Short report for the research project:

Prefabrication Based on Digital Building Survey Examined by the Example of Tailor-Made Vacuum Insulation Panels

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1 Objective of the research project

More than half of the building activity in Germany affects existing buildings. A considerable increase of the efficiency of the construction works on building stock could be achieved by an intensified use of prefabrication. For this purpose an exact and cost-effective measuring technology is needed, which is able to provide stock data for the digital process chain.

Unlike in building industry, computer aided manufacturing of fitting parts on the basis of digital 3D-measurement are daily practice in various technical branches. Tailor-made clothes and custom-fit dental prostheses can be taken as examples for that.

The aim of the research project was to examine whether this method can be transferred into building industry: Is it possible to realize computer aided planning and prefabrication on the basis of modern surveying technologies in combination with special measuring software.

Figure 1: Test objects (from left to right) “Façade Vorhoelzer-Bau” (two pictures), “Ceiling Meyer-Jens-Halle”, “Cellar room Gabelsbergerstraße”

Taking a suitable building material as an example it was to demonstrate, how the realisation of prefabricated elements for existing buildings can be achieved by the use of available 3D measuring technique in conjunction with special software and computer-aided assembly. Vacuum insulation panels (VIP) were chosen, since prefabrication is mandatory here. Because of the gas-tight enclosure, the panels cannot be tailored or reworked on-site. Insulation panels with vacuum technology have a very low conductivity up to only 0,004 W/(m·K). Hence, they often represent the only way for energy-efficient renovation on existing buildings, when the insulation thickness is highly limited.

2 Realisation of the research project

Three test objects were chosen on the main campus of the Technische Universität München: a façade, a ceiling of a tall hall and a small cellar room (Figure 1). The test objects represent different measuring situations and typical geometries for installing vacuum insulation panels. These objects were surveyed using different techniques such as 3D-laserscanning and photogrammetry. On the basis of the digital data prefabricated insulation elements were produced for one test object and finally mounted on site.

2.1 Applied measuring techniques

In this project 3D-laserscanning, single-image photogrammetry and multi-image photogrammetry were used. *3D-laserscanning* combines the measurement of angles and distances. By tilting and pivoting the laser beam automatically the whole surface of the object is covered with a dense mesh of measuring points. The output are the coordinates of a huge amount of points (so called point cloud, see Figure 2) describing the surface geometry of the object in three dimensions. With a single scan only those areas of the object can be depicted which can be reached by the laser beam from that very position of the scanner. Generally it is necessary to scan the object from various viewpoints and to create a combined over-all point cloud by joining the single point clouds. Surveying a building or part of it can last between a few hours and several days depending on dimension and complexity. Measurements, visualisations and collision-checks can be done easily within the point cloud. Time-consuming modelling, however, is necessary, if CAD-drawings or -models have to be generated from a point cloud.

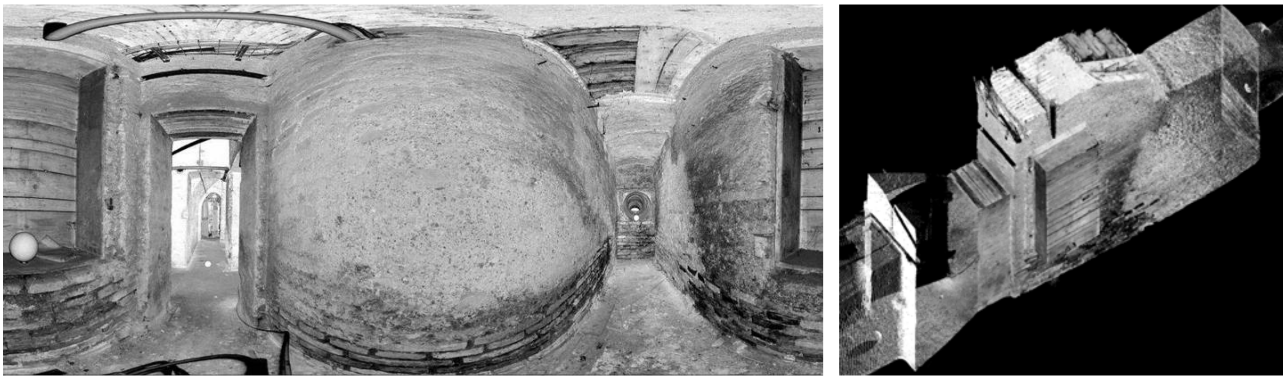

Figure 2: "Cellar room Gabelsbergerstraße", point cloud shown as panorama and as axonometric

With the methods of *photogrammetry* (Figure 5) dimensions of the object can be taken from measurements in photographs. In general digital cameras in combination with special evaluation software are used here today. The acquisition of image-data on site takes only a very short time. Contrary to 3D-laserscanning movements of the sensor during data acquisition doesn't necessarily cause problems. This allows the use of lifting platforms or unmanned aerial vehicles (UAV). Sufficient illumination is necessarily required for photogrammetric survey. Texture and colour of the object depicted in the images represent valuable information. Regarding applications in building, photogrammetry can be divided into two groups: By using *single-image photogrammetry* measurements can only be taken in just one plane of the object (for example a façade). For this purpose the image is geometrically transformed so that elements in that one plane are represented without any distortion and true to scale. Several rectified images can be mosaicked to form an overall view. By means of *multi-image photogrammetry* 3D-coordinates of object points can be calculated using two or more photographs of the same object. A model generated with these points can be textured with image-information from the photographs.

2.2 Survey of the test objects with 3D-laserscanning

The three test objects “Façade Vorhoelzer-Bau”, “Ceiling Meyer-Jens-Halle” and “Cellar room Gabelsbergerstraße” were scanned with five different 3D-laserscanners: one time-of-flight scanner, two phase difference scanners, one intelligent total station (which is able to scan as well) and one hand held scanner using laser sheet triangulation.

The point clouds acquired during the project were of different quality. Basically, differences resulted from the number of scanner positions and the resolution settings. By choosing more scanner positions it is possible to avoid shading and to survey an object including all parts. Especially small detail of buildings requires scans of high resolution for a representation true to reality.

The data were evaluated using one non-commercial and several commercial software products. Modelling was realized applying two different methods: converting the point cloud into a polygonal mesh and modelling of primitive forms (planes, cylinders e.g.) (Figure 3). In the latter case edges and vertices were modelled by the intersection of planes and then connected to form a wire frame model.

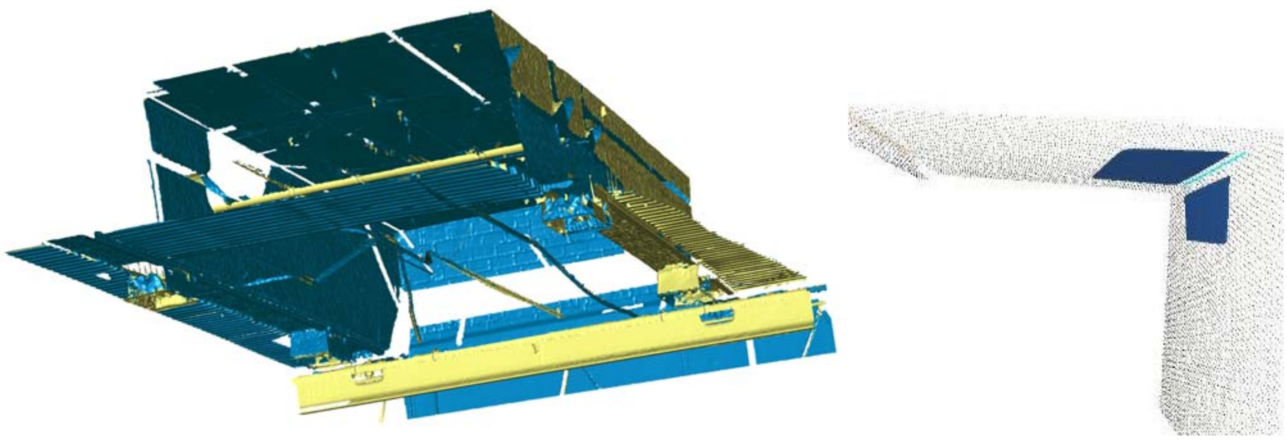

Figure 3: polygonal mesh “Ceiling Meyer-Jens-Halle” (left), modelling of edges (right)

When evaluating the measuring data of the object “Façade Vorhoelzer-Bau” the aim was to generate a model as precise as possible. The model was supposed to be the basis for the fabrication of the vacuum insulation panels, which in the end were mounted on site as samples. Due to missing data by reason of shading some areas of the façade were not sufficiently represented in the point cloud. Those gaps had to be closed in the model by interpretation of the existing data, being aware that this procedure includes the risk of creating errors. Figure 4 (left) shows the point cloud of a window pier with partially missing data.

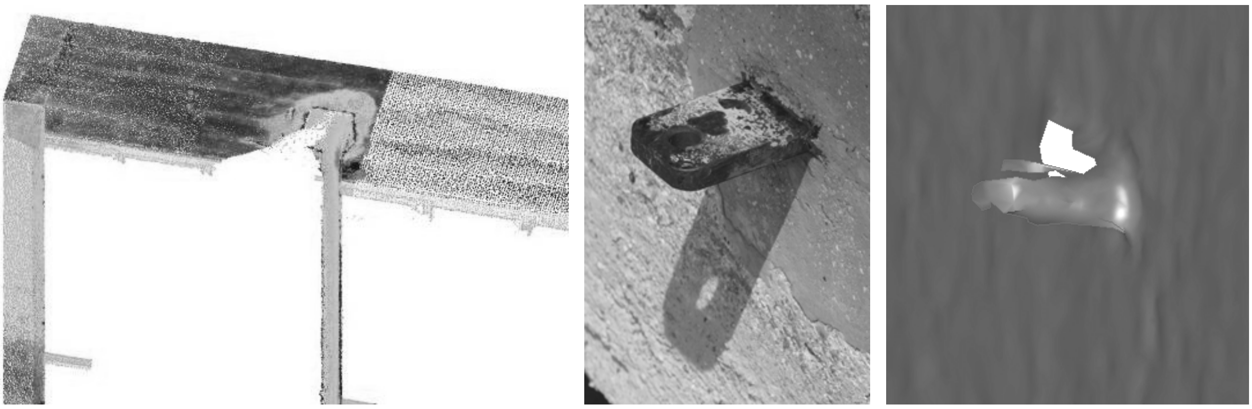

Figure 4: "Façade Vorhoelzer-Bau", shading at the back of a window pier (left), insufficiency of polygonal mesh in the area of a detail (right)

Modelling of details requires a high density of points whereas a low number of points in those areas lead to unsatisfying results. An example is shown in Figure 4, right.

The point clouds produced with different laser scanners were transformed into various wire frame and polygon mesh models. The comparison of the results was realized in two different ways: First, models were compared with the point cloud as well as with each other. Deviations were visualized and evaluated statistically. Second, measurements of distances were made in the models and compared with measurements taken by hand on site.

The aim of comparing the data was not to evaluate the precision of the laser scanners. Instead, the overall quality of the point clouds and the generated models was to be examined. As expected the correlation between point clouds and polygon meshes was very good. Merely in areas with poor data significant deviations could be observed. To compare the point clouds with the wire frame models, planes were spanned between the edges. Thus, the unevenness of the façade could be visualized. Comparing measured distances, the mean value of all measurements related to one distance was used as reference as well as measurements taken by hand. The deviation from the mean was in most cases less than 10 millimetres. The results of the comparison with the measures taken by hand were slightly worse. In general considerable deviations between data and reference value were disclosed in those areas, where modelling had become difficult due to shading.

Scans taken in the "Cellar room Gabelsbergerstraße" were of high quality despite of the narrowness of the room (Figure 2). Spatial data as they are needed for preliminary design could be achieved from the point clouds in short time and without any further modelling. Automatic modelling of beams, openings and pipes was examined on the object "Ceiling Meyer-Jens-Halle". This could not always be realized without any difficulty. Again shading has to be named as the cause.

2.3 Survey of the test objects with photogrammetry

The pictures for the photogrammetric survey of the test objects were taken with calibrated digital single lens reflex cameras. Comprehensive evaluation and analysis were undertaken for the test object „Façade Vorhoelzer-Bau".

Four software products for single-image photogrammetry and two for multi-image photogrammetry were used in this project. Evaluating the photographs four photogrammetric methods were applied: rectification by surveyed points, rectification by parallels, rectification by data from multi-image photogrammetry and multi-image photogrammetry itself.

The smallest deviations compared to the measurements by hand were achieved using multi-image photogrammetry. Very good results were also obtained using rectification by data from multi-image photogrammetry. The latter technique, however, is a mixture of two methods and requires an extra of equipment and effort therefore. Working with pure single-image photogrammetry best results could be achieved using rectification by surveyed points. The largest deviations were caused by rectification by parallels.

Figure 5: single-image photogrammetry showing rectified and dimensioned photograph (left) and wire frame model generated by multi-image photogrammetry (right)

The comparison of 3D-laserscanning and photogrammetry was realized using six measured distances of the test object "Façade Vorhoelzer-Bau". In summary it can be stated that results on a high level of accuracy can be achieved with 3D-laserscanning as well as with multi-image photogrammetry.

2.4 Mounting of prefabricated insulation elements on the test object "Façade Vorhoelzer-Bau"

The project was completed by installing a sample area of tailor-made insulation elements prefabricated on the basis of digital stock data. The sample elements (vacuum insulation panels coated with polystyrene) were mounted on the façade of the 5th storey of the Vorhoelzer-Bau on an area of 23 m². For the fabrication of the elements the producer Variotec was supplied with CAD-data of the façade in form of a 2D development without any dimensioning. The data were achieved by generating a wire frame model based on 3D-laserscans of the object.

In summary the applied method turned out to be very successful. The mounting of the tailor made elements could be realized without any further measuring on site. The chosen process proved to be faster and more efficient than the conventional way of working. The possibility to examine the planarity of surfaces allows the planning and calculation of preliminary work such as the elimination of unevenness by adding or removing of plaster.

Figure 6: sample area during mounting work and after completion

On the basis of the research results a procedure was developed that describes how the application of prefabricated elements in building stock can be realized. A proceeding in two steps is suggested, using different strategies of stocktaking during negotiation phase on one hand and realisation phase on the other hand.

3 Summary of the Results

The research project „Prefabrication Based on Digital Building Survey Examined by the Example of Tailor-Made Vacuum Insulation Panels" could demonstrate that by using modern measuring technique digital stock data for the prefabrication of tailor-made parts can be achieved on a high level of accuracy. The findings are already deepened in several pilot and research projects.

Laserscanning and photogrammetry have completely different characteristics. Therefore, before starting a project, it is necessary to decide which survey method suites best. 3D-laserscanning, for example, is able to represent the topology of a surface. Therefore this method is predestined when the planarity of surfaces has to be examined. Using photogrammetry the dimensions and visual information of objects can be achieved easily. The weaknesses of one technique can partly be compensated when it is combined with another.

The methods presented in this project are not necessarily linked to vacuum insulation panels. In general optoelectronic measuring technology has proved to be a capable way to obtain precise digital data of existing buildings. Such data can easily be used as basis for the prefabrication of accurately fitting elements. It is assumed that prefabrication will be used in building stock more often in future. Further automation of editing digital stock data is expected to go along with this process.