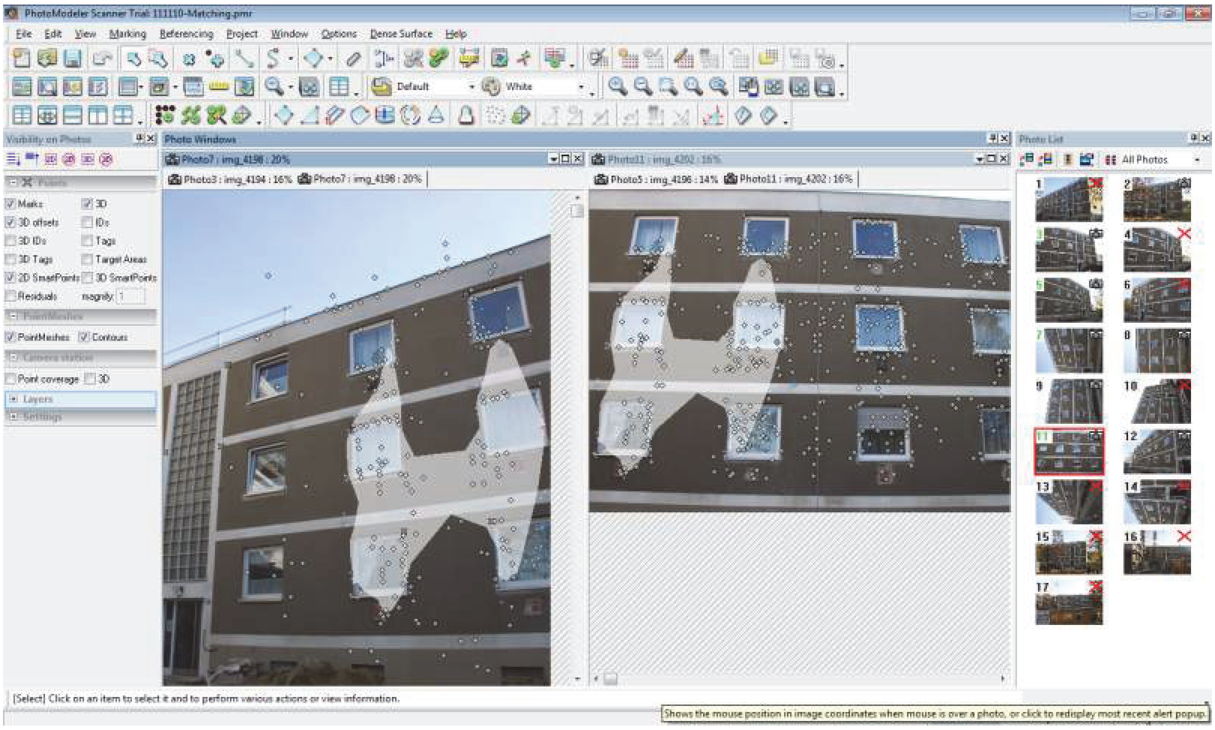

Figure 21 Images with a mesh of automatically detected 3D co-ordinates on the façade surface (Ott).

As a result of the first calculations with the provided images there is a part of the façade available for further use in CAAD software. The edges and outer borders of the façade or not included as the images cannot be calculated appropriate. Due to the site-work the angles and the quality of the images was not good enough to provide a thorough 3D elevation of the entire façade.

The point grid can be exported to 3D-dxf that is readable for most CAAD software and CAD/CAM systems. Other data formats, which are able to transport the texture information, are of proprietary nature and related to specific software tools.

Figure 22 Part of the calculated 3D image with texturizes mesh points (Ott).

The requirements and the necessary boundary conditions for photogrammetry are shown in Figure 23. The angle deviation between the different camera positions should at least 5°. Images should be taken in portrait and landscape format. An overlapping of the images of 50% is recommended. Zoom and autofocus functions have to be locked or set to manual. The camera has to be calibrated with its specific lens type used for imaging. The calibration of the camera could be done afterwards. The calibration is needed to evaluate and define the optical parameters, especially the used focal length and the distance between the sensor and the focal point of the lens. These are called inner orientation of the camera and the parameters are used to calculate each pixel to its referring point in reality.

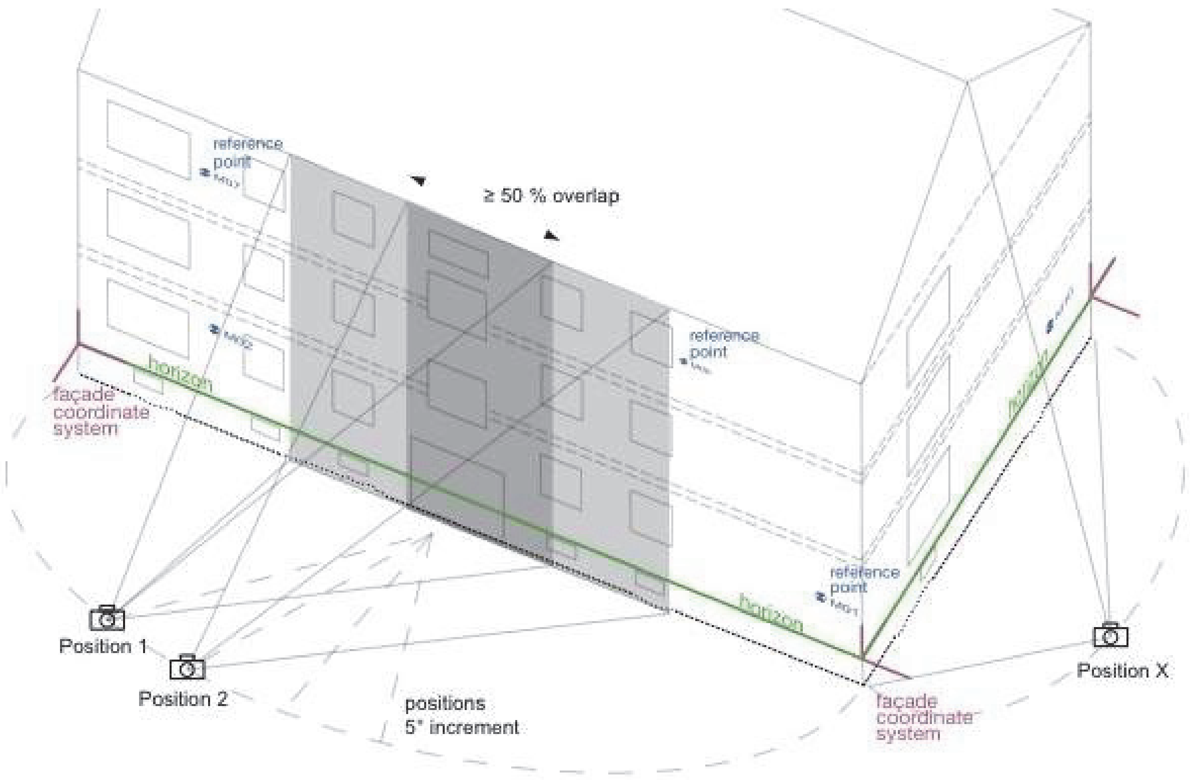

Figure 23 Systematic image acquisition of façade elevations (Ott).

3.2 Post Processing

3.2.1 Process Related Data Structures

Different types of data and information are needed at each time of the retrofit process. By means of modern surveying methods the 3D images can be captures with an adequate effort in each stage of the process. Due to the digital data format the integration of geometry and information is possible and allows a step-by-step enhancement of the building information model.

3.2.1.1 Handles and Helpers

There are basic helpers in façade surveying and post-processing, which have to be planned and implemented into the data models at the very beginning.

- Zero-level or a basic horizon equal for all elevations
- Façade Local-Coordinate-System, individual for each elevation
- Reference Points with durable, artificial marks
- List of natural, discreet reference points.

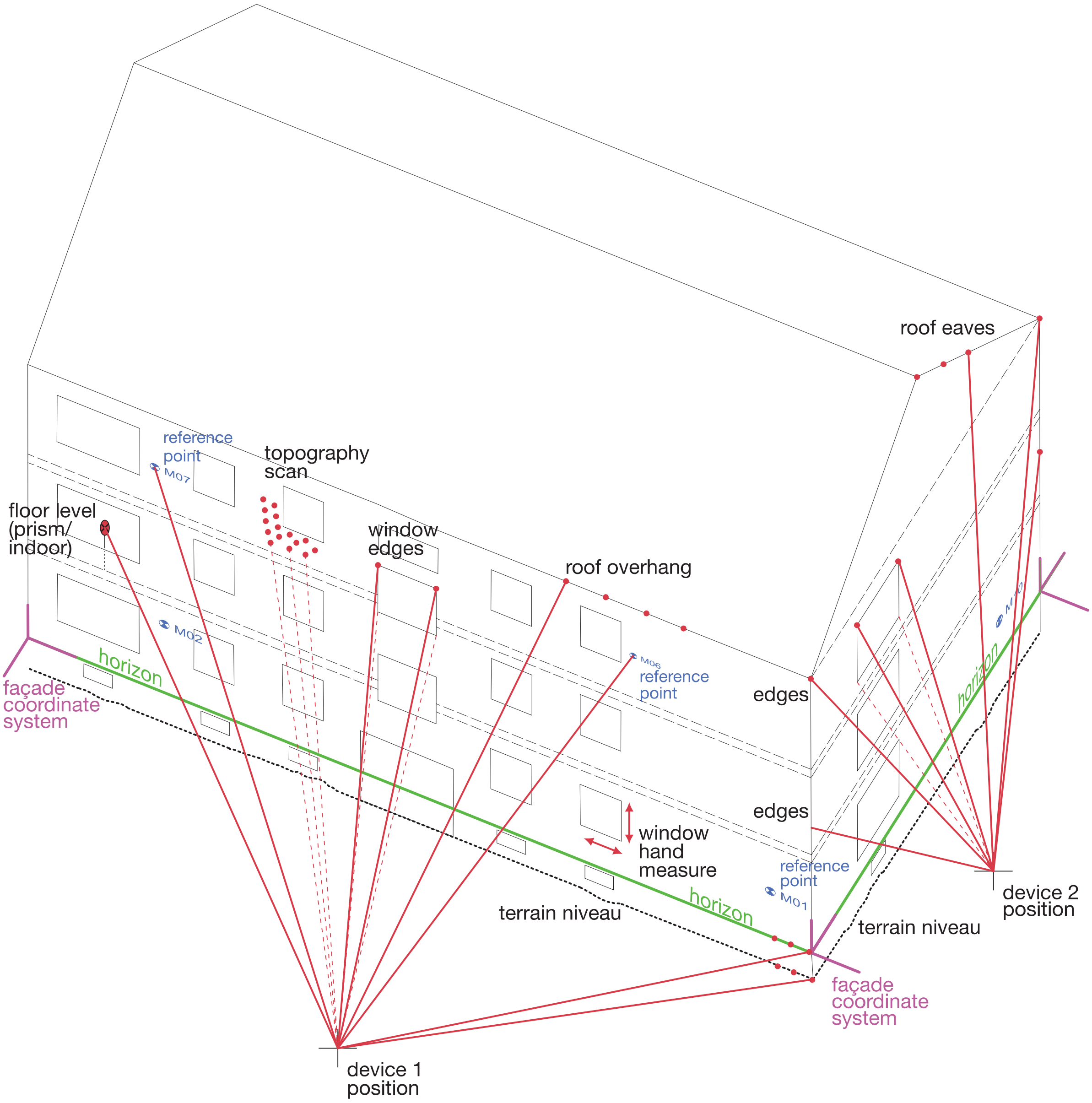

Figure 24 Required points and references in a façade survey and information model (Ott).

3.2.1.2 3D Imaging in Pre-Stages

In pre-stages reliable information is needed with a manageable economical effort and an appropriate level of detail.

In the first stage the level of detail is limited to:

- Overall geometry of the object
- Volume of the object
- Functional floor space
- Number of openings and size

Appropriate methods and data:

- Orthophoto (scaled and rectified 2D image)

- 3D volumetric model (generic model)
- Functional floor space diagram
- Wireframe of the façade (generic).

3.2.1.3 3D Imaging in Design-Stages

The design-stages are based on the first results and integrate further information. The level of detail has to be enhanced compared to the pre-stages.

In the design stages the level of detail is widened and requires:

- Dimensions and geometry of the object
- Volumetric dimensions
- Floor space (gross / net)
- Dimensions of openings
- Building services dimensions
- Structural dimensions

Appropriate methods, data and models:

- 3D image based on 3D photogrammetry
- Scaled 3D model
- Enhanced wireframe model
- Services model
- Structural model.

3.2.1.4 Detailed 3D Survey for Production Stage

The production stages have to reuse the design-stage data. In a next big step they have to develop an accurate and reliable model. It is the basis for production and all geometries are mission critical.

The production stage model requires:

- Accurate dimension + position of openings
- All existing façade related components
- High-density point cloud
- Unevenness of the façade surface
- Deviation of angles zero-level
- Deviation of angles to each façade elevation
- Inner floor and ceiling levels
- Inner reveals of windows.

Appropriate methods, data and models:

- Discreet 3D point mesh of openings
- Scan of the façade surface 100 – 500 mm grid
- Documented façade components

- Digital terrain model for topography analysis
- Perpendicular to façade surface layer
- Interior survey.

3.2.2 Outlook Integration in Planning & Production Process

The next tasks in WP4 *Innovation in Technology and Construction* are T4.2 off-site planning & production and T4.3 on-site assembly & logistics. A big obstacle at the moment is the (re-) use of the BIM within the production model of the contractor for its own preparation of work. In order to streamline the planning process a definition of requirements as well as quality standards of the model is needed that allow facilitating the data for the entire project team.

The critical issue beside the knowledge on the existing geometry is the correct amount of material and integrated sub-components like windows or building services. Sub-components have certain lead time. They have to be ordered just in time for the manufacturing.

Support methods and tools for the off-site planning & production process:

- Building information model including the latest design phase
- Tendering documents
- Production model for manufacturing.

3.2.3 Outlook Assembly Process

The assembly process brings planning back to reality. Building information models can be used for planning and simulate the retrofit process within a site model in order to minimise the risk of unexpected situation on-site. The surveying tools namely the totalstation is useful to project the planning data back onto the real façades.

Support methods and tools for the off-site planning & production process:

- Demolition and disposal planning
- Assembly simulation
- Projection / marking of fixation points
- Adjustment of axis (vertical / horizontal)
- Quality control

4 Conclusions

Taken into consideration the importance of energy performance retrofits of existing buildings in the agenda of regional and national policies and the size of this market, it is obvious that retrofit projects will in the years to come be a major challenge for the building industry. Therefore, it is necessary to develop methods and solutions for the retrofit that are in themselves environmentally friendly and sustainable. The prefabrication in retrofit is such a vision. The prefabrication approach has advantages as a sustainable building solution. The general advantages of prefabrication are also applicable to the retrofit. These advantages include:

- High quality because the construction work of the elements is carried out in the controlled environment of a factory
- Less waste because less adaption and adjustment is necessary.
- The waste generated in the prefabrication plant can be recycled.
- Lower erection costs on site.
- Minimized construction works on site
- No construction moisture during erection.

Although the actual fabrication of elements and assembly on site is efficient and may be brief, there remain challenges during the documentation and planning stages of the retrofit process in order to streamline the method and make it more cost-effective. As discussed, these challenges are (1) the efficient and automated documentation of the as-built/as-maintained condition of the existing buildings and (2) the extended use of BIM technologies during the planning stage and the creation of a continuous digital chain from the initial documentation to the on-site phase and subsequent management of the retrofitted building. Thus, the requirements for further development related to automation in the post processing of data from 3D imaging dedicated to the construction sector and innovative developments in the use of BIM tools for existing buildings renovation and retrofit.

Full 3D data clouds are still difficult to handle by architects and planners in daily business although most CAAD software vendors provide an import option for point clouds nowadays.

Useful for architects and planners are two different approaches:

- wireframe or parametric volume models of the existing object that are developed via the direct connection from the totalstation to a design software. The measuring points are combined and interpreted directly by the operator on site during the survey. This is demonstrated in the Grüntenstrasse case very well. An additional surface scan provides the necessary data for topography analysis.
- horizontal sections (thru data cloud) in about 500 mm layers (very little data treatment by specialist, strong reduction of data) and planarity pictures of façades (also usable for measuring). With this information, the architect can plan the renovation modules and tolerances.

Further improvement should be made for mounting the renovation modules and the quality control processes during assembly to ensure accuracy. Further advancements and the integration of survey data in production environments will be shown in the next step in work package 4.2 *Innovation in production*.

Appendix A Technical Specification of LEICA

Datasheet: technical specification of LEICA Viva TS15, courtesy of LEICA Geosystems.

Technical Specifications TS15

Leica Viva TS15	TS15 M	TS15 A	TS15 G	TS15 P	TS15 I
Angle measurement	●	●	●	●	●
Distance measurement to prism	●	●	●	●	●
Distance measurement to any surface (reflectorless)	●	●	●	●	●
Motorized	●	●	●	●	●
Automatic Target Aiming	–	●	●	●	●
PowerSearch (PS)	–	–	–	●	●
Wide-Angle Camera	–	–	–	–	●
RS232, USB and SD card interface	●	●	●	●	●
Bluetooth	●	●	●	●	●
Internal Flash Memory (1GB)	●	●	●	●	●
Hotshoe interface for RH15	●	●	●	●	●
Guide Light (EGL)	●	●	–	●	●
Laser Guide	–	–	●	–	–
SmartStation/SmartPole GS15 GNSS receiver	○	○	○	○	○
SmartStation/SmartPole GS12 GNSS receiver	○	○	○	○	○
Radio field controller CS10/CS15	○	○	○	○	○

● = Standard ○ = Optional – = Not available

Angular Measurement	Accuracy Hz, V[1]	1" (0.3 mgon), 2" (0.6 mgon), 3" (1 mgon), 5" (1.5 mgon)
	Display resolution	0.1" (0.1 mgon)
	Method	absolute, continuous, diametrical
	Compensation	Quadruple axis compensation
	Compensator setting accuracy	0.5" (0.2 mgon), 0.5" (0.2 mgon), 1.0" (0.3 mgon), 1.5" (0.5 mgon)
Distance Measurement	**Distance Measurement (Prism)**	
	Range[2]	
	Round prism (GPR1)	3500 m (12000 ft)
	3 Round prisms (GPR1)	5400 m (17700 ft)
	360° prism (GRZ4, GRZ122)	2000 m (7000 ft)
	360° mini prism (GRZ101)	1000 m (3300 ft)
	Mini prism (GMP101)	2000 m (7000 ft)
	Reflective tape (60 mm x 60 mm)	250 m (800 ft)
	Accuracy[3,4] / Measurement Time	
	Standard	1 mm + 1.5 ppm / typ. 2.4 s
	Fast	3 mm + 1.5 ppm / typ. 0.8 s
	Continuous	3 mm + 1.5 ppm / typ. <0.15 s
	Distance Measurement (Any Surface)	
	Range[6]	
	PinPoint R30 / R400 / R1000	30 m (98 ft) / 400 m (1310 ft) / 1000 m (3280 ft)
	Accuracy[3,7] / Measurement Time	
	PinPoint R30 / R400 / R1000	2 mm + 2 ppm / typ. 3 s
	Distance Measurement (Long-range)	
	Long-range[2,4]	>10000 m (>32800 ft)
	Accuracy[3,6] / Measurement Time	
	Long-range	5 mm + 2 ppm / typ. 2.5 s
	General	
	Display resolution	0.1 mm
	Shortest measurable distance	1.5 m
	Method	System analyzer based on phase shift measurement (coaxial, visible red laser)
	Laser dot size (Non-Prism)	At 30 m: 7 mm x 10 mm, at 50 m: 8 mm x 20 mm
General	**Operating system & Processor**	
	Operating System	Windows CE 6.0
	Processor	Freescale i.MX31 533 MHz ARM Core
	Telescope	
	Magnification	30 x
	Free objective aperture	40 mm
	Field of view	1° 30' (1.66 gon) / 2.7 m at 100 m
	Focusing range	1.7 m to infinity
	Keyboard and Display	
	Display	640 x 480 pixel (VGA) color TFT with LED backlight and touch screen
	Keyboard	36 keys (12 function keys, 12 alphanumeric keys), illumination
	Position	face I standard / face II optional
	Memory, Ports & Communication	
	Internal memory / Memory devices	1 GB (nonvolatile NAND Flash) / SD card, USB stick
	Interfaces	RS232, *Bluetooth®* Wireless-Technology, USB mini AB OTG
	Operation	
	Sensitivity of Circular level	6' / 2 mm
	Centering accuracy of Laser plummet	1.5 mm at 1.5 m
	Number of drives	1 horizontal / 1 vertical
	Power Management	
	Internal Battery	Lithium Ion
	Operating Time	5 – 8 h (GEB221)
	Voltage / Capacity	7.4 V / 4.4 Ah
	Weight and Dimensions	
	Weight of Total Station / Battery GEB221 / Tribrach GEB121	4.9 – 5.5 kg / 0.2 kg / 0.8 kg
	Height / Width / Length	345 mm / 226 mm / 203 mm
	Environmental specifications	
	Working / Storage temperature range	-20° C to +50° C / -40° C to +70° C
	Dust / water (IEC 60529) / Humidity	IP55 / 95%, non-condensing
Guide Light (EGL)	Working Range	5 – 150 m
	Positioning accuracy	5 cm at 100 m

Leica Viva One-Person-Surveying

Motorization	Rotation speed	45° (50 gon) / s	
Automatic Target Aiming (ATR)	**Range**	**ATR Mode**	**Lock Mode**
	Round prism (GPR1)	1000 m (3300 ft)	800 m (2600 ft)
	360° prism (GRZ4, GRZ122)	800 m (2600 ft)	600 m (2000 ft)
	360° mini prism (GRZ101)	350 m (1150 ft)	300 m (1000 ft)
	Mini prism (GMP101)	500 m (1600 ft)	400 m (1300 ft)
	Reflective tape (60 mm x 60 mm)	55 m (175 ft)	–
	Shortest distance to 360° prism	1.5 m	5 m
	Accuracy[1] / Measurement Time		
	ATR angle accuracy Hz, V	1" (0.3 mgon)	
	Base positioning accuracy	±1 mm	
	Measurement Time for GPR1	3 – 4 s	
	Maximum speed (Lock Mode)		
	Tangential (standard mode)	5 m / s at 20 m, 25 m / s at 100 m	
	Radial (tracking mode)	4 m / s	
	Searching		
	Search time in field of view	Typ. 1.5 s	
	Field of view	1° 30' (1.66 gon)	
	Definable search windows	Yes	
	Method	Digital Image processing	
Power Search (PS)	**Range**		
	Round prism (GPR1)	300 m (1000 ft)	
	360° reflector[8] (GRZ4, GRZ122)	300 m (1000 ft)	
	Mini prism (GMP101)	100 m (330 ft)	
	Shortest distance	1.5 m	
	Searching		
	Typical search time	5 – 10 s	
	Default search area	Hz: 360° (400 gon), V: 36° (40 gon)	
	Definable search windows	Yes	
	Method	Digital Image processing (rotating laser fan)	

Leica Viva Imaging

Wide-angle Camera	Sensor	5 Mpixel CMOS sensor
	Focal Length	21 mm
	Field of view	15.5° x 11.7° (19.4° diagonal)
	Frame rate	20 frames per second
	Focus	2 m (6.5 feet) to infinity
	Image storage	JPEG up to 5 Mpixel (2560 x 1920)
	Zoom	3-step (1x, 2x, 4x)
	Whitebalance	User configurable
	Brightness	User configurable

Leica Viva SmartStation

Add-on GS12 / GS15	**Position accuracy[9,10]**	Horizontal: 10 mm + 1 ppm, Vertical: 20 mm + 1 ppm
	RTK Initialization	
	Reliability / Time of initialization	>99.99% / Typically 8 s, with 5 or more satellites on L1 and L2
	Range	Up to 50 km, assuming reliable data-link is available
	RTK Data formats for data reception	Leica proprietary formats (Leica, Leica 4G), GPS and GNSS real-time data formats, CMR, CMR+, RTCM v2.1 / 2.2 / 2.3 / 3.x
	GNSS Antenna	
	Number of channels	GS15: 120 GS12: 120
	Dimensions (diameter x height)	GS15: 196 mm x 198 mm GS12: 186 mm x 89 mm
	Weight	GS15: 1.34 kg GS12: 1.05 kg

[1] Standard deviation ISO 17123-3
[2] Overcast, no haze, visibility about 40 km; no heat shimmer
[3] Standard deviation ISO 17123-4
[4] To Round Prism GPR1
[5] Fast Mode
[6] Object in shade, sky overcast, Kodak Grey Card (90% reflective)
[7] Distance >500 m 4 mm + 2 ppm
[8] Target perfectly aligned to the instrument
[9] Measurement precision, accuracy and reliability are dependent upon various factors including number of satellites, geometry, obstructions, observation time, ephemeris accuracy, ionospheric conditions, multipath etc. Figures quoted assume normal to favorable conditions. Times can also not be quoted exactly. Times required are dependent upon various factors including number of satellites, geometry, ionospheric conditions, multipath etc. The following accuracies, given as root mean square, are based on real-time measurements.
[10] When used within reference station networks the position accuracy is in accordance with the accuracy specifications provided by the reference station network.