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FakultätBauingenieurwesen Institut für Bauinformatik

Comparison of facade design methodologies based on point cloud data and traditional surveying techniques.

Thesis Work

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Schneider Fassaden Gmbh &Co.KG

Dresden, 21.09.2020

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Task sheet for the Master Thesis
Aufgabenstellung zur Masterarbeit

Name: Harikrishnan Ramanathan Matriculation No.: 4 735 050

Program: Advanced Computational and Civil Engineering (ACCESS)

Title: **Comparison of façade design methodologies based on point cloud data and traditional surveying techniques**
Vergleich verschiedener Vorgehensweisen bei Entwurf und Fertigung von Fassadenelementen für Um- und Erweiterungsbauten

Goal

Façade design provides an opportunity to create an aesthetic value of the building. The precision of façade design mainly depends on the accuracy of measurements taken from an existing building. Traditional surveying techniques have been developed over decades aiming to detect and specify relevant building objects. From a renovation perspective, there usually is a substantial amount of time-consuming surveying activities (e.g. measurements to be taken) required to collect all data and put them into drawings of buildings. Using more advanced surveying tools (e.g. laser scanner) one can acquire geometric data more rapidly.

This thesis focuses on a comparison of both traditional surveying techniques and fast mapping methods. The main aim of the thesis is to define complete workflows for façade design of a given building (i) based on laser-scanned point cloud data and (ii) based on the traditional surveying. The student is expected to capture as-built data relevant to façade design of a given building on the site utilizing laser scanners. The acquired data should be processed aiming to create a 3D-model of the building with necessary details of the façade. The model is to be enriched with so-called "BIM data". Moreover, the design of the façade elements should be executed using static calculations and architectural models. The workflow specification is to be completed by creating excel sheets specifying parameters for the final production and fabrication of façade elements.

In a second step, the student is expected to carry out data acquisition on the same building in the traditional way (i.e. using measuring tape, and rotation lasers). Drawings should be developed using the architectural and static calculations in the worksite. Schedules for façade plate production and fabrication should be created in consultation with skilled personnel employed in Goldbeck's manufacturing plant.

Finally, the student is expected to compare the results of the two distinct façade design approaches against pre-defined performance indicators, such as e.g. time, cost analysis, personnel required, complexity of the workflow, etc.).

Scope of work:

The work on this thesis must address the following aspects.

1. Development of the as-built status of a given building using fast mapping methods and traditional surveying methods. Post-processing should be done to develop a 3D-model of the building.
2. To create drawings holding details of façade dimensions and positions in a given building by considering static calculations in both methods and also architectural drawings. Create façade details in both cases for the manufacturing process.
3. Compare the design of the façade based on traditional surveying and point cloud data acquisition on the basis of the specific demonstration project.
4. To enrich the geometry model with additional "BIM parameters".

Recommended tools for the thesis:

- Leica P40
- 3D Reshaper
- AutoCAD, Revit
- Autodesk Recap

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Topic handed over to student:	19/05/2020
Expected Submission Date:	21/09/2020

DRESDEN concept

Die besonderen Hinweise für die Anfertigung der Projektarbeit des Instituts sind zu beachten. Page 2

Declaration

I confirm that this assignment is my own work and that I have not sought or used inadmissible help of third parties to produce this work. I have fully referenced and used inverted commas for all text directly quoted from a source. Any indirect quotations have been duly marked as such.

This work has not yet been submitted to another examination institution – neither in Germany nor outside Germany – neither in the same nor in a similar way and has not yet been published .

Dresden, 21.09.2020

Signature

Acknowledgment

I would like to express my earnest thanks to the people who have supported and helped me so much throughout this period. I would particularly like to single out my industry mentor Mr. Frank Mitterlindner, Geschäftsführer Schneider Fassaden Gmbh & Co.KG. The guidance and inputs provided by him served as an invaluable part in the completion of my thesis work. I would also like to thank my supervisor Mr. Prathap Valluru, M.Sc for his excellent cooperation and for all of the opportunities. I wish to express my sincere gratitude to Dr.-Ing. Katja Heine.

In addition, I feel deeply honoured in expressing my sincere thanks to Prof. Dr.-Ing. habil. Karsten Menzel who gave me an opportunity to do my thesis work in the Fakultät Bauingenieurwesen, Institut für Bauinformatik, TU Dresden.

Finally I would like to thank my friends and family for supporting me in my endeavours.

Abstract

The word ‘Facade’ means Face in French. Facade generally refers the front of a building. Facade design is a possibility to create a character to a building. The accuracy of measurements from an existing building plays an important role in the precision of facade design. The measurements of the building geometry can be carried out by traditional surveying and fast mapping methods.

The main aim of the thesis is to define the entire work flow process of facade design based on traditional measurements and laser scanned point cloud data for a given building. Later, the accuracy of building geometry acquired from both of these techniques are compared and studied in a detailed manner.

The thesis mainly focuses on defining the steps involved in renovation of an existing facade of a given building. The as-built data of an existing building is carried out by both the traditional surveying technique (Rotation laser and tape measurements) and 3D laser scanning (Leica P40). Later, comparative analysis of design of facade is done based on traditional and point cloud data acquisition on the basis of the demonstration project. Finally an enriched 3D model holding BIM parameters is created for future operations.

It is important to understand the workflow of facade design step by step before performing a comparative analysis on it based on traditional and point cloud measurements. So an effort is taken to explain the design of facade in a detailed manner from an industry oriented approach.

The workflow of Facade design involves various activities such as capturing as-built measurements, post processing of point cloud data to attain 3D trace of the building geometry, preparing 2D elevations, static calculations for determining position and depth of sub-construction required, creating standard and critical details for facade based on static calculations, optimisation of Facade plates based on standard plate measurements, producing facade mounting plans and preparing excel sheets for estimating list of facade elements.

The outcome of the thesis is to demonstrate the methodologies of comparison of facade design based on point cloud data and traditional surveying techniques.

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List of abbreviations

Abbreviation	Complete name
BIM	Building Information Modelling
CNC	Computer Numerical Control
2D	Two Dimensional
3D	Three Dimensional
AEC	Architecture Engineering and Construction
LV-EH	Leistungsverzeichnis Einheitpreis (Bill of Quantity)
LOD	Level of Detail
EDM	Electronic Distance Meter
CAD	Computer Aided Design
TLS	Terrestrial Laser Scanning
TOF	Time of flight
HDS	High Definition System
GB	Giga Byte

1. Introduction

The facade is an important exterior element in the context of building functionality. From a technical view the facade is one of the most complex building parts. The growing complexity of modern facade constructions made the allowable tolerances lie in the millimetre range for facade systems. The production and assembly of facade have also reached to a high degree of prefabrication.

Accuracy is the most important criteria to be ensured in a facade construction project. Accuracy of measurements plays a prime role in facade design, as an inexact measurement leads to greater obstruction to the overall facade design project. Whereas the exact measurements acquired saves huge amounts of time, labour and money for facade builders.

There are many ways to acquire measurements from an existing building right from traditional methods to modern surveying techniques. A comparative analysis of facade design methodologies is carried out based on the traditional and modern surveying techniques.

1.1 Facade Design Methodologies

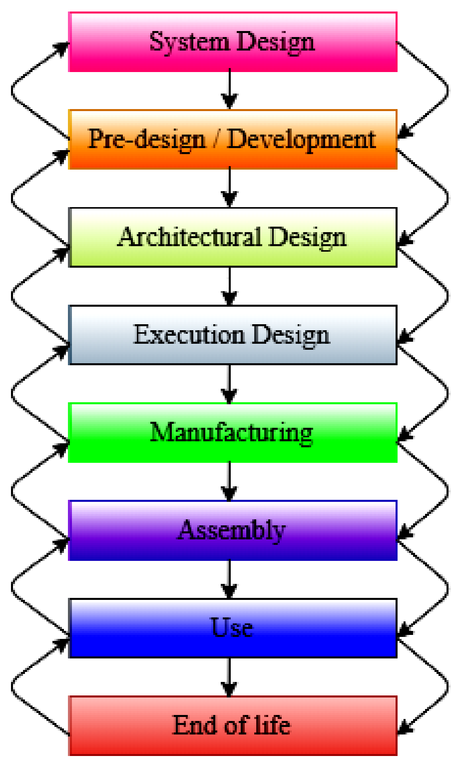


Figure 1: Facade design and construction phases [1]

System design:

System design is carried out in the earlier stages of authentic design process. Facade systems are developed by system providers, based on the current market trends. System design need to meet legal requirements and the requirements from architectural design. The main aim of the system provider is that his products are to be clearly explained in the tender document and he thus he could upgrade his system portfolio. He sells his product to facade builder and helps in assisting the design team.

Pre-design/development:

In the pre-design stage the fundamental needs of the building are identified. The location, size of the building, purpose of the building along with legal requirements from system design phase gives an overall picture of the functional requirements for the facade.

Architectural design:

Based on the functional requirements of the building a preliminary design sketch is initiated and the design is further developed to produce drawings for building permit by negotiating with authorities. Based on these drawings, the architect develops working drawings specifying all technical details for creating tender documents. This process makes the architect to work in pre-defined steps with continuous and iterative measurements of building in coordination with structural, facade and climate engineers. The client approval and cost calculations are done simultaneously.

In Germany the architects work with predefined steps and their execution planning is prepared before the technical specifications which helps the architect and the engineers to work together on developing the building plan with greater responsibility and liability.

Execution design:

The facade builder plays a major role in execution design phase. The facade builder follows linear design steps unlike the architect. He follows three major execution design steps. The first step involves creation of basic project design based on architectural design. This step helps to identify the missing details in tender document such as vent profiles or any special profiles, delivery time for facade elements etc. Which are initially communicated with the architect in the first step. The second step is to create detailed design drawings and any complications identified with solutions and got approval from the architect. Final step is the production and assembly execution phase.

The drawings created by the facade builder has higher detailing than the architect's drawing as he prepares numerous internal design steps for live execution of work at site. Finally the confirmation of which facade system to be used is finalized in this design phase.

Production:

The facade production is a process which involves high efforts in proper planning. The various profiles, sub construction and facade fittings are supplied by the system provider to the facade builder. The facade plates are fabricated with the help of Computer numerical control (CNC) machines and skilled labour in the manufacturing plant in dry conditions and sent out for erection in the work site.

It is important to make sure every facade plate is having same coat of colour at this stage of facade production and protective foil is covered over each facade plate to avoid any damage during transport to the work site. In the production stage the design of facade gets frozen and any further design changes will lead to greater logistical efforts. The sub components such as ventilation profiles, sun shading devices or glass panes will have to be designed, ordered and integrated in the production process.

With available production facilities, the facade builder will pre- assemble most of the construction parts in manufacturing plant because it is easy to identify any mistakes and compensate them with tools and spare parts in hand at the production plant rather than in the work site.

Assembly:

The important factor to be considered during the assembly of facade is the weather conditions. Bad weather conditions pose a threat for assembly of facades on site. The more the complexity of facade systems the greater is the requirement for pre-fabrication and pre-assembly of facades in the manufacturing plant. To reduce the time involved for assembly of facade plates skilled personnel are required. Facade installation is highly dependent on the completion of primary building structure.

The tolerance level for facade construction cannot be more than few millimetres (say 2mm). Facade installations can be affected by internal finishing touches of the building but still the quality of facade should be taken on account.

Use:

When the facade construction is completed this phase of design shows whether the facade matches the desired functionalities for which it is built. The energy performance, insulation, climate balance, user comfort are examined at this phase of design. A failure at this stage is unacceptable and the design team will have to take the overall responsibility to avoid such situations.

The maintenance and cleaning of facade for which the cranes, ladders used lead to considerable cost issues which should be clearly mentioned in tender document at the early design phase. Initiatives have to be taken to avoid cleaning costs by considering suitable measures.

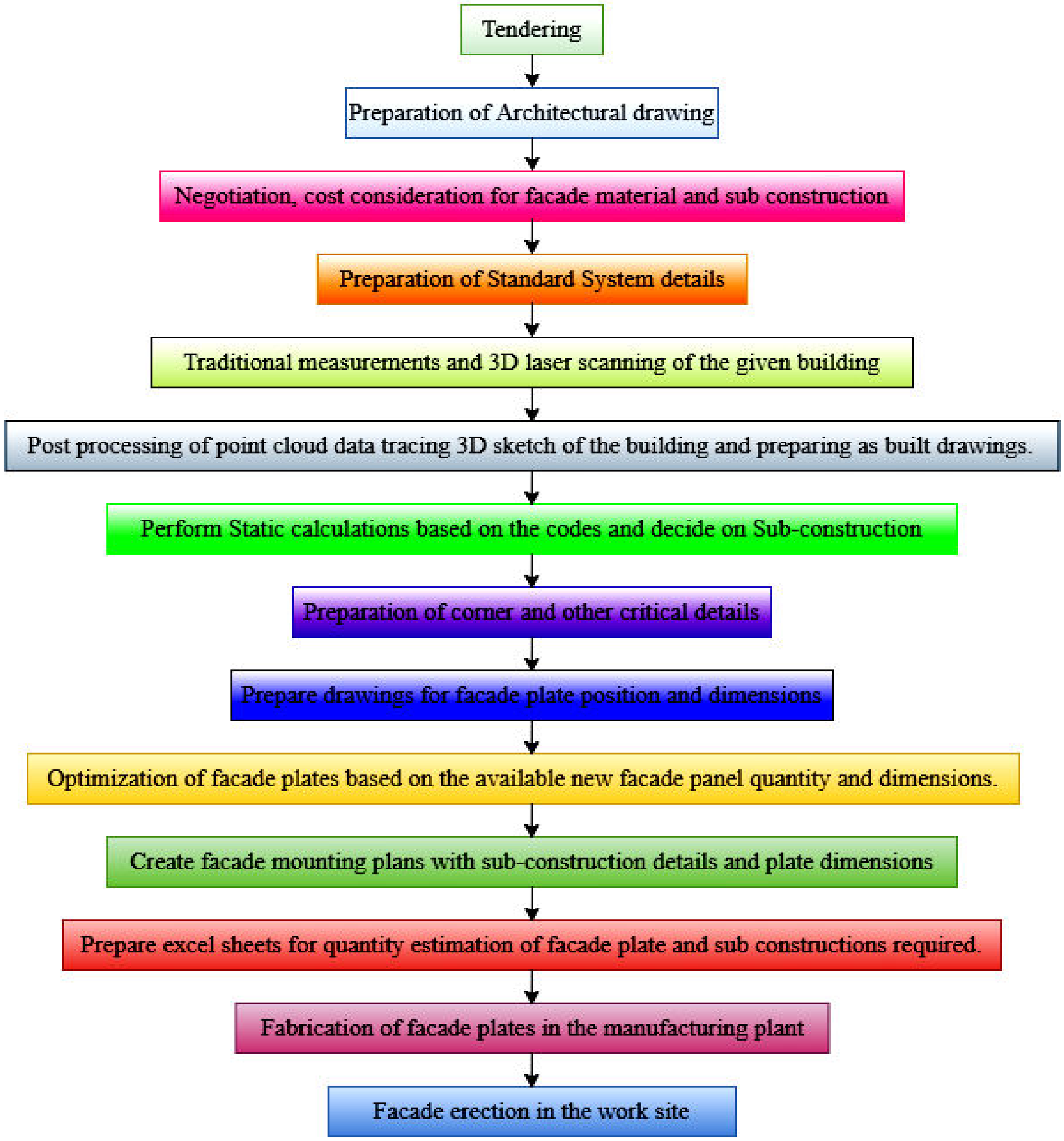


Figure 2: Specific Design Steps involved in Facade design

Fig. 2 shows the specific steps for facade design which has a greater scope for a facade builder. These design steps has a greater dependence on accuracy of measurements recorded. Now let us discuss in detail the step by step process involved in facade design.

The tender document holds the LV-EH (Leistungsverzeichnis Einheitspreis) which refers to specification and unit prices commonly known as bill of quantities. This LV-EH holds various information such as the execution dates for the project, list of construction site equipments involved, information about the construction site, details of design, details of bill of quantities and cost of final offer.

The facade builder will study the tender document and in case of any missing details will inform the client or the architect. After this stage the architectural drawings are prepared. In most cases after the tender is accepted by the client, he will provide the architectural drawings. But in few cases such as renovation projects there might be very old drawings which cannot be used, as there could be many changes in the building on the latter years. In such situations preliminary measurements are carried out in the site to sketch the architectural drawing. It is important to understand that in most of the small renovation projects the facade builder takes the complete control over the project as he prepares the architectural drawings based on initial site inspections.

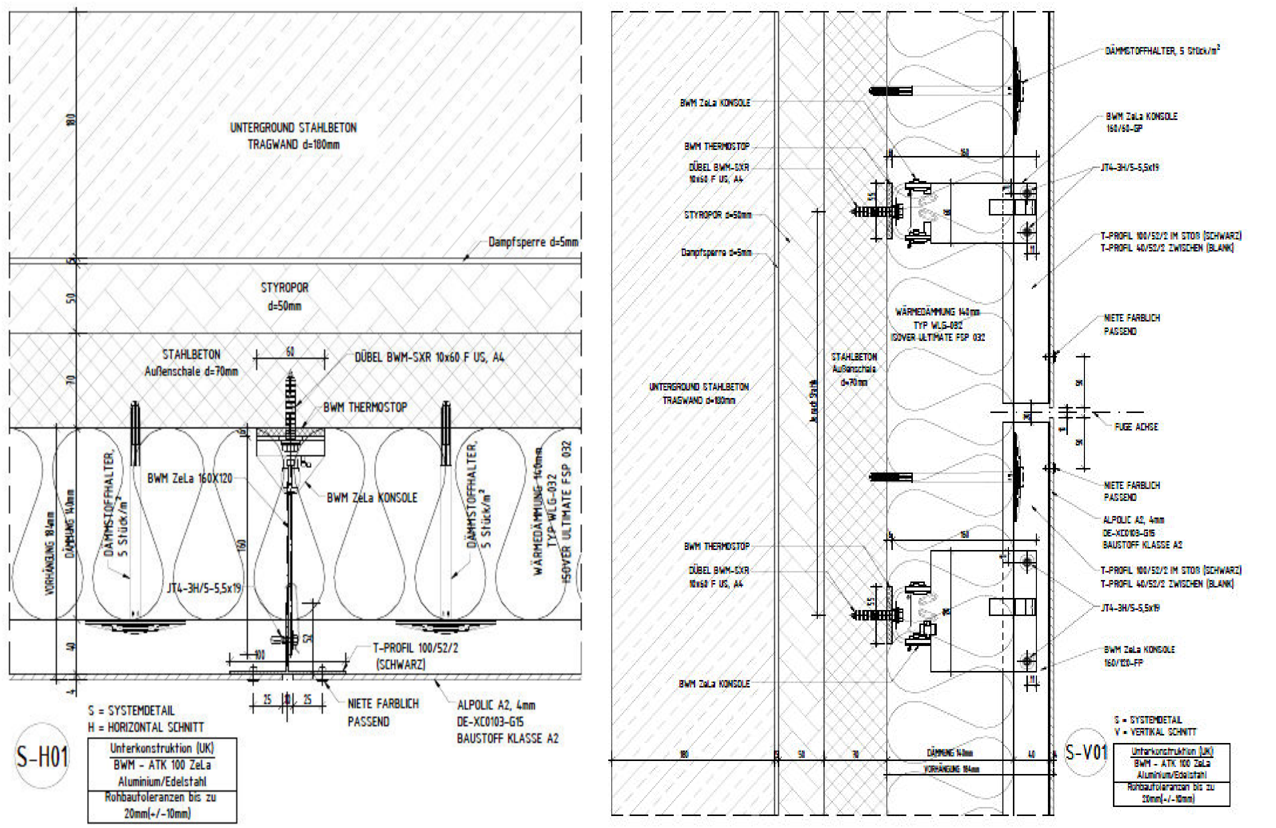


Figure 3: System details for Facade design

The next step is the preparation of standard system details which indicates the sub-construction, insulation, profile used, curtain distance from the wall etc. These drawings are sent to the client for approval and once it is confirmed the detail measurements are taken in the building site by traditional or modern surveying techniques. Further the measurements acquired are post processed and CAD drawings are prepared showing facade elevation views in north, south, east and west directions. The depth of sub construction is analysed using 3D re-shaper tool and tolerance of depth is considered as 20mm (+/- 10mm). At the same time the system details are sent to the structural engineer for statistical analysis and based on static calculations the number and position of sub-construction are decided.

All other critical and corner details are created based on exact measurements available in the elevation drawings prepared before head. After this stage the CAD drawings are prepared showing the facade plate position and dimensions. Optimisation of plates is done based on the available raw uncut plates using software to save the material wastage. Later the facade mounting plans are prepared. The plate measurements are extracted from the drawings to excel sheets and are fed to the CNC machine for the production process. Later the fabrication of facade plates is carried out in the manufacturing plant and transported to the work site for erection.

1.2 Surveying methods

Surveying is a measuring technique to determine terrestrial or three dimensional position of points, distance and angle between them. Now, let us discuss the various surveying techniques and the corresponding instruments used in each of it to get an overall idea about traditional and modern surveying.

1.2.1 Traditional surveying methods

Chain and tape survey:

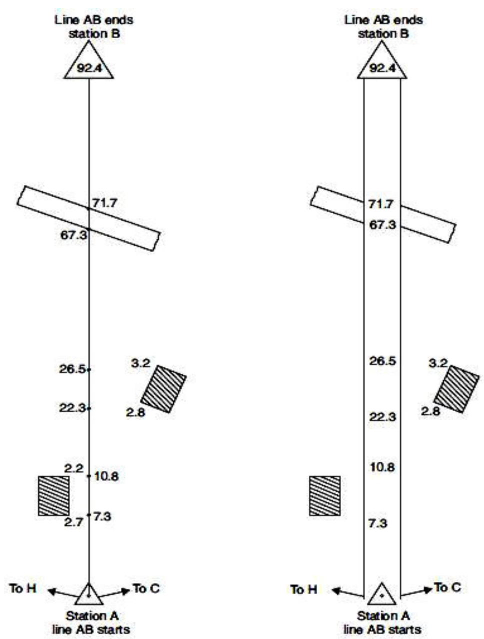


Figure 4: Chain and tape surveying [21]

Chain survey is the simplest method of surveying. This surveying technique is suitable to small plane areas with fairly levelled ground surface. If carefully done, it gives quite accurate results. Chain or tape survey can be carried out using traversing or triangulation techniques. All the details and measurements such as rough sketch of different types of stations, offsets as shown in Fig. 4 are recorded in a book called field book. The measuring equipments required to perform this survey are namely chain, tape, trough compass, ranging rod and arrows.

Tacheometric Survey:

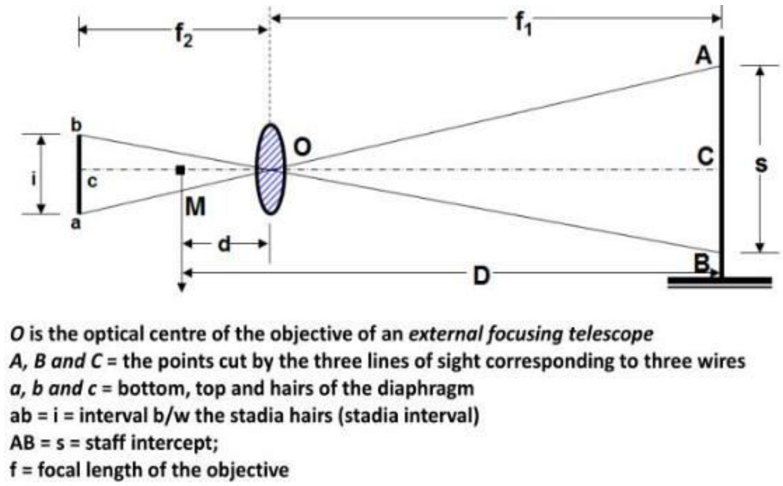


Figure 5: Tacheometric surveying [22]

Tacheometry is a surveying technique to measure the horizontal and vertical distances by taking angular observation with an instrument known as a tachometer which has an ordinary transit theodolite fitted with stadia diaphragm in most cases. Tachometric surveying is used in unlevelled, rough and difficult terrain where direct levelling and chaining are not possible. The accuracy attained under favourable conditions will have an error that will not exceed 1/100. Tacheometric survey is very rapid and helps in preparing contour maps for Railways, Roadways, and reservoirs.

Traversing survey:

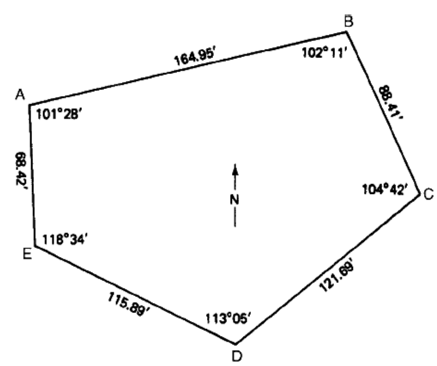


Figure 6: Traverse surveying [23]

Traversing is a type of survey in which several survey lines are connected to form one framework. The length and direction of the each of the survey lines are measured with the help of an tape or chain and angle measuring instruments. Traversing can be done in two ways. When the start and end point of the framework of survey lines remains the same to form a closed circuit, it is known as a closed traverse. When the survey lines have different start and end points in a framework it is known as open traverse. Traversing survey can be carried out by various survey instruments namely Chain and compass, Plane table etc.

Plane table survey:

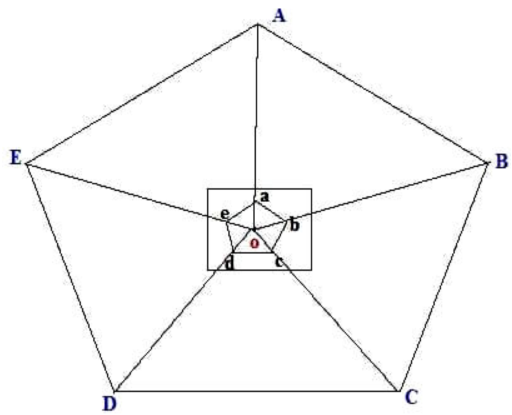


Figure 7: Plane table surveying [24]

The plane table surveying is the one of the fastest method of surveying. In this method of surveying the plan is plotted in the drawing sheet attached to the plane table and field observations can be done at the same time. In plane table surveying the geometrical measurements of site are recorded in the sheet map with particular scale. The equipments required for conducting plane table survey are Plane table, Plumb bob, plumb fork, Compass, Spirit level, Alidade for sighting, Chain, Ranging rods, Tripod, Drawing sheet and drawing tools, Paper clips or screws.

Resectioning survey:

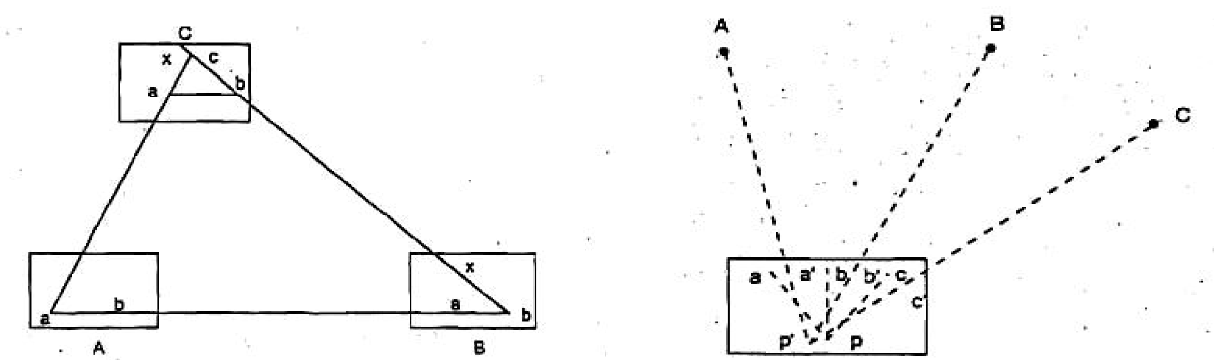


Figure 8: Resectioning surveying [25]

Resection is a type of plane table surveying in which location of inaccessible point is determined by sighting it to accessible points. Resectioning survey is also familiarly known as method of orientation and it can be conducted by two methods namely three point and two point problem. In the two-point problem shown in fig.7 left side, the unknown point C is sighted from two known points A & B. In three point problem as shown in fig. 7 right side, three known points A, B and C are sighted from a point P. The point P is chosen in such a way that all three known points are visible for sighting. The unknown point P is finally determined based on triangulation.

Contouring survey:

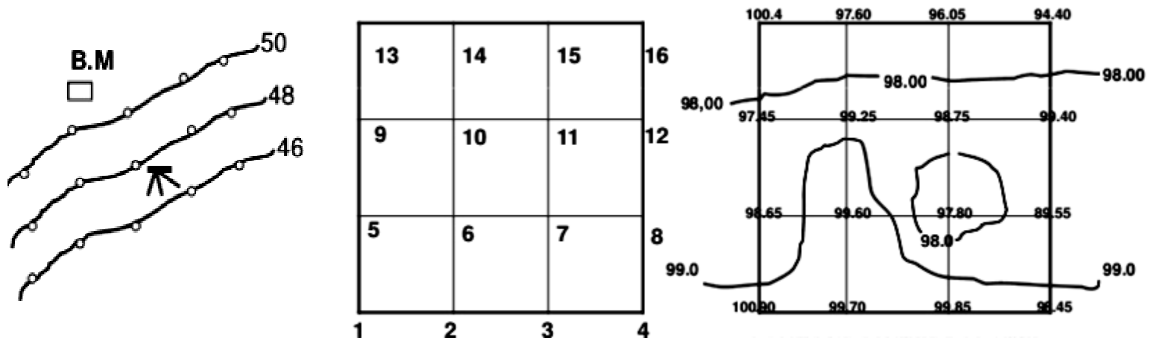


Figure 9: Contouring surveying [26]

Contour is an imaginary line with points of equal elevation connected together on the ground surface. The process of tracing these lines on the ground surface is known as contouring survey. Contour survey is the basic survey which is done in construction of a road, railway, canal, dam or any building. Contour lines can be plotted by two methods namely direct and indirect methods. In direct method, the contours are directly traced on the location with points of similar elevation as shown in fig.9 left side. Though it is accurate it is a tedious and time consuming process. In indirect method, the field area is divided into a grid pattern in squares or blocks and elevation at each point on the squares are recorded. Then the points of same elevation are calculated by interpolation and a contour map is plotted as shown in fig.9 right side.

1.2.2 Modern Surveying methods

Electronic distance meter (EDM) survey:

In this surveying technique electromagnetic waves are used for measuring distances up to 100kms. EDM is reliable and convenient instrument. Some EDM instruments are hand held EDM, Auto Level,Digital level, theodolites and total stations.

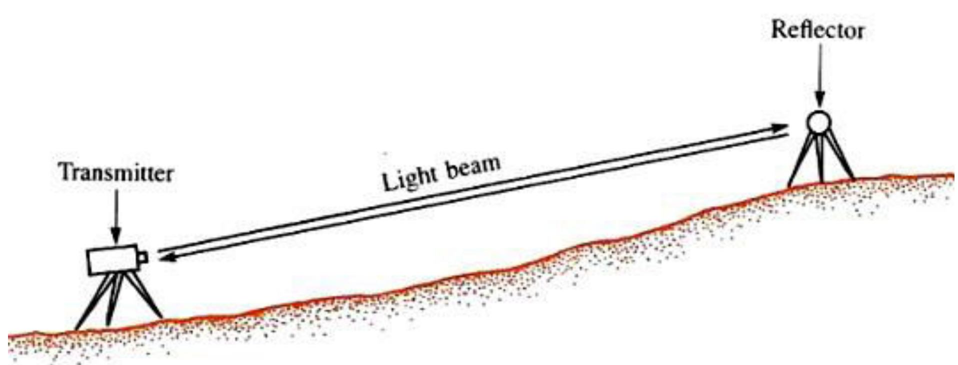


Figure 10: EDM surveying [27]

EDM equipment has a digital screen to record the measurements and display them. The phase change of electronic waves during their transmission and reflection is used to determine the length between two points. EDM cannot be used in rough terrain where huge obstructions are caused and the measurements become less accurate. The electromagnetic waves such as infrared light or laser light or microwave is transmitted from the EDM instrument and it is reflected back from a receiver which is placed at the measuring point. Atmospheric corrections are significant for long distance EDM measurements as the electromagnetic waves can be affected by atmospheric pressure, temperature, water vapour content in the atmosphere.

Photogrammetric survey:

The word photogrammetry is the combination of the words photo and meter which means measurements acquired from photographs. Reliable information regarding any physical object and the complete environment is acquired through photogrammetry. The measurements are evaluated from terrestrial and aerial photographs. Photogrammetry uses technology for modifying the images to reliable measurements and it requires skilled person.

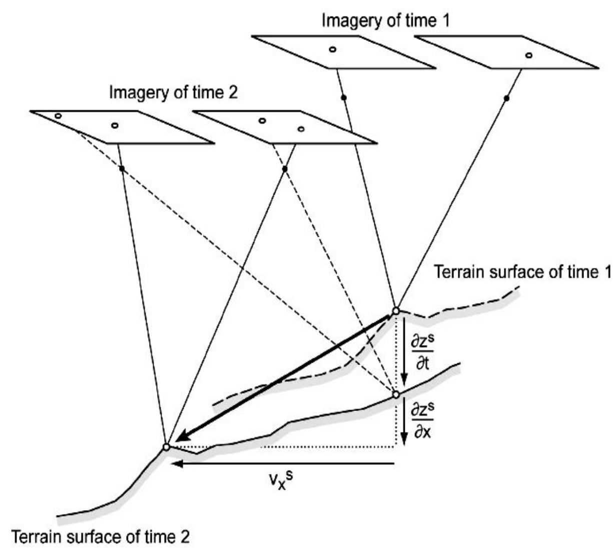


Figure 11: Photogrammetric surveying [28]

The recent photogrammetric technique uses radar images for evaluating the position and measurement of particular object. The various steps involved in photogrammetric process are planning, image acquisition, image processing, manage data for image orientation, data accumulation and finally presenting the results. Photographs used for photogrammetry are capture using special cameras or digital sensors. Aerial photogrammetry is used to prepare large area topographic maps and used in places where it is impossible to access from the ground. Weather has a significant effect and can hinder the photogrammetric process. The sun angle should lie between 30° to 45° to achieve best results. When sun angle is less than 30° there is shadow effect in images and when greater than 45° leads to sun spots in images.

3D Laser Scanning Survey:

Laser scanning survey is performed by flashing the reflector less laser light over a surface to collect three dimensional data. The surface data is captured in the form of 3D survey points by a camera sensor mounted in the laser scanner to form a point cloud. This technique is used for rapid surveying of complex geometrical details which are not accessible.

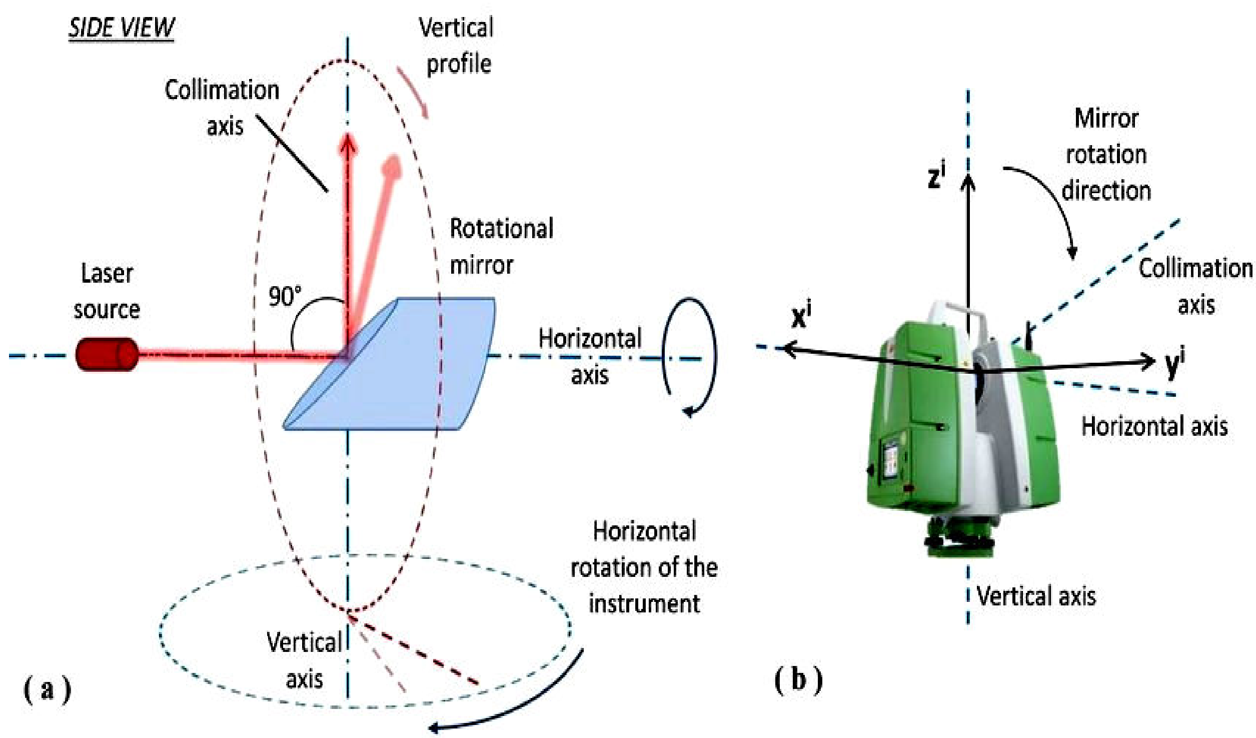


Figure 12: 3D laser scan surveying [29]

Point clouds can be viewed in the form of multi hue colours based on the intensity of signal received or in the form of true colour from a digital camera. The 3D laser scan data can be matched with topographical survey plans, elevations and sections. Laser scanning can be carried out in both terrestrial and airborne ways. Terrestrial scans can be captured from 20m to 2kms with accuracy ranging from 3mm to 100mm and it depends on the instrument used. Helicopters are used for capturing airborne laser scans but they less accurate compared to terrestrial laser scanning.

The point cloud data captured using laser scanners can be later processed and exported to various applications to create 2D CAD drawings or 3D models. It is not possible to scan any surface which not in the line of sight of the equipment. The severity of interference of ambient light with laser light may lead to noisy scan data which is inaccurate. 3D scanners are very expensive and its cost ranges from €50,000 to €150,000. The cost of laser scanning survey can be reduced by outsourcing the job.

1.3 Case Studies

Case study analysis is carried out by taking three research papers which gives an idea to learn about the complexities, benefits and limitations of both traditional and fast mapping survey techniques in the facade renovation process.

1.3.1 Case Study 1

In this paper the author has attempted to create a BIM model and analyse the facade damage for an existing building by using terrestrial laser scanning (TLS) and total station surveying techniques. The paper describes the steps involved in terrestrial laser scanning technique and post processing of point cloud data in acquiring a 3D model.

The accuracy of information necessary for building renovation is increasing in the fields of architecture, construction, engineering and building management. Fig. 13 shows the workflow for the case study undertaken.

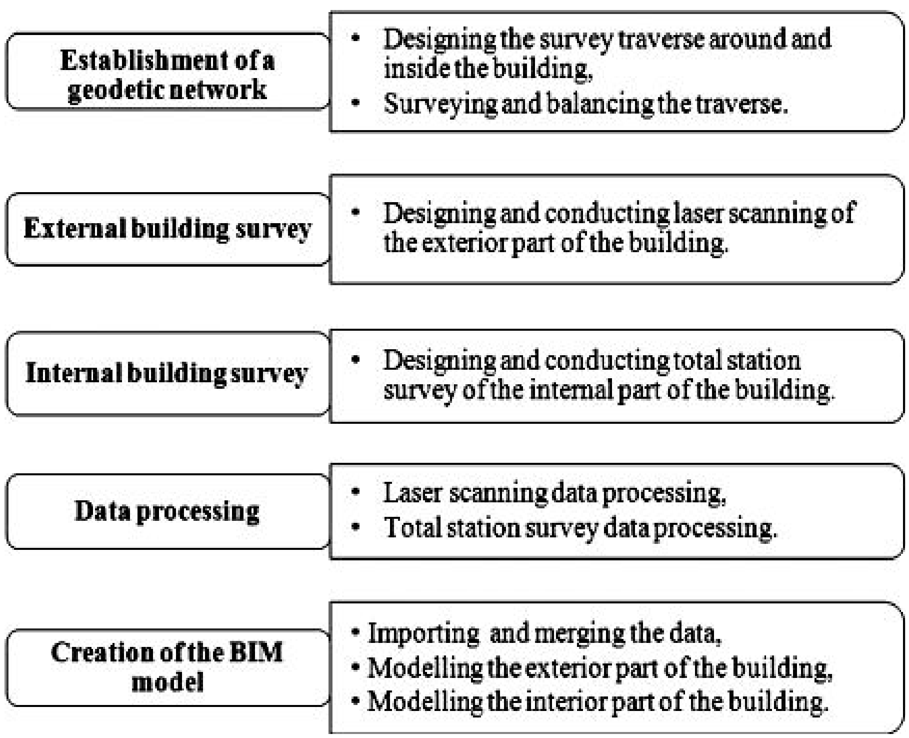


Figure 13: Workflow in creation of a BIM model [3]

The external building survey was conducted using a time of flight (TOF) terrestrial laser scanner Leica C10 with 26 scan stations. The maximum range of the device is 300 m with a 360° x 270° field of view and maximum scanning rate of up to 50,000 points/sec. The internal survey was done using total station Trimble M3 and Leica Disto A2.

The laser scan data is processed using Leica Cyclone 7.3 software. The data was saved in a *pts format for further processing in Autodesk Revit Structure 2013. Total station survey data processing was done using Autodesk AutoCAD 2011. First, 2D floor plans at zero height were created. Using the heights of ceilings in rooms, walls were created and since the perimeter was now known, door and window openings were added. The surface of the facade was modelled entirely using the laser scanning point cloud data.

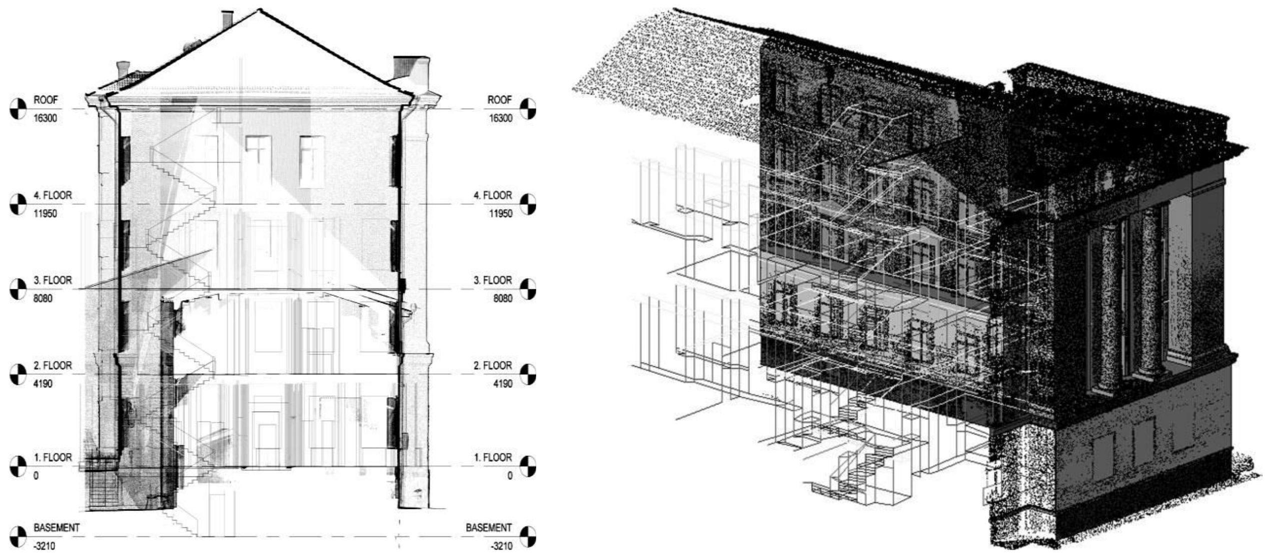


Figure 14: Internal 3D trace of building with external point cloud data. [3]

Fig.14 shows the merging of internal 3D trace of building with external point cloud data to analyse the damaged areas in the facade for renovation work. The major benefit of laser scanning technique is to trace the complex geometrical object in 3D space very accurately.

The author had listed the problematic areas for future research and development that need to be resolved,

- **Lack of flexibility when integrating different point cloud data** - Problems arose when trying to merge different sets of point cloud data since the software used does not support working in survey coordinate systems. The merging should be done in point cloud processing software. [3]

- **Absence of a best-fit algorithm -** A best-fit algorithm that could help the modeller create surfaces more easily is missing. At the moment a modeller has to choose the best-fit location of surfaces. This could result either in too much generalisation or too little generalisation in the produced model. Either way, modelling will take extra time, since the work has to be done manually. [3]

- **Creating window openings -** Creating window openings in cases where the opening is not shaped like a cuboid have to be done manually. Other difficulties arise if wall thicknesses differ significantly. Since there is no automatic reconditioning method for windows, this should be considered a significant shortcoming, especially when dealing with larger facilities. [3]

The case study highlights several benefits resulting from creation of a BIM model using a point cloud, such as the ability to detect and define the extent of facade damage. Problem areas concerning the process of composing the BIM model using different survey data were also pointed out. The case study shows that the surveying time, data processing time and level of detail are essential in the process of creating a BIM model of an existing building.

1.3.2 Case Study 2

In this paper the author has taken an effort to review techniques involved in historic site documentation based on traditional and pre-electronic techniques to 3D laser scanning. The evaluation is based on obtained quality of data, time, costs and specific skills required. The graphical technique (hand measuring & tachometry), photographic (photogrammetric) and 3D scanning surveying techniques were compared for evaluating the documentation. In this case study only hand measurement, tacheometry and 3D scanning techniques are discussed.

Based on the review the author has the following findings,

- **Hand measurements** using tapes are particularly favourable for taking single measurements where visibility is limited. Simple method, cheap technique however time consuming, not accurate, no coordinate reference as an analogue format.

- **Tacheometric survey** can produce 3D wire frame-modelling with high absolute point accuracy. The point accuracy, even in surveys of extensive, complex objects with curved surfaces, is with a few millimetres comparatively very good and homogeneous, practically independent of the size of the object. However it is time consuming, needs high skills operation and low in efficiency for surveys of complex forms with a large number of points.

- **3D scanners** Due to the high point density and its availability of a near real time 3D coordinates, 3D scanning will probably yield better results for objects that are asymmetric, free-forms, irregular surfaces, large and high details building and complex in terms of the number of curves and ridges such as parts of a skeleton and caves as shown in Fig.15. However, there are some surfaces, which could not scan particularly well (any transparent material such as glass, mirrors, water, and crystal). Transparent objects such as glass will refract the light and give false three-dimensional information.

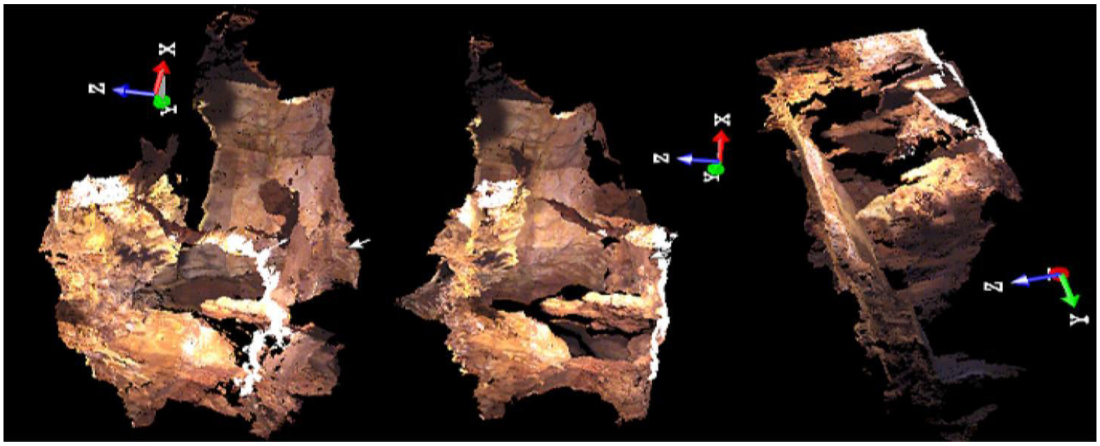


Figure 15: Different mesh view of the 3D laser scanner of a cave [4]

The author had concluded that, among the several techniques used for the documentation of solid objects, 3D laser scanning has shown that it has the potential to be of major value to recording professionals. Laser scanning has the main advantage of allowing the acquisition of dense data sampling with high accuracy, high speed and flexibility in 3D digital data format.

1.3.3 Case Study 3

In this paper the author has experimented by replacing traditional surveying methods with modern methods for achieving cost effective urban survey with best achievable accuracy. Fig 16 shows the overall planning process involved in surveying.

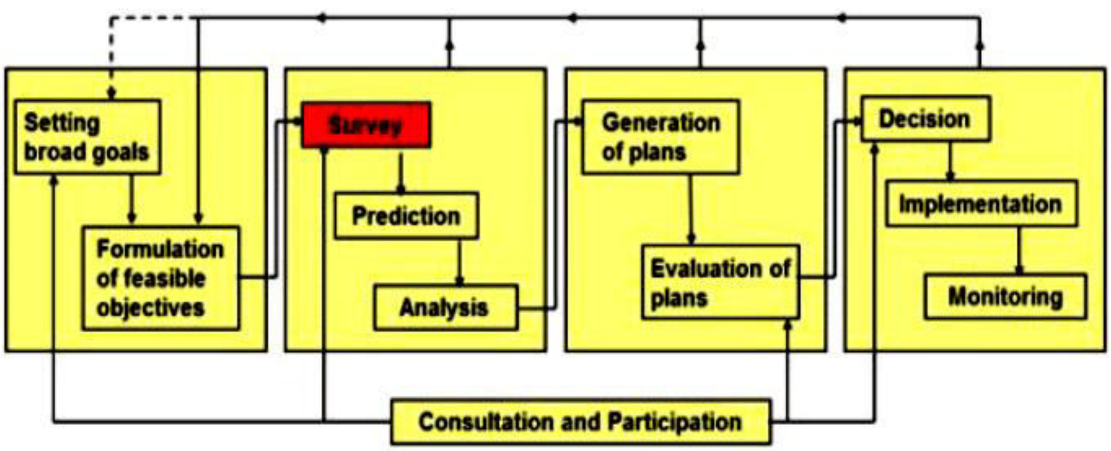


Figure 16: Different stages in physical planning process of a survey [2]

Six adjacent buildings as a part of a building complex are considered for urban survey. Two of these buildings are about 11 floor buildings and the others are intermediate height buildings consisting of five floors.

Traditional surveying was carried out with tapes for the six buildings whether from the ground, the roof or any floor. From a practical point of view, several photos and sketches were taken for proper visualization and reliability of all surveyed buildings. This extensive time taken for the surveying process is accompanied with hard working paid labour, however on the contrary the whole process is executed using cheap surveying tools, such as the tape, along with moderate payments for regular not necessary skilled trained labour.

Modern surveying was carried out using Trimble reflector less total station for surveying of the outer perimeter of buildings from the ground. Each building was surveyed relative to some control points for all its floors.

Building	Floors	Tape		Total Station (TS)					Time difference between TS and Tape (sec)	Remarks
		Measurements	Time required (sec)	Points	No. of setups	Setup Location	Time required (Setup & Observation) (sec)	Effective Required Time		
	G	18	540	8			320	320	220	
	1	29	870	24			360	360	510	
	2	51	1530	35			525	525	1005	
	3	52	1560	39			585	585	975	Similar to 8th Floor
	4	54	1620	39			585	585	1035	
	5	54	1620	39	3	G	585	585	1035	
B1	6	54	1620	44			660	660	960	
	7	54	1620	43			645	645	975	
	8	-	-	-			-	-	-	
	9	54	1620	47			705	705	915	
	10	54	1620	42			630	630	990	
	11	54	1620	38			570	570	1050	
	Roof	44	1320	36	2	Roof	900	900	420	
	G	22	660	16			960	960	-300	
	1	68	2040	44			660	660	1380	
	2	99	2970	70			1050	1050	1920	Similar to 3rd Floor
	3	-	-	-			-	-	-	
	4	52	1560	37			555	555	1005	
	5	99	2970	71	4	G	1065	1065	1905	
B6	6	123	3690	83			1245	1245	2445	
	7	62	1860	39			585	585	1275	
	8	71	2130	45			675	675	1455	
	9	62	1860	40			600	600	1260	
	10	71	2130	45			675	675	1455	
	11	62	1860	38			570	570	1290	
	Roof	83	2490	50	2	Roof	1110	1110	1380	

Table 1: Report on tape and total station survey [2]

Table 1 shows the comparative report for tape and total station survey for building 1 and 6. The time required for acquiring tape and total station measurements are tabulated. It is evident that from the time difference column that the time is greatly reduced when adapting total station surveying rather than tape surveying.

The author came down to few conclusions based on the surveying tasks performed in the urban site,

- The applied modern surveying techniques showed high efficiency regarding cost and effort, while saving observation time reaching to 60%.

- The use of modern surveying equipment in the form of total stations improved accuracy and efficiency of the surveying task, reduction in number of manpower, time saving in performing the survey and planning process.

- The surveying data acquired through modern surveying techniques provides co-ordinates and can be easily formatted.

- Total number of instruments, manpower per day and number of days can all be set in advance before start of the survey, which offers a very powerful tool for modern surveying.

- Modern surveying technique helps in pre-estimation of the surveying process cost in advance.

1.4 Aim and Objective

1.4.1 Aim

The main aim of the thesis is to define the complete work flow of facade design based on the traditional measurements and laser scanned point cloud data for a given building. Later the accuracy of building geometry acquired by using both of these techniques is compared and studied in a detailed manner.

1.4.2 Objective

- Development of the as-built status of a given building using fast mapping methods and traditional surveying methods. Post-processing should be done to develop a 3D-model of the building.

- To create drawings holding details of façade dimensions and positions in a given building by considering static calculations in both methods and also architectural drawings. Create facade details in both cases for the manufacturing process.

- Compare the design of the façade based on traditional surveying and point cloud data acquisition on the basis of the specific demonstration project.

- To enrich the geometry model with additional “BIM parameters”.

1.5 Conclusion

The end of this chapter gives an overall idea about the facade design methodologies and the evolution of surveying techniques through the years. From the case studies undergone the comparison strategies for surveying techniques are learnt. From the literature review the advantages and limitations of laser scanning and tape measurements are studied in detail. The problematic areas of future research in case studies undergone will have to be further discussed in this thesis work.

2. Development of As-built status of building

2.1 Project information and initial inspection

A student dormitory in Freiburg, Germany is considered for the renovation of facade work. The existing front facade of the building was built in the year 1963. The existing facade was mounted on the reinforced concrete sandwich and consists of asbestos-free fibre cement (eternit) facade plates. The cladding on the south side of the building starts at the ceiling above ground floor and extends over 8 storeys to the reinforced concrete parapet on both sides of the central lying balconies up to the corners of the building. On both sides of the slightly drawn-in balcony there are again wall surfaces of width approximately 90 cm with the facade cladding.

The facade panels on the south side have already suffered several breakages in the area of the panel corners. For this reason the facade cladding of the south facade was renewed. The attic was built in wood construction by approx. 75 cm raised and slightly protruding, also with the fibre cement boards dressed. There are cantilevered balcony slabs with metal railings. The height of the building is 25m.

2.1.1 Preparation of architectural drawings

The architectural drawings provided by the client were very old and hence an initial site inspection was carried out before the dismantling of the old facade in the building to sketch the new updated architectural details in the building in cross comparison with the old drawings.

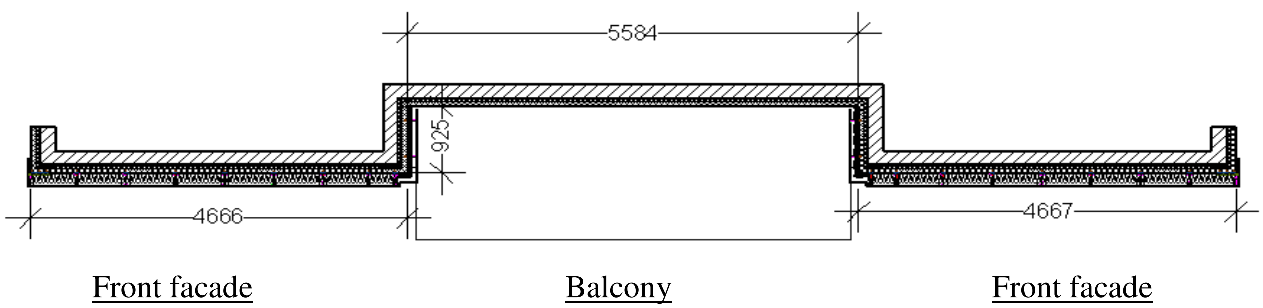


Figure 17: Plan view of the building

On the ground floor there are various functional rooms, in the 8 upper floors small flats and larger shared flat units for the students. In 1995, a rehabilitation and conversion of the existing flat roof into a wooden roof truss with flat sloping roof and cement-fibre corrugated sheets roofing was carried out. Thermal insulation of 60 mm mineral fibre and a ventilated cladding made of storey-high fibre cement panels mounted. On the south side lies in the middle a large balcony, half of which is drawn into the building. On both sides of it are the curtain walls to be renovated. Area of facade involved in renovation is $296m^2$.

The structure of the old facade had the following specifications:

- Eternit panels thickness = 8 mm, dimension of each panel 1.25 x 2.625 m, vertical standing, storey high fixed with aluminium rivets to the profiles.
- Aluminium substructure of vertical L and T profiles, depth 100 mm, distance approximately 62.5 cm. Fischer dowels S10 RSS 70 or S12 RSS 70 are used with increasing dowel density at the edges of the facade and the upper floors taking wind loads on consideration.
- Soft mineral fibre insulation thickness=60 mm between the aluminium support profiles, glued / dowelled
- Bottom end profile and ventilation strips made of metal are installed.

After the initial site inspection the following details where gathered. Based on these details the architectural drawings were created as shown in Appendix B.

2.1.2 Creation of standard system details

Based on the discussions with the client and the previous experience of the facade builder standard system details are created. Once these system details drawings are produced they are sent to the structural engineer or system provider for performing static calculations. The following specifications for sub-construction were considered for renovation of new facade. The system detail drawings are attached in Appendix A.

For front facade:

- Depth of curtain wall 184mm.
- Alpolic A2 facade panels thickness = 4 mm with panel distance of 10mm, maximum dimension of each panel 1.25 x 2.600 m, vertical standing, storey high fixed with aluminium rivets to the profiles.
- Sub construction - BWM - ATK 100.Zela Aluminium/ Stainless steel console with structural tolerance of 20mm(+/- 10mm). BWM Zela 160x120 (Fixed point), 160x60(Glide point)
- T- profile 100x52x2 , 40x52x2, Dowel BWM –SXR 10x60
- Insulation: Thermal insulation 140mm thick TYP WLG-032, Isover Ultimate FSP 032.

For facade in Balcony area:

- Depth of curtain wall 114mm.
- Alpolic A2 facade panels thickness = 4 mm with panel distance of 10mm, maximum dimension of each panel 1.25 x 2.600 m, vertical standing, storey high fixed with aluminium rivets to the profiles.
- Sub construction - BWM - ATK 100.Zela Aluminium/ Stainless steel console with structural tolerance of 20mm(+/- 10mm). BWM Zela 100x120 (Fixed point), 100x60(Glide point)
- T- profile 100x52x2 , 40x52x2, Dowel BWM –SXR 10x60
- Insulation: Thermal insulation 60mm thick TYP WLG-032, Isover Ultimate FSP 032.

2.1.3 Static Calculations

Eurocode1: DIN EN 1991-1-4 (Windload),

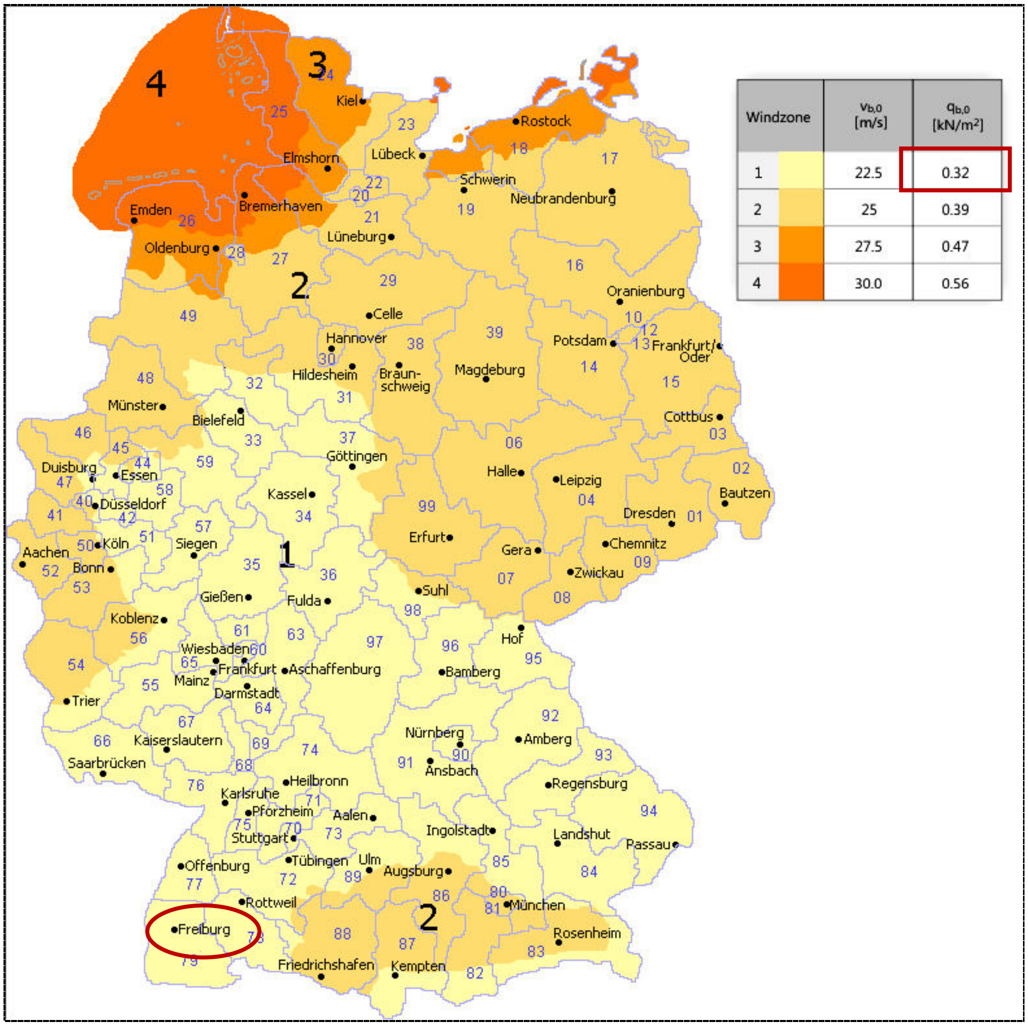


Figure 18: Wind zone map for Germany [30]

Windzone - 1 (Freiburg, Germany)
Terrain Category - Mixed profile (domestic or inland) MP1
Exposed location - No
Building susceptible to vibration - No
Terrain height above sea level - < 800m

Building Dimensions:

Height - H $\leq$ 25m
Length - D $\geq$ 15m
Breadth - B $\geq$ 15m

Determination of wind load:

$q_p(z) = 1.7 * q_b * (H/10)^{0.37}$

Based on the Wind zone 1 and terrain category MP1, $q_b = 320\ N/m^2$

So, $q_p(z) = 764\ N/m^2$

Determination of resulting wind loads:

According to DIN EN 1991-1-4, Table NA.1 for load surface of 1 m^2,

$H/D \leq 1.67$

Zone	A		B		C		D		E	
h/d	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,7	
1	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,5	
≤ 0,25	-1,2	-1,4	-0,8	-1,1	-0,5		+0,7	+1,0	-0,3	

Table 2: External pressure coefficients for vertical wall of rectangular buildings [8]

$C_{p,D} = 1.00$; $C_{p,S,A} = 1.45$; $C_{p,S,B} = 1.1$

Wind pressure max. $W_{D,k} = q_p(z) * C_{p,D} = 764\ N/m^2$

Wind suction max. $W_{S,A,k} = q_p(z) * C_{p,S} = 1107\ N/m^2$

Weight of the facade:

Plate thickness t = 4mm

Self weight of facade plate = $g_{be} = 75\ N/m^2$

Self weight of vertical profile = $g_{Pr.} = 8\ N/m$

For plate width $B \leq 1250$ mm

Overall self weight = 75 * 1.25 + 8 = 102 N/m

The other static calculations for the Aluminium sub construction is carried out by the Structural engineer based on the following Euro codes mentioned below.

- Euro code 9: DIN EN 1999-1-1(Aluminium Construction)
- Euro code 0: DIN EN1990 Principle of Structural Design

2.2 As built data from 3D laser scanning technique

There are series of steps involved in acquiring the as-built data of the building using 3D laser scanning technique as shown in fig.19

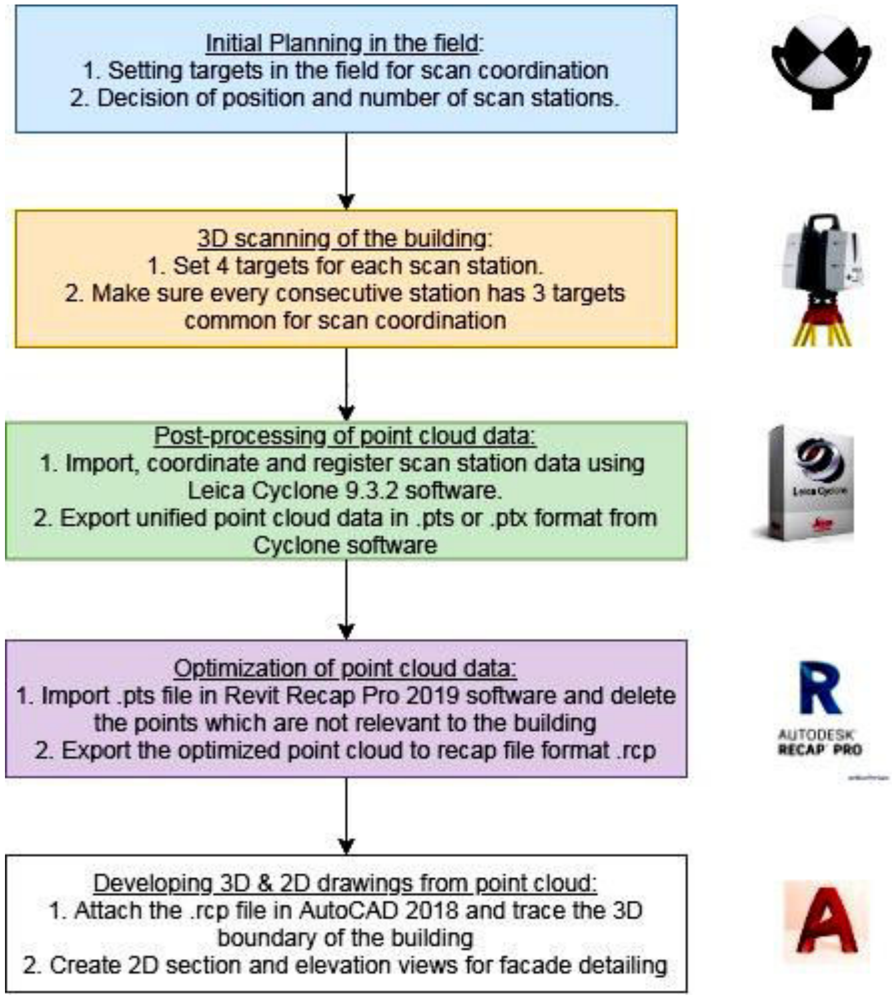


Figure 19: Steps involved in acquiring as-built data from 3D laser scanning

Initial planning in the field:

This is the first step involved in 3D scanning of a given building. Planning is very important to save the time involved in the overall scanning process. The aim is to scan the south facade of the student dormitory building. There were two new buildings constructed on the adjacent side of the dormitory. The work site has a lot of construction equipments and it seems to be very congested. There is a big obstruction in the front side of the building with a tall standing tree. So totally 4 ground scan station positions were chosen and 8 scan stations were chosen in the balcony in each floor. In total 12 Scan station were planned. The circular targets had been sprayed on the wall surface as shown in fig 20. Apart from these sprayed targets, 4 HDS targets were placed for each scan station respectively.

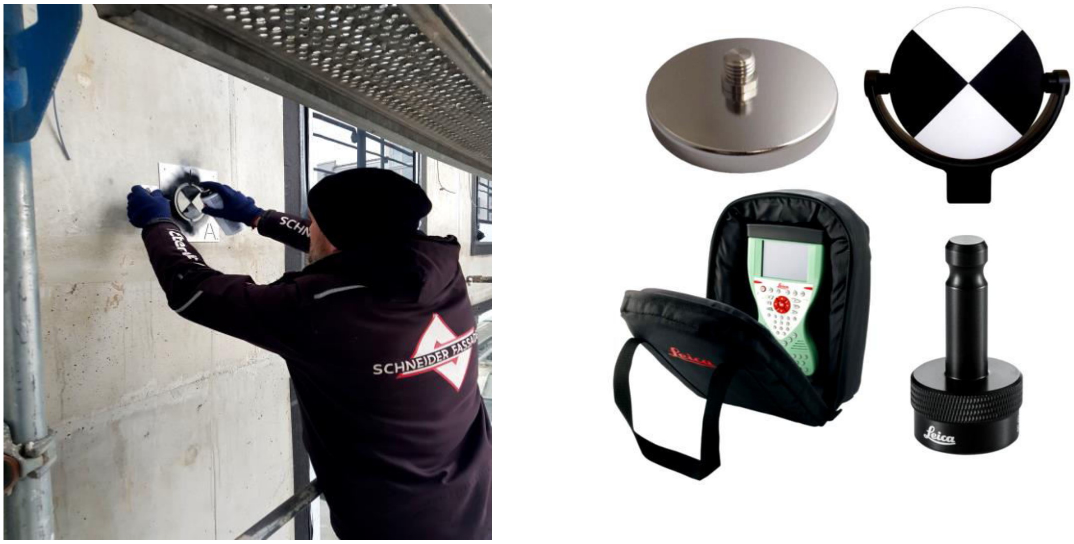


Figure 20: Paint sprayed targets and high definition system targets

3D scanning of the building:

3D scanning is performed with Leica P40 scanner for high accuracy mapping. The scanner is set at each of the appropriate stations which were decided in the initial planning stage and scanned. The scanner has a field of view of 360° horizontally and 290° vertically. The maximum range for the scanner is 270m with scanning rate of 500,000pts/sec. The laser scanner emits rapidly pulsing laser beam with an oscillating mirror which rotates around vertical axis. As the laser beam hits on the surface of the object, the time of reflection of the pulse is detected by the sensor to calculate the accurate distance. For each distance measurement additional data is recorded including the horizontal angle of the rotating laser and the vertical angle of moving mirror. The scanner automatically combines this to create a 3D X, Y and Z coordinate position for each point. For each scan station 4 HDS targets are fixed. The targets are fixed in such a way that every consecutive scan stations will have three common targets. This well help to merge all scan stations in post processing of point cloud data captured. 12 scan stations were set and each scan was performed with resolution of 3.1mm@10m with estimated time of 3minutes 30 seconds.

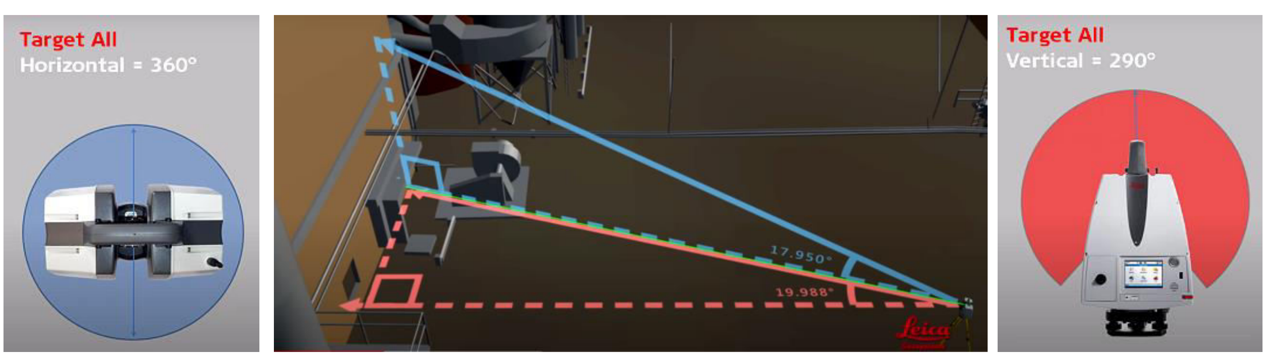


Figure 21: Field of view of Leica P40 scanner [25]

Post processing of point cloud data:

The raw point cloud data acquired in .imp format is exported to the hard disc and imported in Leica Cyclone 9.3.2 software as a data bank. Each scan station is coordinated with common targets and registered as a single point cloud file. It is to be noted that during the registration process of point cloud data the maximum group error should be less than 0.05mm. Later the point cloud file is merged and exported either in .pts or .ptx file formats. The .pts file size exported was 32.5GB.

Optimization of point cloud data:

The .pts file is imported in Revit Recap Pro 2019 software and all the points on the unnecessary objects which are irrelevant to the building project is cropped and deleted. This will greatly reduce the file size. After the optimisation of several trillions of points in the point cloud the file size was greatly reduced from 32.5GB to 7.7GB. The optimized point cloud data is saved in .rcp file format.

Developing 2D & 3D drawings from point cloud:

Finally the point cloud in .rcp file format is attached in AutoCAD 2018 software and then using the section planes the point cloud is sliced on different views to trace even the smallest of the details in the building. The CAD lines are used to trace the boundary of the building by the means of point cloud data. The UCS is set for each face of the building. Later the details such as opening, doors, windows etc. in each face of the building are drawn accurately in 2D views created using UCS option. 3D re-shaper software is used to analyse the depth of the curtain wall with the help of point cloud data. The point cloud is also attached in Revit 2018 software to create an enriched 3D model with BIM parameters for monitoring and future operations. The damages on the facade can be easily spotted by inserting the point cloud in the BIM model which overlaps with each other.

2.3 As built data from traditional surveying technique

There are series of steps involved in acquiring the as-built data of the building using traditional surveying technique as shown in fig.22

Initial Planning:

Since the building is 25m tall it was important to plan and acquire the measurements floor by floor. The position for setting the rotation lasers in each floor is decided in such a way that the moving thin laser line hits the surface of both front face and the inner balcony face of the building. Horizontally and vertically self-levelling rotary laser hedue R2 with high accuracy (0.6 mm/10 m) is used for creating level markings on the wall with the help of a laser beam detector. Since one side of the building is the approximately the mirror of the other side, measurements are acquired for left side of the building as shown in key plan in Appendix H.

Setting out the coloured lines on the wall:

The rotation laser is used for creating level markings in the front facade and balcony facade in the left half of the building in all the eight floors of the building. The horizontal chalk lines are snapped using the coloured ropes in each floor. Then the rotation laser is placed on the ground in the corners of the front facade in the left side. The laser beam from the ground is detected in each floor and vertical lines are drawn on the wall surface using coloured ropes. Hence a grid of horizontal and vertical line is created on the wall which helps in measuring small distances accurately. Refer the drawing in appendix H in which the dotted green lines indicate the horizontal and vertical lines. This work is carried out by two persons.

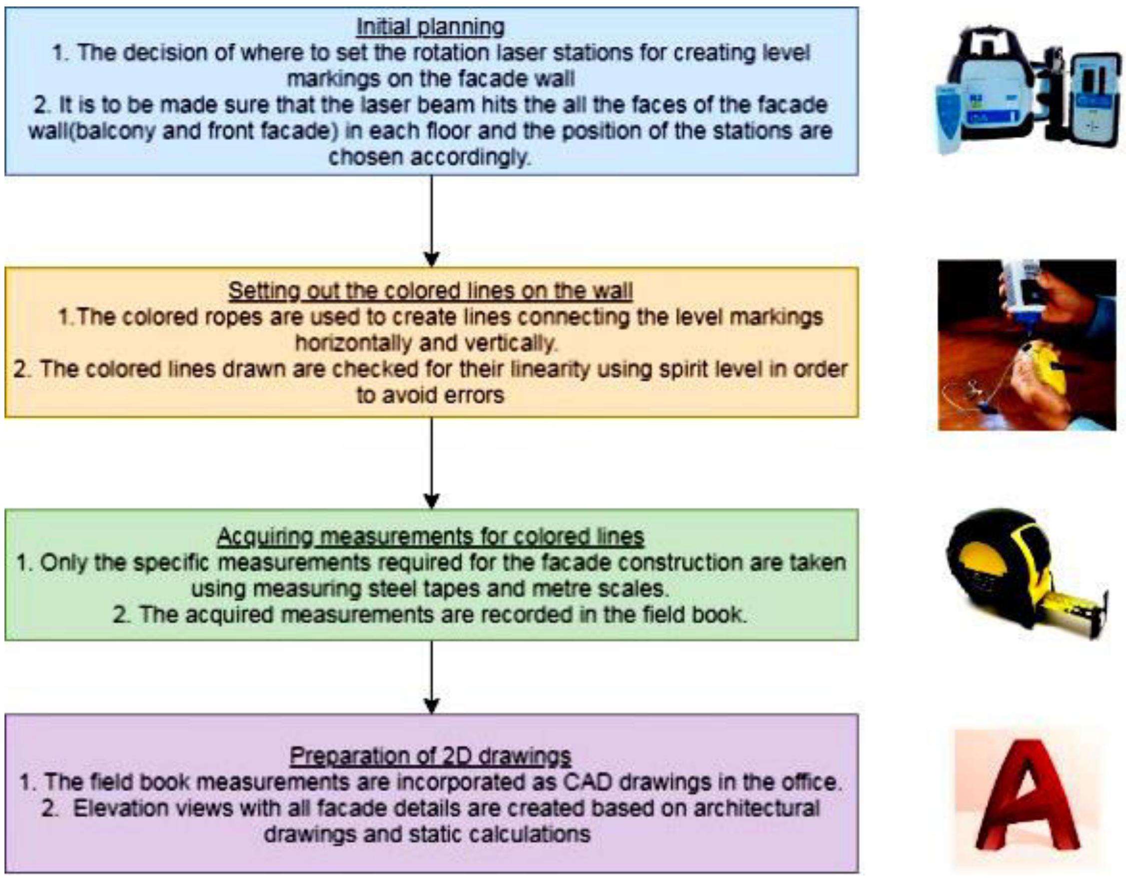


Figure 22: Steps involved in acquiring as-built data from traditional surveying

Acquiring measurements from coloured lines:

The coloured lines are measured using a measuring tape and recorded in the field book. The depth of the wall is not the same throughout and the surface of the wall has some undulations. The depth of the wall is measured at the point of intersection of the horizontal and vertical lines drawn on the wall. The metre scale is placed horizontally at the point of intersection of the lines drawn on the wall. The rotation laser positioned for drawing vertical lines in the ground hits the calibration of metre scale which is recorded as the depth of wall from the position of rotation laser. Similarly for every intersection point, the depth of the wall is measured. This work is carried out by two persons.

Preparation of 2D drawings:

All the measurements taken in the field work is replicated as CAD drawing using AutoCAD 2018 software. The elevation view for the front facade and the balcony area is drawn for the left side of the building. Based on the architectural drawings and static calculations the facade dimensions and positions are created.

2.4 Conclusion

By the end of this chapter the complete work flow for acquiring measurements of the building using 3D laser scanning and tape measurements are explained in a detailed manner. The static calculations performed are explained briefly. Based on the workflow procedure and acquired measurements from both the techniques the various factors such as complexity, cost involved, time involved and labour required are compared and evaluated in further chapters.

3. Facade design

In this chapter, the various steps involved in creating drawings holding details of façade dimensions and positions, facade mounting plans with sub-construction details, schedule for production of facade plates are discussed.

3.1 Creation of corner, parapet and other critical details

After the exact as-built measurements are acquired the critical details which are necessary for facade construction are produced by the facade builder as shown in fig.23

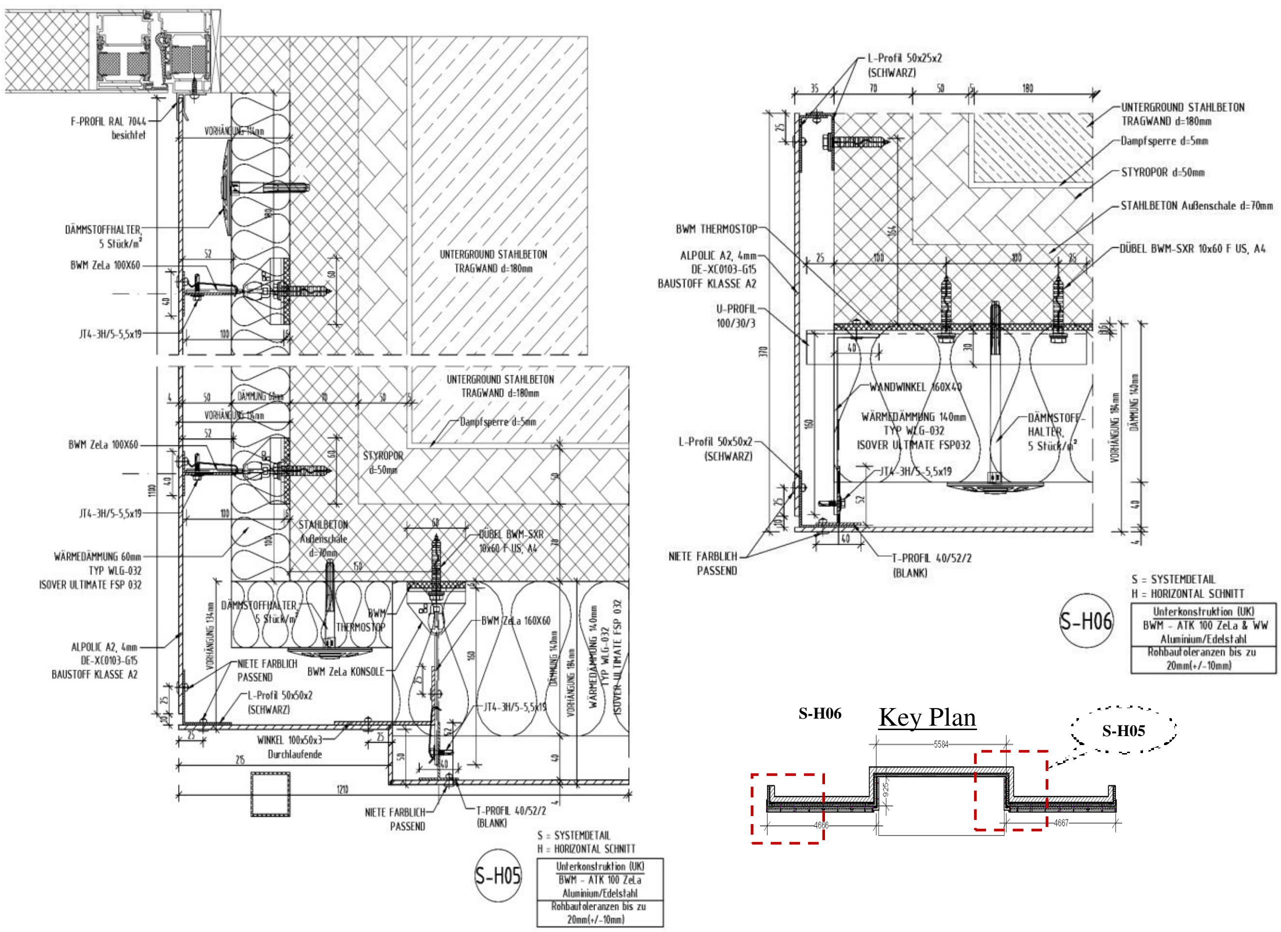
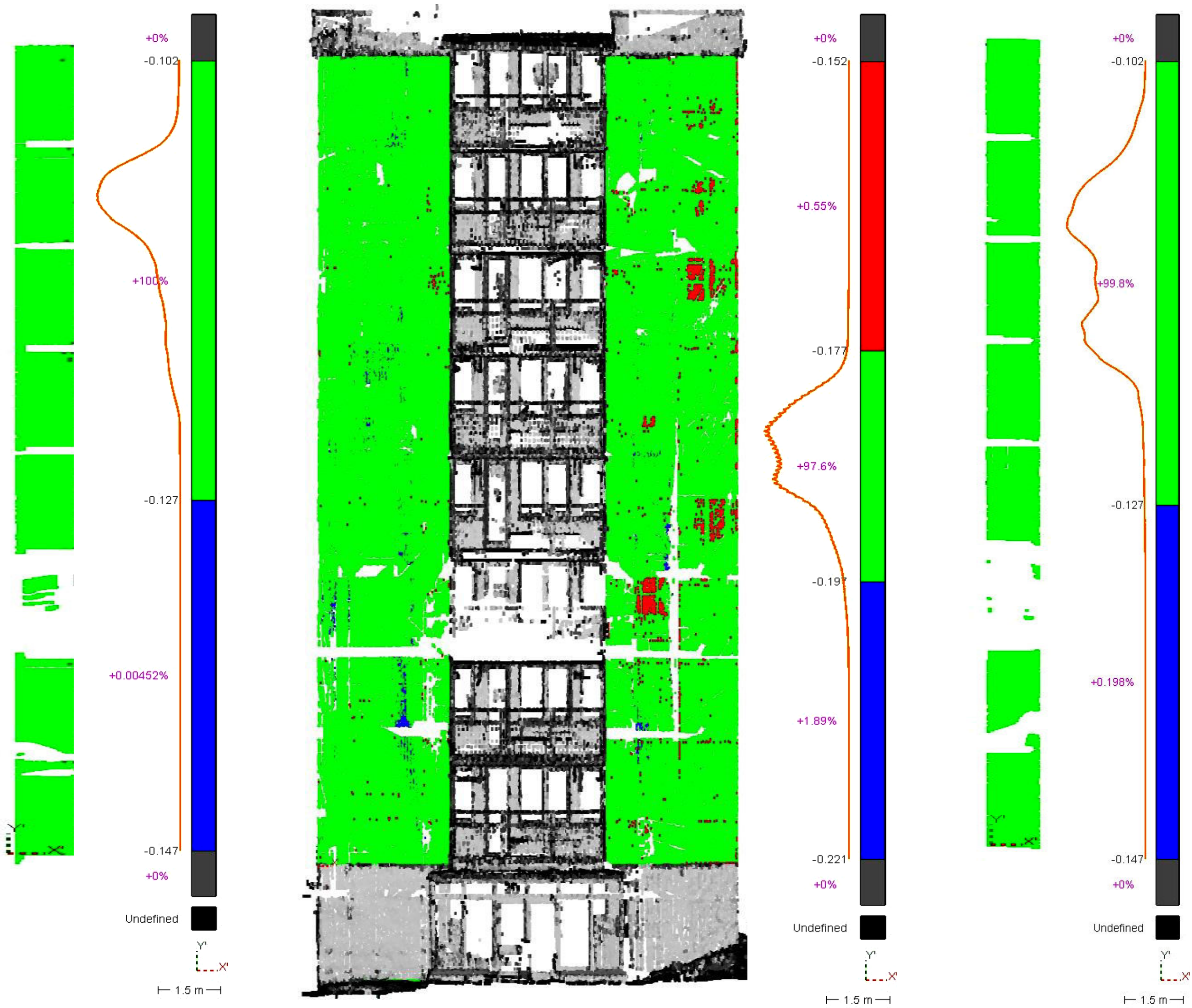


Figure 23: Facade corner details

The other critical details and parapet details are attached in appendix C. These details serve as important drawings for sub construction installations in the site and during facade mounting. Once these details are created they are sent to the client for approval. Any updates from the client is incorporated in these detail drawings and kept ready for construction process.

3.2 Analysis of depth of wall



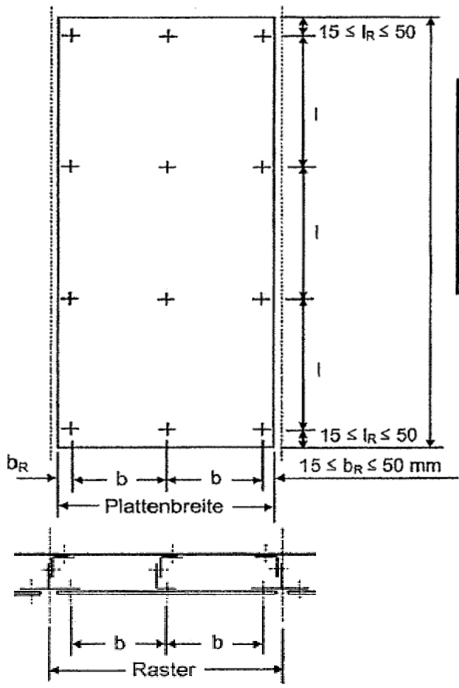
Balcony left side | Front facade | Balcony right side

Figure 24: 3D re-shaper – Analysis of depth of wall surface

The point cloud data is imported in 3D re-shaper software. The points on the surface of the wall are measured at a distance of 1.5m of the front facade and facade in balcony area for surface flatness as shown in fig.24. It was observed that in the front facade 97.6% of the points stay in the range from 177mm to 197mm. This difference was 20mm and hence the length of sub construction remained same in the front facade. The facade on the balcony in the left and right have 100% and 99.8% of the points in the range between 102mm to 127mm. The difference was 25mm. It is more than the tolerance level hence length of sub construction will vary based on the depth which will be discussed in chapter 4.2

The decision of the length of the sub construction used is decided based on the depth analysis of the wall surface. In this project the surface of the wall is flat and fewer undulations are detected during the analysis of the point cloud data. The wall brackets and wall angles used in this project have a shell tolerance up to 20mm (+/-10mm). Hence any undulations in surface of the wall with 20mm (+/-10mm) can be adjusted during the installation of sub-construction on the wall surface.

3.3 Drawings for facade plate dimensions and position



d = 4 mm	maximale Stützweite "b" [mm]																
Last in [kN/m²]	0,30	0,40	0,50	0,60	0,70	0,80	0,90	1,00	1,10	1,20	1,40	1,60	1,80	2,00	2,20	2,40	2,60
Sog : max b	1243	1129	1046	986	937	896	862	832	806	783	728	681	642	609	581	556	534
max. l [mm]	500	500	500	500	500	500	485	452	424	400	361	330	305	285	267	252	239
Druck: max. b	1498	1361	1243	1137	1055	988	933	887	847	812	753	706	668	635	606	582	560
max. l [mm]	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500

- Bohrloch-Ø in den ALUCOBOND Platten:
  - Ø 7,5 mm (max. Stützweite B = 1000 mm
    max. Länge L = 4000 mm
    Nietkopf-Ø K11 mm)
  - Ø 8,5 mm (max. Stützweite B = 1500 mm
    max. Länge L = 8000 mm
    Nietkopf-Ø K14 mm)

Table 3: Alucobond: Static guidelines for 3 support (2 field plates)
Flat facade panels - riveted

The static detail for the corresponding facade material (Alucobond) is provided by the system provider. Based on this the number of holes in facade plates for riveting is decided. The standard dimension of the facade plate used is 2600x 1250mm. From the wind load calculations in chapter 2.1.3 we know that,

Wind pressure max. W D,k = 0.764 KN/m^2
Wind suction max. W S,k = 1.107 KN/m^2

Considering the maximum wind load Wk = 1.107KN/m^2,

From table 3,
The maximum distance between rivets horizontally b ≤ 806mm
The maximum distance between rivets vertically l ≤ 424mm
The diameter of holes to be drilled in the facade plate for rivet joints is ø7.5mm
The cover distance lr and br are 50mm and 25mm respectively.

Dynamic blocks are created in AutoCAD with specific attributes holding measurements for facade plates. In total 115 facade plates are created in the CAD drawing as dynamic blocks. The block attributes are extracted in excel format from CAD drawings. The excel sheets holding the facade dimensions are imported in plate optimisation software SWIFTOPT V8.95. The best suited plate format with minimum wastage of material is chosen based on the optimisation report produced by SWIFTOPT V8.95 software. Later based on the optimized chart the data is imported in the CNC machine for the production process. The different facade plate types used are given as detailed drawings in the Appendix D. The drawing for the facade dimension and position are attached in Appendix H.

3.4 Drawings for sub-construction position and dimension

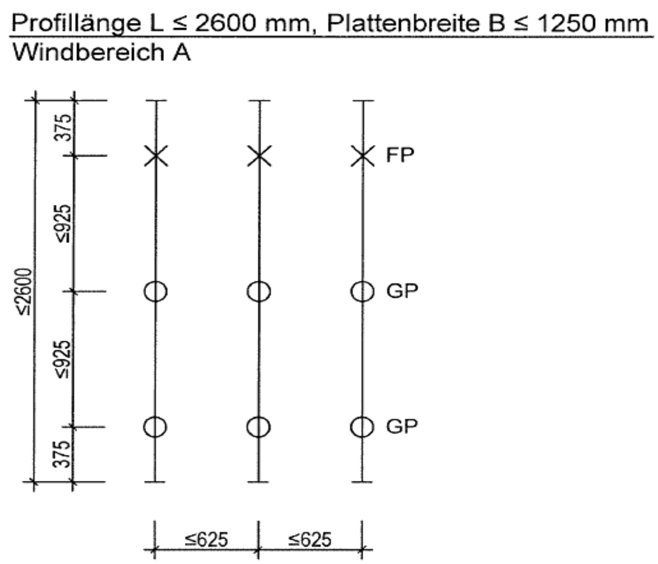


Figure 25: Profile system for vertical profile - ATK 100 Zela

The fixed point and the glide points are decided based on the static details as shown in the fig.25. CAD drawings are created to identify the dimension of the profiles and the number of wall brackets required. The dimensions for the position of the fixed and glide points are taken from the sprayed permanent target reference created on the wall surface. For each profile used in the drawing a dynamic block is created with necessary attributes. This helps to extract the block attributes to excel sheets and prepare bill of quantities. By creating dynamic blocks the quantities can be exactly estimated without any mistakes and orders can be placed for the construction work. The CAD drawings and excel sheets for the sub construction are attached in appendix I and K.

3.5 Conclusion

By the end of this chapter the list of drawings for the facade construction is prepared. The bill of quantities for ordering the facade plates and the sub construction items are prepared. The facade mounting plans are created with the accurate measurements based on the architectural drawings and static calculations. Based on these drawings the production, fabrication and erection of facades are carried out in the worksite.

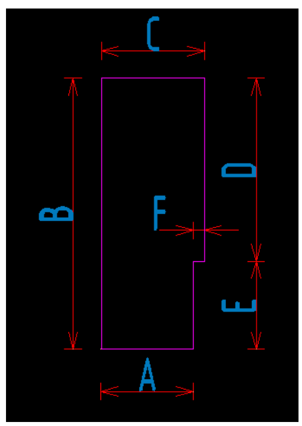
4. Comparison methodologies for facade measurement

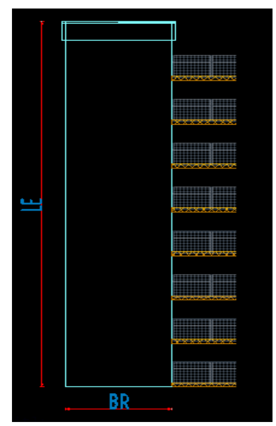
The facade measurements recorded using laser scanned technique and traditional surveying technique is compared based on the following key performance indicator factors,

- Accuracy of measurement
- Complexity of work flow
- Time Analysis
- Cost Analysis
- Personnel required

4.1 Accuracy of measurement

Accuracy is an important factor to be considered for facade construction. The tolerance in accuracy can be compromised up to 2mm. An attempt was taken to compare the traditional measurements with the laser scan measurements.

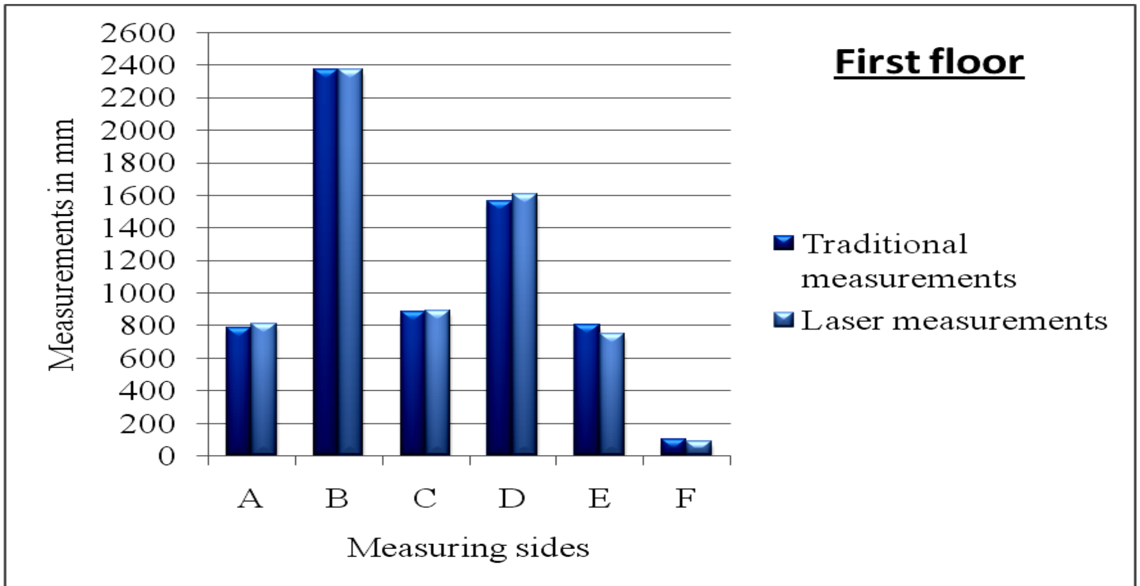



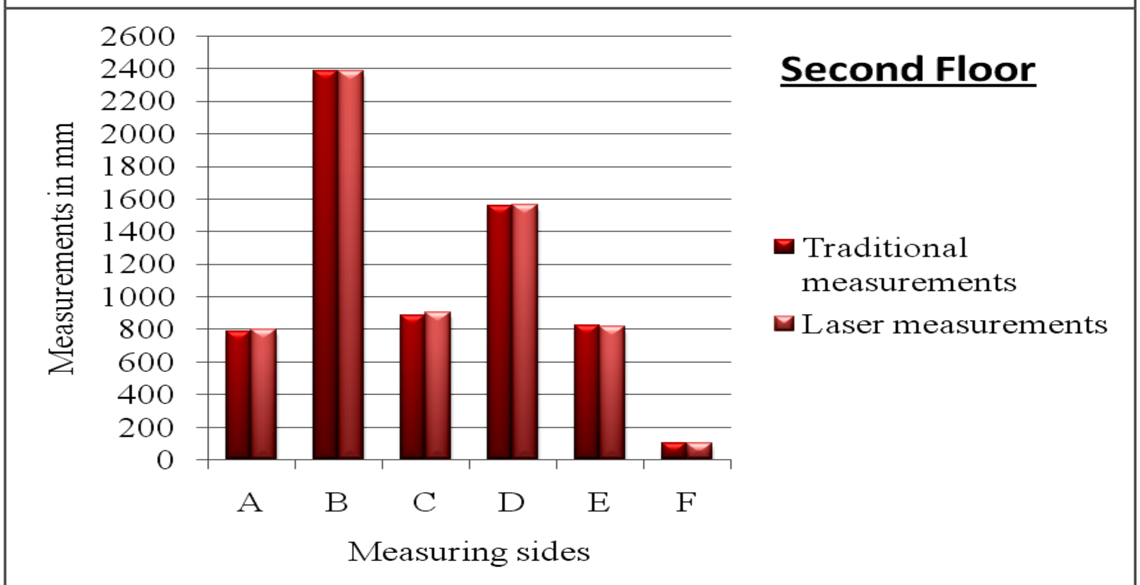
Front façade left side	Traditional surveying	Laser surveying	Error in mm
Length (LE)	21813	21825	12
Breadth(BR)	4675	4666	-9

Balcony façade left side	Traditional surveying						Laser surveying						Error in mm					
Measurements in mm	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
1st floor	786	2373	885	1565	805	100	810	2375	894	1610	752	88	24	2	9	45	-53	-12
2nd floor	787	2384	887	1559	826	100	802	2384	903	1567	817	101	15	0	16	8	-9	1
3rd floor	785	2403	885	1567	814	100	812	2377	909	1605	765	97	27	-26	24	38	-49	-3
4th floor	788	2385	888	1577	805	100	812	2383	909	1599	775	97	24	-2	21	22	-30	-3
5th floor	790	2378	890	1574	805	100	807	2378	900	1606	767	93	17	0	10	32	-38	-7
6th floor	797	2378	897	1563	810	100	807	2378	904	1598	771	96	10	0	7	35	-39	-4
7th floor	797	2385	897	1563	810	100	808	2380	908	1554	824	106	11	-5	11	-9	14	6
8th floor	789	2387	896	1569	810	100	810	2385	908	1603	769	98	21	-2	12	34	-41	-2

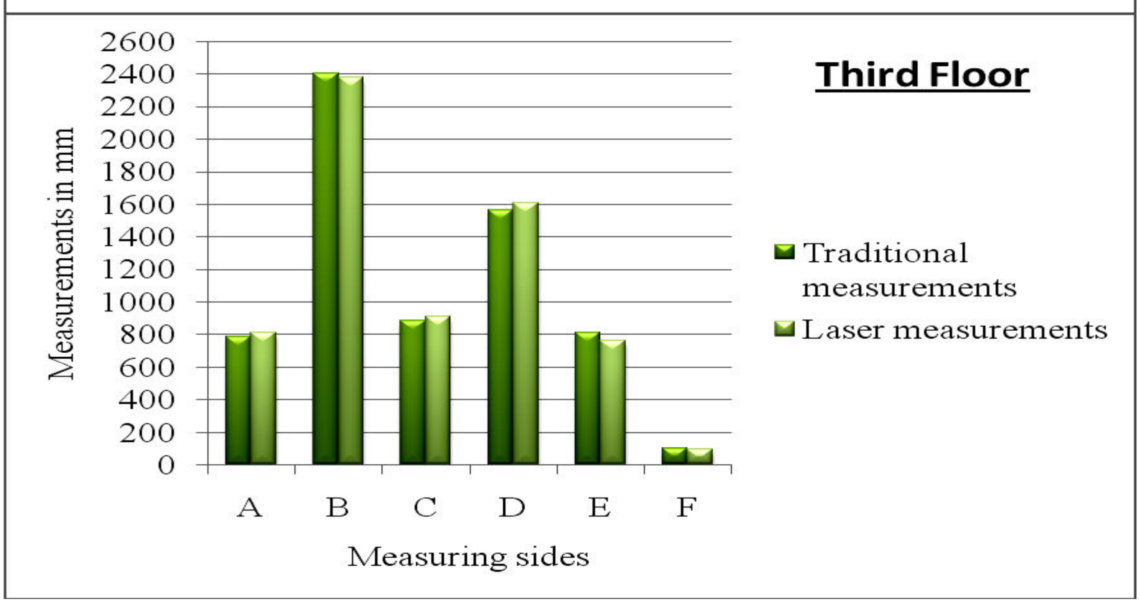
Table 4: Traditional and laser surveying measurements



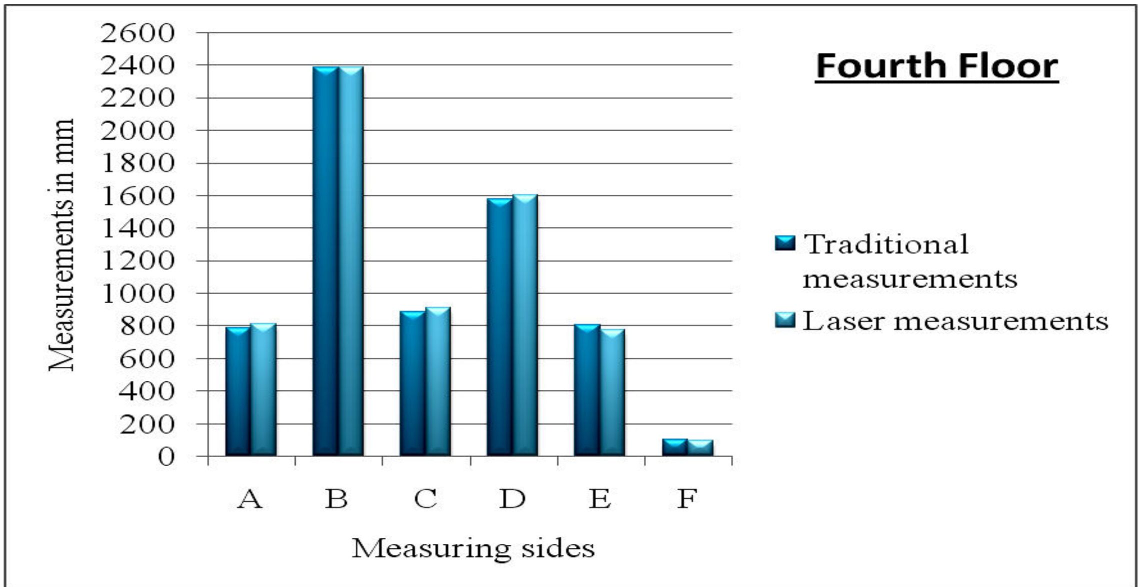
First floor
Measurements in mm
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
A
B
C
D
E
F
Measuring sides
Traditional measurements
Laser measurements

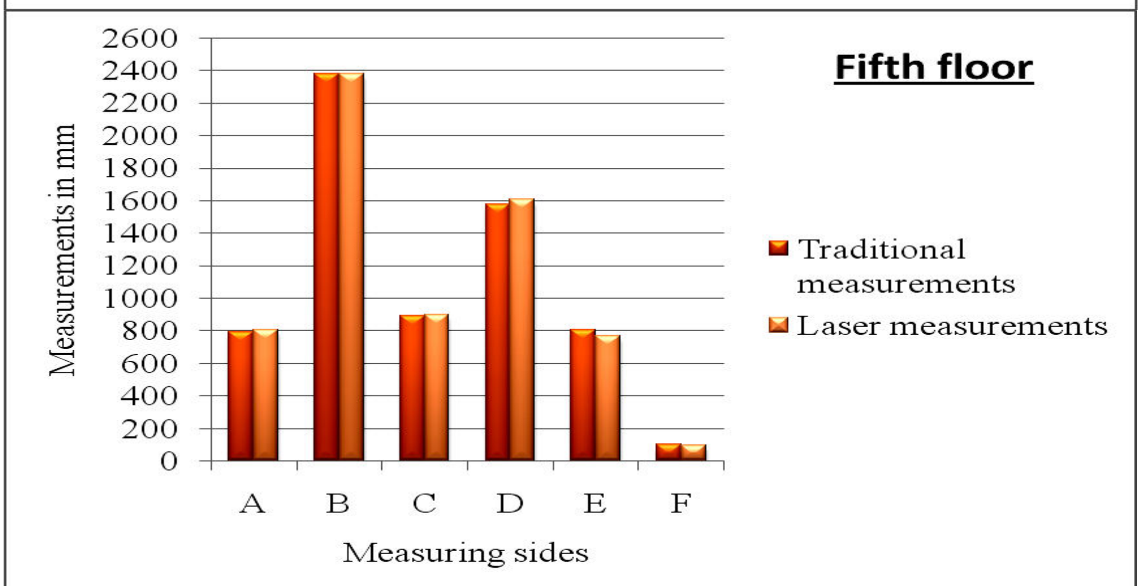


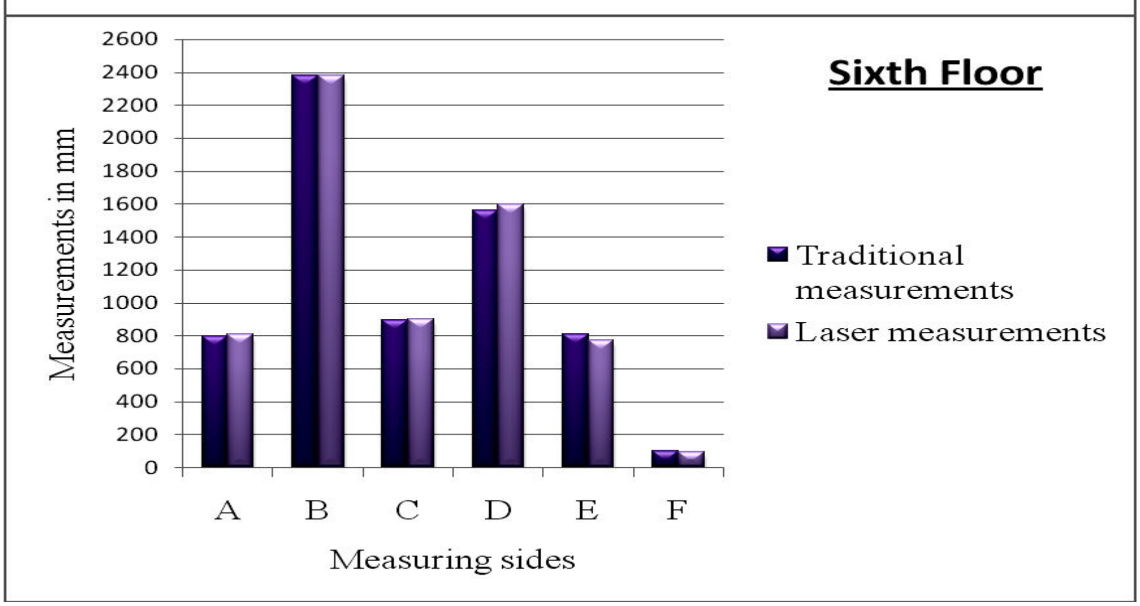
Second Floor
Measurements in mm
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
A
B
C
D
E
F
Measuring sides
Traditional measurements
Laser measurements



Third Floor
Measurements in mm
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
A
B
C
D
E
F
Measuring sides
Traditional measurements
Laser measurements


Fourth Floor
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Measurements in mm
A
B
C
D
E
F
Measuring sides
Traditional measurements
Laser measurements


Fifth floor
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Measurements in mm
A
B
C
D
E
F
Measuring sides
Traditional measurements
Laser measurements


Sixth Floor
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Measurements in mm
A
B
C
D
E
F
Measuring sides
Traditional measurements
Laser measurements

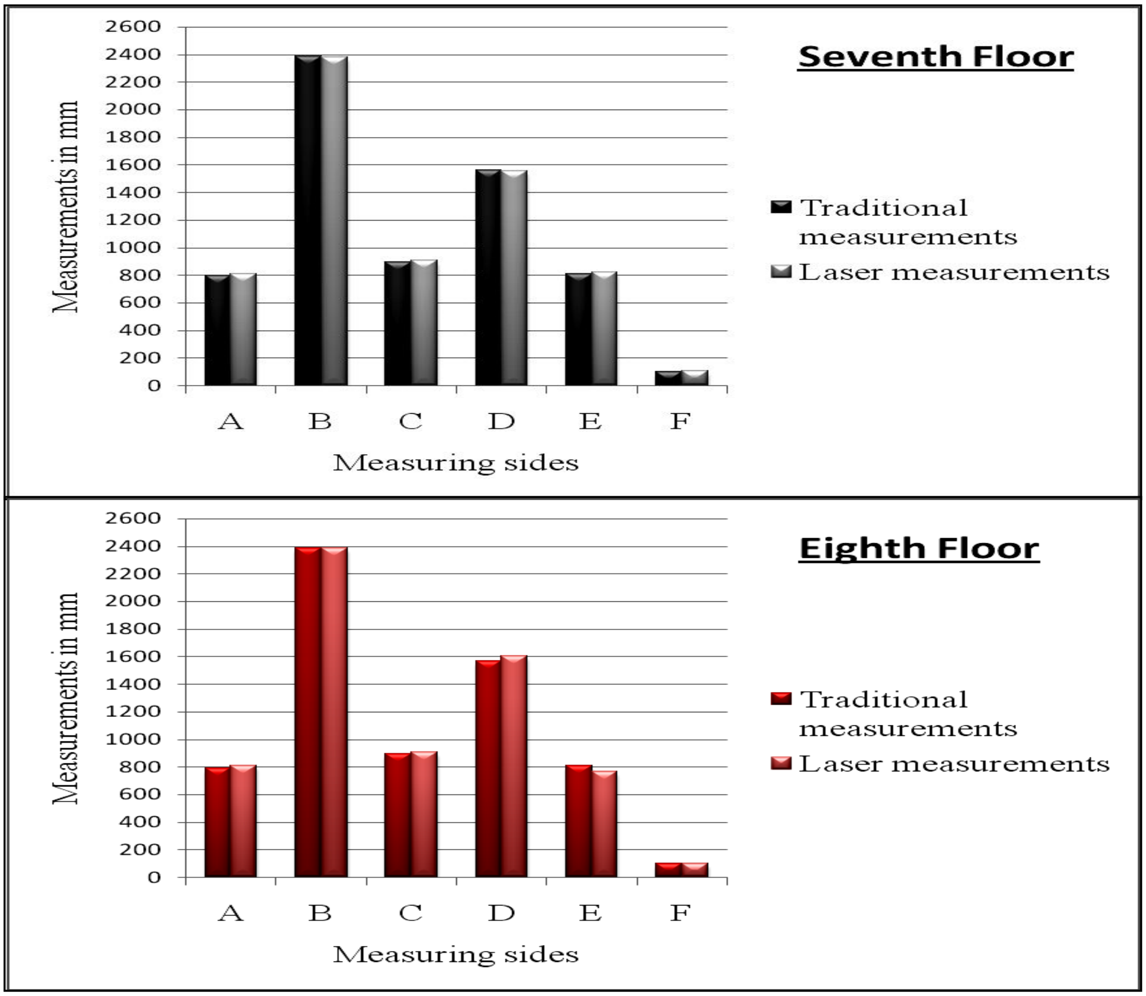


Figure 26: Trends of differing measurements in balcony area

Table 4 shows the list of measurements acquired using traditional and laser scan surveys for the front facade and the facade in the balcony area. The difference of these measurements showed the error occurred. Traditional measurements acquired had many errors with a maximum value of 53mm. While using metallic tapes there a lot of errors occurred. The metallic tapes are placed over coloured lines drawn on the wall surface for acquiring linear measurements. But the fact is that the wall surface is not levelled and has some undulations resulting in errors. The other reason is stiffness or sag of tapes while measuring the distances between any two given points on the wall surface.

The facades should be mounted in an even and uniform manner on the surface of the wall. Hence it is important to perform a depth analysis on wall surface to find out the depth at which most of the points of the wall occur. The rotation lasers RL1 and RL2 are placed at a distance of 257mm and 186mm from the wall surface as shown in fig.27. The vertical laser beam is captured from RL1 and RL2 using a metre scale. Totally at 16 different positions the depth of the wall is measured to find the flatness of the surface. The maximum difference in depth was 9mm (+3/-6mm) as shown in table 5. Since the wall brackets used for this project has a shell tolerance of 20mm (+/-10mm) the difference in depth of 9mm can be adjusted.

Floor	RL 1 (257)	RL 2 (186)	Depth variation in mm-RL1	Depth variation in mm-RL2
G	257	186	0	0
1	257	186	0	0
2	256	183	-1	-3
3	258	181	1	-5
4	259	183	2	-3
5	257	184	0	-2
6	254	180	-3	-6
7	260	181	3	-5
8	251	181	-6	-5

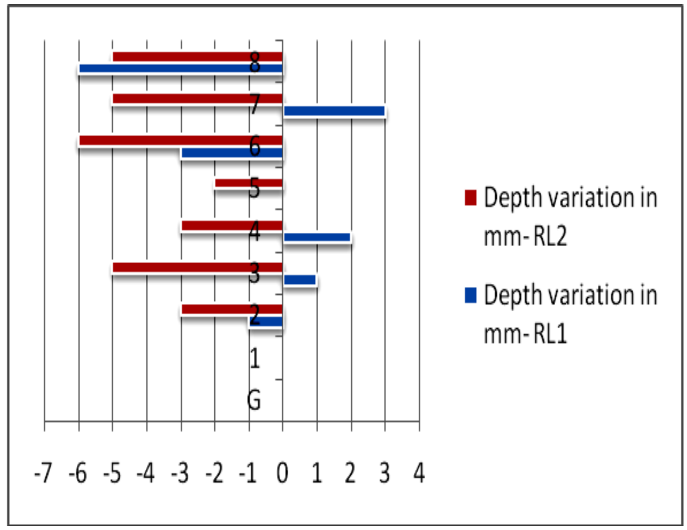


Table 5: Traditional measurement for depth of the wall

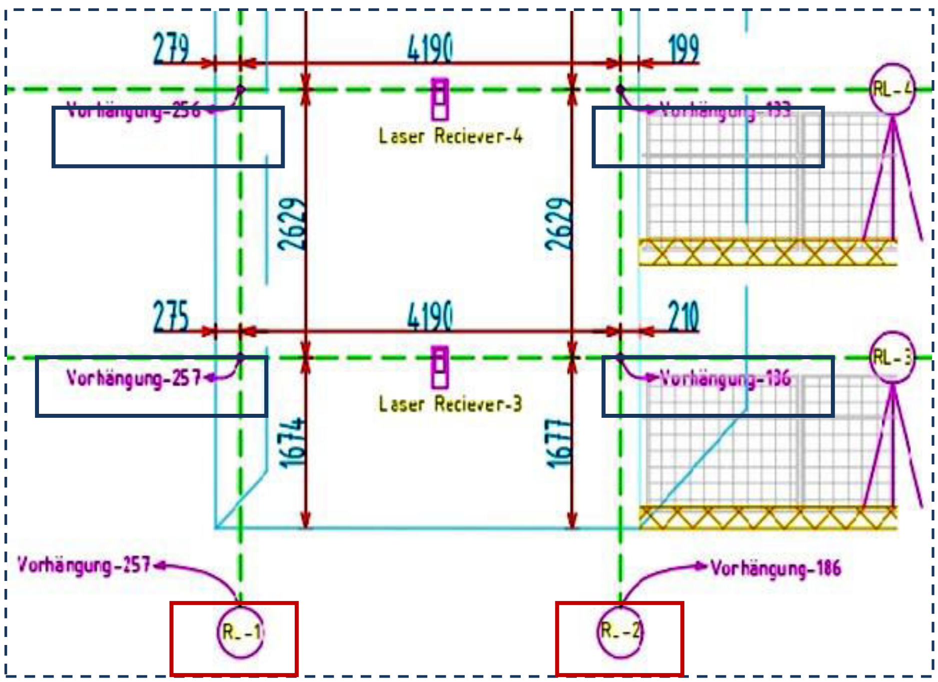


Figure 27: Traditional measurement – depth analysis of wall surface

The depth of wall was previously analysed with laser scanned point cloud data by 3D re-shaper software in chapter 3.2. In comparison with traditional way of analysing the depth of the wall the laser scanned point cloud data analysis has greater accuracy. This is very obvious because millions of points were measured in point cloud data for analysing the depth. But in traditional way the depth is measured only at 16 points on the wall surface.

4.2 Complexity of workflow

Balcony in the Floor level	Curtain wall distance in mm	Distance from wall surface to window frame corner in mm		Distance from curtain wall panel to the inner edge of window frame in mm	
		Left	Right	Left	Right
1	114	33.01	34.11	9.01	10.11
2	114	32.13	30	8.13	6
3	114	40.16	37.5	16.2	13.5
4	114	25.42	35.5	1.41	11.5
5	114	34.03	55.47	10	31.5
6	114	38.66	43.67	14.7	19.7
7	114	33.65	38.34	9.62	14.3
8	114	42.49	37.09	18.5	13.1

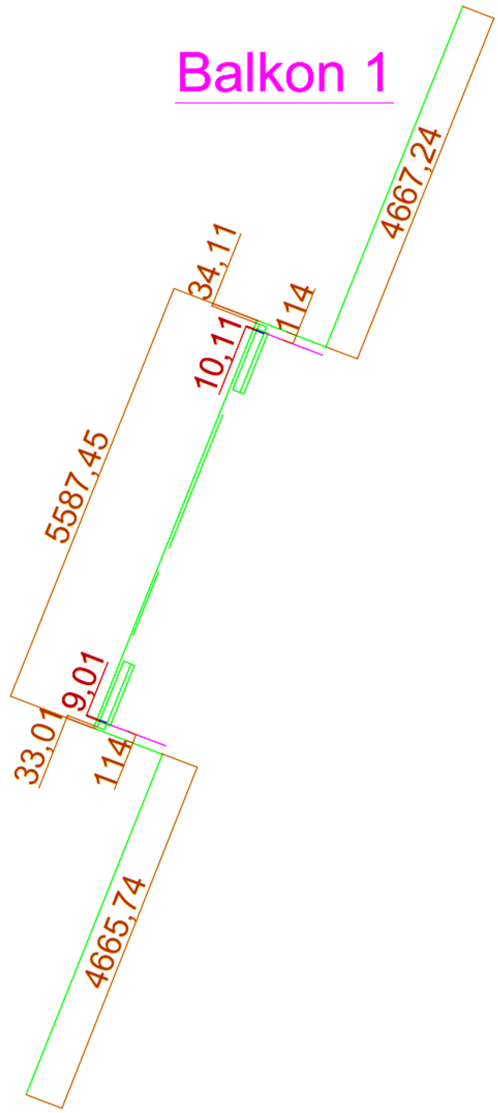


Table 6: Check for collision of facade in the balcony with the window frame

During the depth analysis of the left and right facade in the balcony it was observed that 100% of points lie in the range between 102mm to 127mm. The difference was 25mm. It is more than the shell tolerance of sub construction used which is 20mm (+/-10mm). Hence the same length of sub construction cannot be used commonly for all the facades in balcony. It was important to check the curtain wall distance of 114mm is suitable for each of the facade in balconies. During the 3D trace of the point cloud data it was found that the windows are not placed uniformly in every floor and there are some axial rotations and displacements in position of windows in each of the floor. As shown in table 6, the cells highlighted in yellow colour shows the balcony facade in respective floors which has the risk of exceeding the window frame hindering the aesthetical view.

In the above scenario discussed the traditional measurements do not give enough information about the tilt position of the windows and few points for the depth analysis in traditional measurements cannot be trustworthy data. By laser scan point cloud data clear decisions can be made and helps avoiding confusions and time lags for the facade construction process. Even the minute of the details can be obtained and every decision can be made in advance in the design stage of the facade construction process. Any kind of complexity or inaccessible areas in a building can be measured using point cloud data acquired by 3D laser scanners.

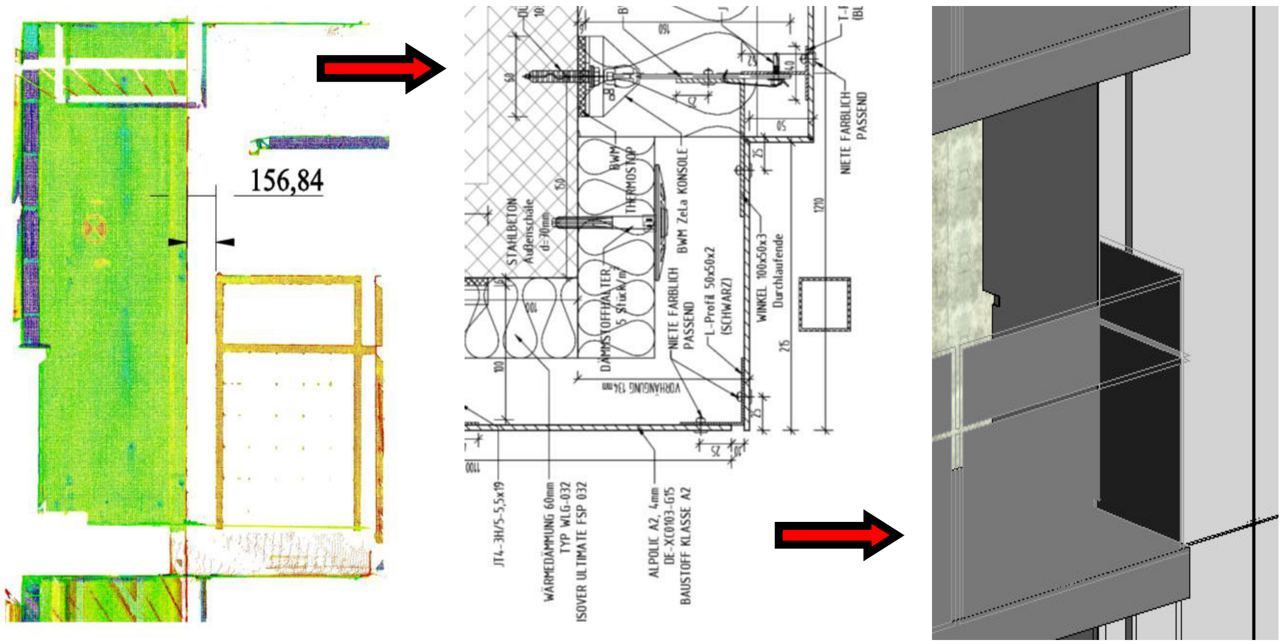


Figure 28: Point cloud measurements for corner details

The curtain wall distance for the front facade is 184mm which was decided in the initial stage of the project when the system details were created. But there was a complex scenario observed while tracing the 3D sketch from the point cloud data at the junction of front and the balcony facade. There was no enough curtain wall distance at the inner edge of front facade as the steel bar of the railing in the balcony obstructs it. The point cloud measurements were very important to decide on such situations and as shown in fig.28 the available curtain wall distance in the corner was 156.84mm. Based on this measure the corner details were created with a curtain distance of 134mm at this junction and the front facade plate was bent 50mm and connected to the facade plate in balcony area.

Point cloud measurements were helpful in measuring any small detail of a building at any given point of time. In traditional tape measurements only the particular dimensions required for the building project renovation was recorded and in case of any requirement of additional measurements the site visit has to be done to record them every single time. This is a time consuming process critical details should have high measurement accuracy for prefabricating the facade panels at these positions of the building. This can be achieved with point cloud measurements.

Initially in the tender document the facades in the roof level of the building were not mentioned for the renovation. But halfway through the project the client made an additional contract to renovate the facades in the roof of the building as well. The necessary as-built measurements required for facade design were acquired before the additional contract was made. Traditional measurements were only recorded for the front facade without the roof facades and facade in balcony area. So in this situation the point cloud data was really helpful to trace the roof of the building. It is evident that the point cloud measurements are used for documentation and recording the complete information of the building which can be used or referred at any given situation. This greatly reduced the timeframe for completion of the building project.

4.3 Time Analysis

Floor	Tape measurements						Laser scan measurements				Time difference in seconds
	Number of measurements taken for left side of building	Time taken for setting rotation laser station in seconds	Time taken for drawing coloured lines on the wall surface in seconds	Time for recording measurements using metallic tape in seconds	Multiple factor considered for right side and left side of building	Overall time taken in seconds	Number of scan stations	Time taken for setup and observations	Time for Scanning	Overall time taken in seconds	
G	18	240(RL1& RL2)	1080	1080	2	4320	4	600	420	2040	2280
1	10	120 (RL3)	600	600	2	2400	1	300	210	510	1890
2	10	120(RL4)	600	600	2	2400	1	300	210	510	1890
3	10	120(RL5)	600	600	2	2400	1	300	210	510	1890
4	10	120(RL6)	600	600	2	2400	1	300	210	510	1890
5	10	120(RL7)	600	600	2	2400	1	300	210	510	1890
6	10	120(RL8)	600	600	2	2400	1	300	210	510	1890
7	10	120(RL9)	600	600	2	2400	1	300	210	510	1890
8	10	120(RL10)	600	600	2	2400	1	300	210	510	1890
						23520				6120	17400

Table 7: Time report for tape and laser scan survey

The traditional tape measurements are carried out only for the front facade and the facade in balcony area in the left side of the building. The multiple factor is considered in Table 7 for the tape measurements since the right and the left side of the building are similar and same number of measurements would be taken. So from the above table it is observed that the total time taken for traditional survey using tape, coloured rope and rotation lasers is 23520 seconds which is around 6 hours and 32 minutes. For the same building the laser scan measurements took only 6120 seconds which is 1hour and 42 minutes.

At the end of this time analysis it is evident that the time taken for laser measurement is 3.84 times less than the time taken for the tape measurements and could save 4 hours 50 minutes which is 75% of the time taken.

The time taken for post processing of point data took 8 hours of time (1 man day). Later the 3D trace of the building from point cloud data, creation of drawings for facade panel and sub construction position and dimension took 16 hours of time (2 man days). In total it took 24 hours (3 man days) for preparing facade mounting plans from laser scanned data. By using traditional measurements the drawings for facade and sub construction position and dimension can be prepared in 20 hours of time (2.5 man days). In this case the traditional measurements acquired helps to lessen the office work compared to laser measurements.

The pre-fabrication and pre- assembly of facades was not possible for complex facade panels since the accuracy of measurement is a question mark in traditional surveys. In this situation the facades are fabricated on-site. Generally the brick and stone facades used in traditional times were fabricated on the site. In this project the Aluminium facades are used and hence the cutting and milling of facade plates is easier in the fabrication plant rather than on site. The pre-assembly of facades can be done with trustworthy measurements obtained through laser scanning and this will reduce the time greatly.

4.4 Cost and labour Analysis

Type of survey	Cost of Instrument	Number of surveyors required	Wage paid per hour for the surveyor	Time taken for surveying	Cost of labour	Cost of post-processing software	Total cost
Traditional tape survey	€ 700 (Rotation laser+ Coloured rope+ Metallic Tapes)	2	€ 10	6 hours and 32 minutes	€ 130	_	€ 960
Laser scan survey	€ 81,200 (Terrestrial Laser scanner)	1	€ 30	1 hour and 42 minutes	€ 50	€ 1,950	€ 81,250

Table 8: Cost Analysis for tape and laser scan survey

The major cost for acquiring as-built measurements would be the cost of instrument used for this purpose. The price of Leica P40 scanner is around €81,200 which is a huge investment made on measuring equipment. Comparatively the instruments used for traditional measurements namely the rotation laser, Coloured chalk powder rope and metallic tapes all together costs roughly around €700. There is huge leap observed in the cost comparison for the instruments used for traditional and laser scan surveys. Apart from the instrument cost, for the post processing of the point cloud data special software is required. The cost of Leica Cyclone Basic 9.0 software is €1950. For traditional surveying only the basic CAD drawing tool is required.

For traditional surveying two surveying persons are required in order to hold the tape between two different points and record the measurements. The salary ranges from €9 to €10 per hour for one person. As discussed earlier the total time taken for traditional survey was 6 hours and 32 minutes. So in total for two surveyors €260 was spent to record the measurements of the building project.

To perform 3D laser scanning of the building site one surveying person is enough and the time spent for the overall laser scanning process was 1 hour and 42 minutes. The salary paid for handling the laser scanners was €25 to €30 per hour. So, the money paid for 3D scanning was round about €50. The cost incurred for labour is 5.2 times lesser for laser scan surveying compared to traditional tape surveying.

In the current scenario the small scale companies rent 3D laser scanners for a day to record the as built measurements since they cannot afford huge sum of money in owning the laser scanning instruments. The Leica P40 scanner is rented on an average of €800/day. 3D laser scanning is affordable when it is outsourced to a company that is specialized in 3D scanning services. This eliminates the training cost for the worker in handling the scanner and operating the software.

4.5 Conclusion

At the end of this chapter all the key performance factors such as time, cost, labour, complexity of workflow and accuracy of measurements are compared based on the tape and laser scanned measurements acquired for the building project. The overall analysis of these performance factors with help of charts and tables gives clarity on the advantages and disadvantages in both the surveying technique with respect to the facade design project. Each of the performance factors is directly proportional to one another and they are interlinked. Laser scanning technique proves to be the best surveying technique to attain more accuracy in measurements which will have a direct effect on cost and time involved in the building project. The design of facades at complex situations cannot be decided with tape measurements as they are linear measurements whereas the point cloud data holds the three dimensional information for each point from which any measurement can be easily referred and readily available at any given point of time. The laser scan data can be used for preparing building documentation for old buildings which are to be demolished. The laser scan data helps in preparing enriched 3D models to monitor the future operation of the building.

5. Results and discussion

The demonstration project considered for the facade renovation helps to differentiate the tape measurements and the laser scan point cloud measurements. The comparison of the measurements were based on various factors considered during the workflow of acquiring the as built measurement and post processing of these measurements to create 2D facade mounting plans and details. The following results were arrived based on complete analysis of the facade design methodologies based on traditional tape surveying and 3D laser scan surveying.

- The raw 3D point cloud data can be processed to create a semantically enriched 3D model as shown in fig. 29 but the post processing of the point cloud data requires more time and skilled technician. However in the recent trends many commercial software like POINT CAB, GEOMAGIC etc. are used for tracing the 2D and 3D as built measurements easily and automatically from point cloud data which saves a huge amount of time.

- The traditional tape measurements are suitable mostly for small scale projects where linear measurements are recorded for simple objects. The inaccessible parts of the building project cannot be measured by tape measurements. In this project in order to record the tape measurements in the balcony area the user of the balcony floor is disturbed. Hence traditional measurements disturb the privacy of the user in a building renovation project.

- Laser scan survey can be carried out at a certain distance from the building and no physical contact with the building is necessary for capturing the measurements. The point cloud data from 3D scans are dense and each point on the building holds a three dimensional co-ordinate in space which is the reason for its precision and accuracy.

Figure 29: Enriched 3D model of the south facade in Revit

- The 3D laser scanners are very expensive compared to any of the traditional surveying instruments and handling these scanning machines on site should be done with utmost care. In case of any damage it leads to huge repair costs.

- The pre-fabrication of facade panels in the manufacturing plant was considered a big risk with traditional measurements acquired because the accuracy of the measurements were very poor in linear tape measurements. This leads to wastage of material of facade construction.

- In the workflow of the facade design based on the traditional measurements it was very clear that the site work takes much time than the office work. But for laser surveying the 3D scans were recorded quickly on site but the office work for post-processing of point cloud data takes much time.

- During the 3D scanning of the south facade of the building the integrated camera function in Leica P40 scanner was switched off and only the points are captured in hue pattern based on their intensity. This could save huge amount of scanning time. Many pictures were clicked on the site using normal camera for reference.

- The work site was very congested with many construction equipments and natural disturbances like vegetations which obstruct the line of sight for scanning the south facade of the building. To overcome this situation the HDS targets were set near the building at different locations and many scanning was performed at four different ground stations and one station in each of the balcony area.

- In case study 1 there was a future scope of development discussed for lack of flexibility when integrating point cloud data. This was overcome by setting minimum 3 common HDS targets between consecutive scan stations which helps in integrating the point cloud data by registering and merging of scans together in post processing software.

- Particularly in renovation projects the point cloud data is used to identify the exact measures of damages area in a building and it is very advantageous in limiting the wastage of raw material and sure decisions can be made. Only two dimensional data can be acquired from tape measurements but the laser scan point cloud data is used in the three dimensional digital reconstruction of building

- 3D scanners are overlooked for their cost but they can still be rented or the complete process can be outsourced if the quality of measurements and time frame for project completion are given much importance. The tape measurements for vast project will be tedious and huge effort of human labour and time are spent resulting in inaccuracies of the measurements. The deadlines for project completion get extended and lots of confusion arises at the work site.

6. Conclusion

The thesis helps us to understand the workflows for facade design based on the traditional and laser scanned point cloud measurements. Data density, time taken, cost impaired, complexities in the workflow and precision of measurements were analysed in a detailed manner. The only limitation about the 3D laser scanning technique is the investment cost for the instrument. The major drawback for traditional tape measurements is that the data acquired is two dimensional and only few points on the wall surface are considered for depth analysis of the wall surface. The point cloud data is used for documentation purposes and creating semantically enriched 3D model of the building project which can be used for future operations. The density of point cloud data gives incredible levels of detail for the renovation projects. In tape measurements the recorded measurements in the field book are transferred to CAD drawings line by line. The 3D laser scanning technique has proven to be more rapid in capturing the as built measurements of the building compared to traditional tape measurements with respect to the facade renovation project undertaken.

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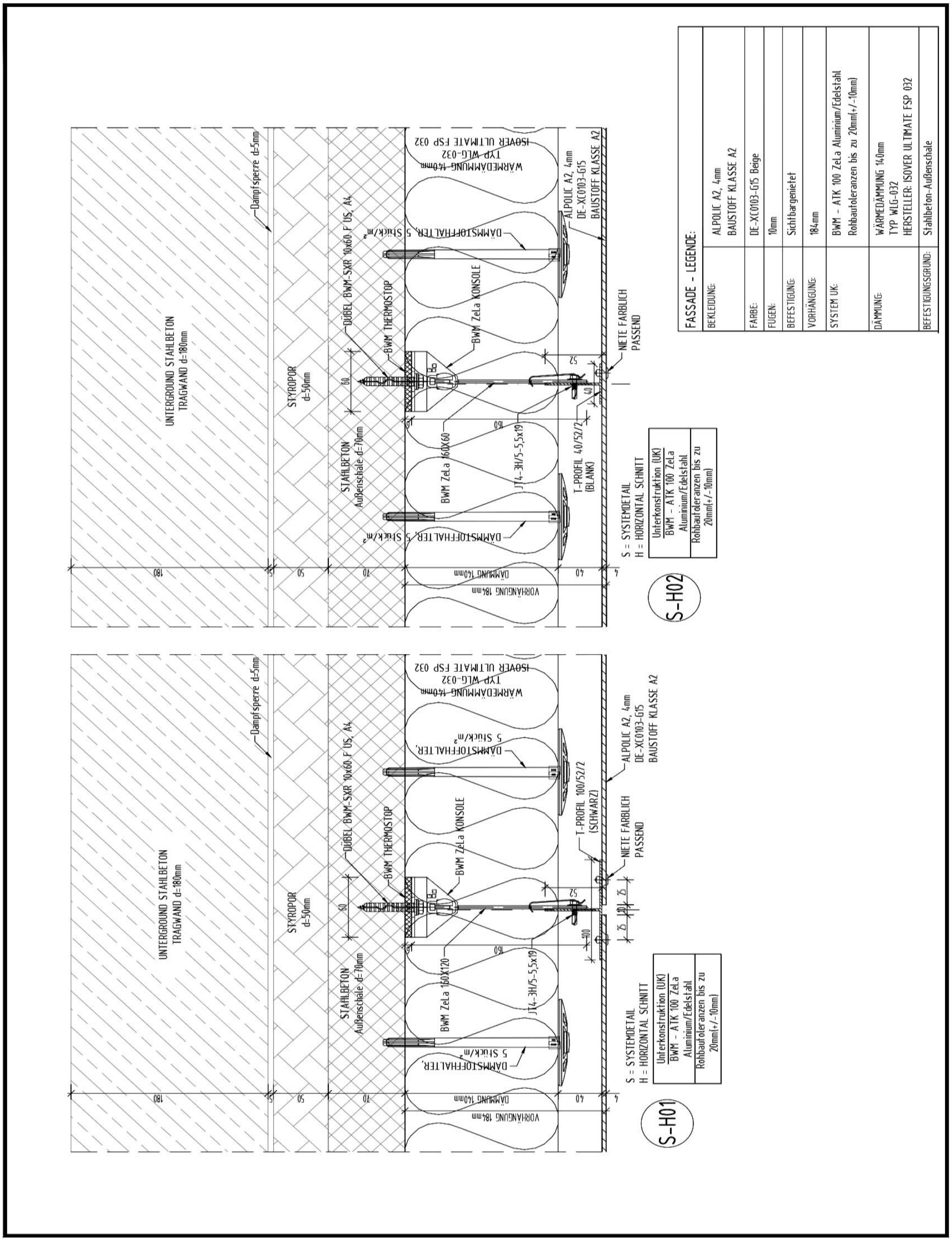
8. Appendices

Appendix A: System details



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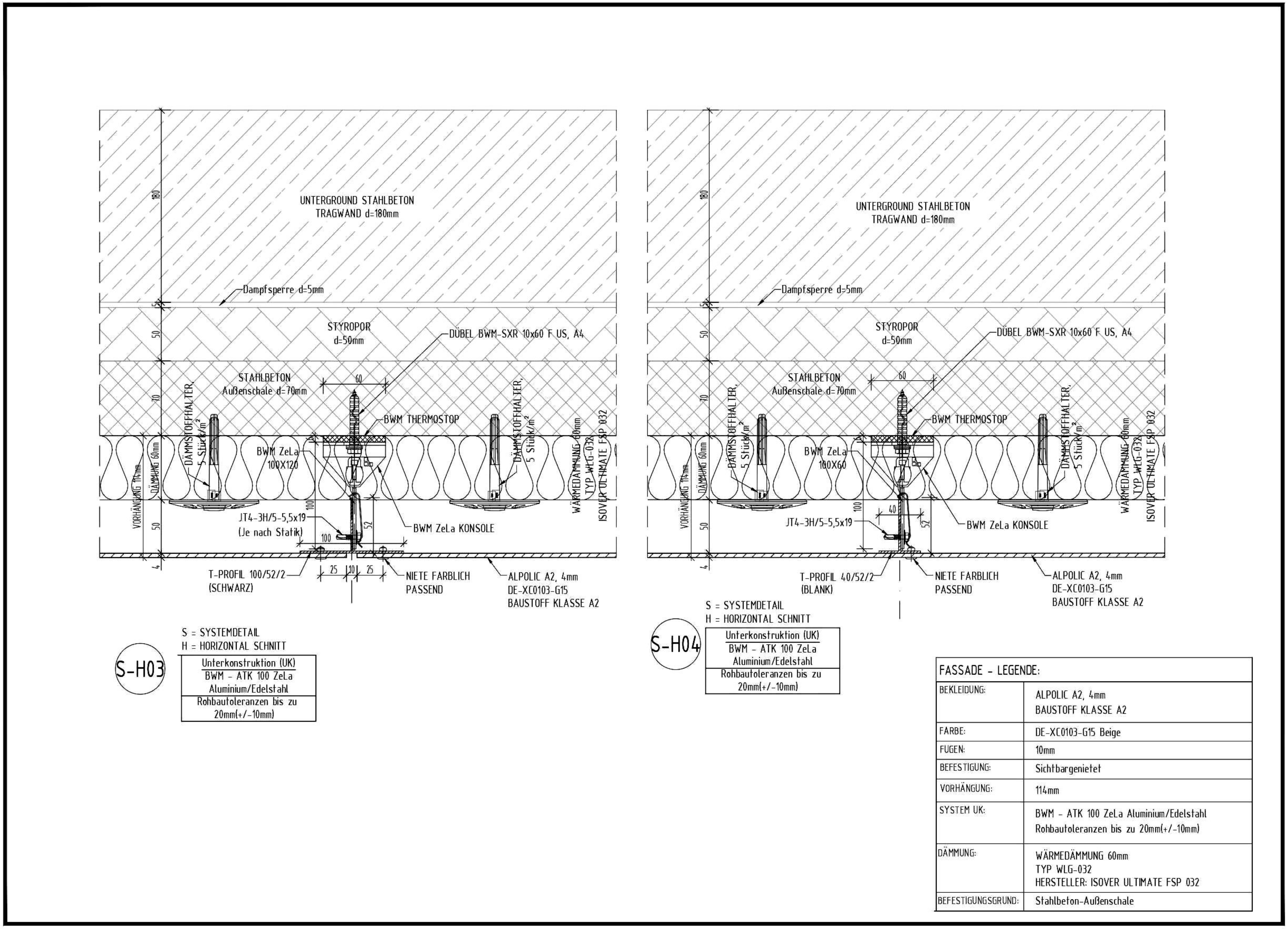
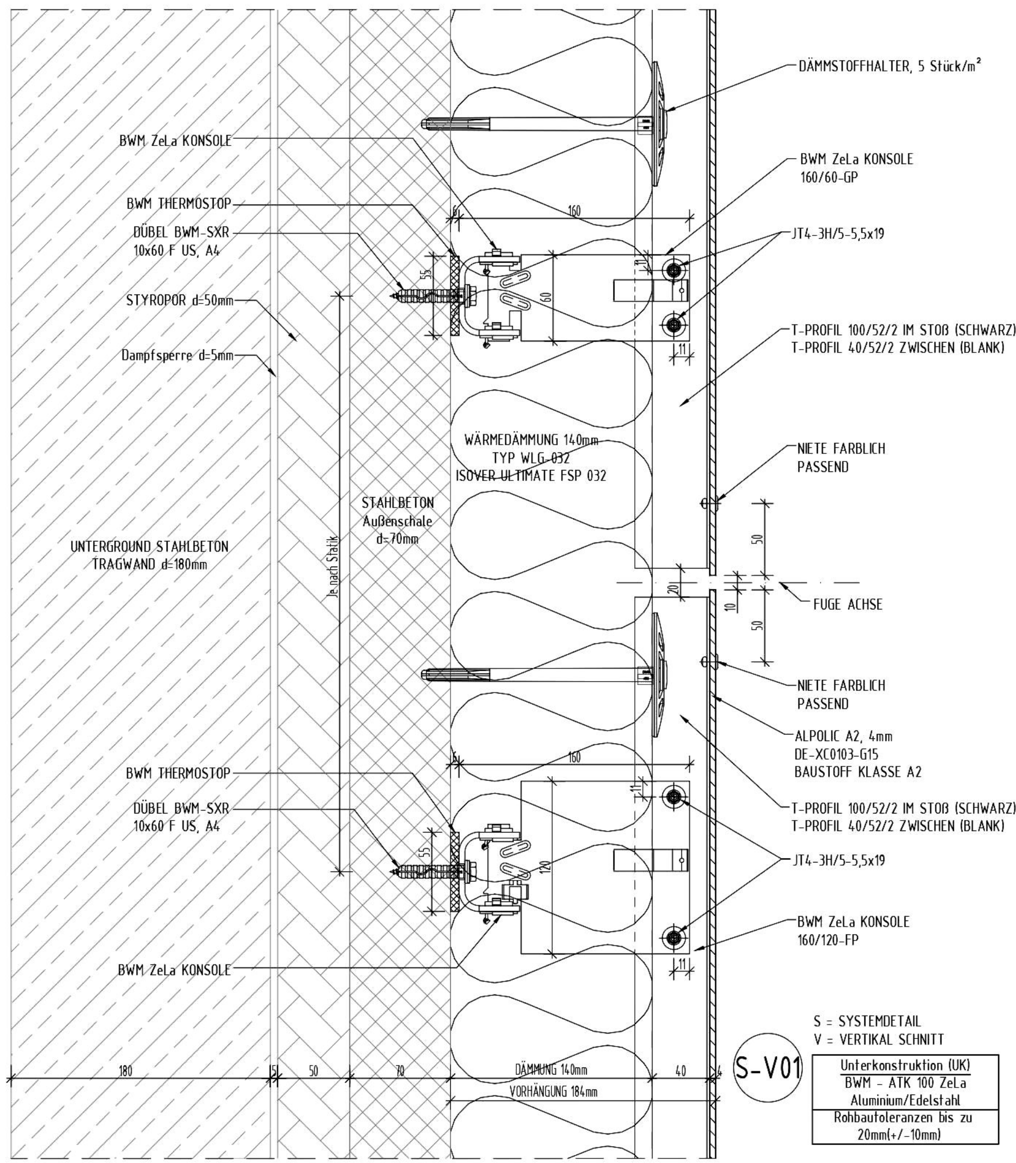
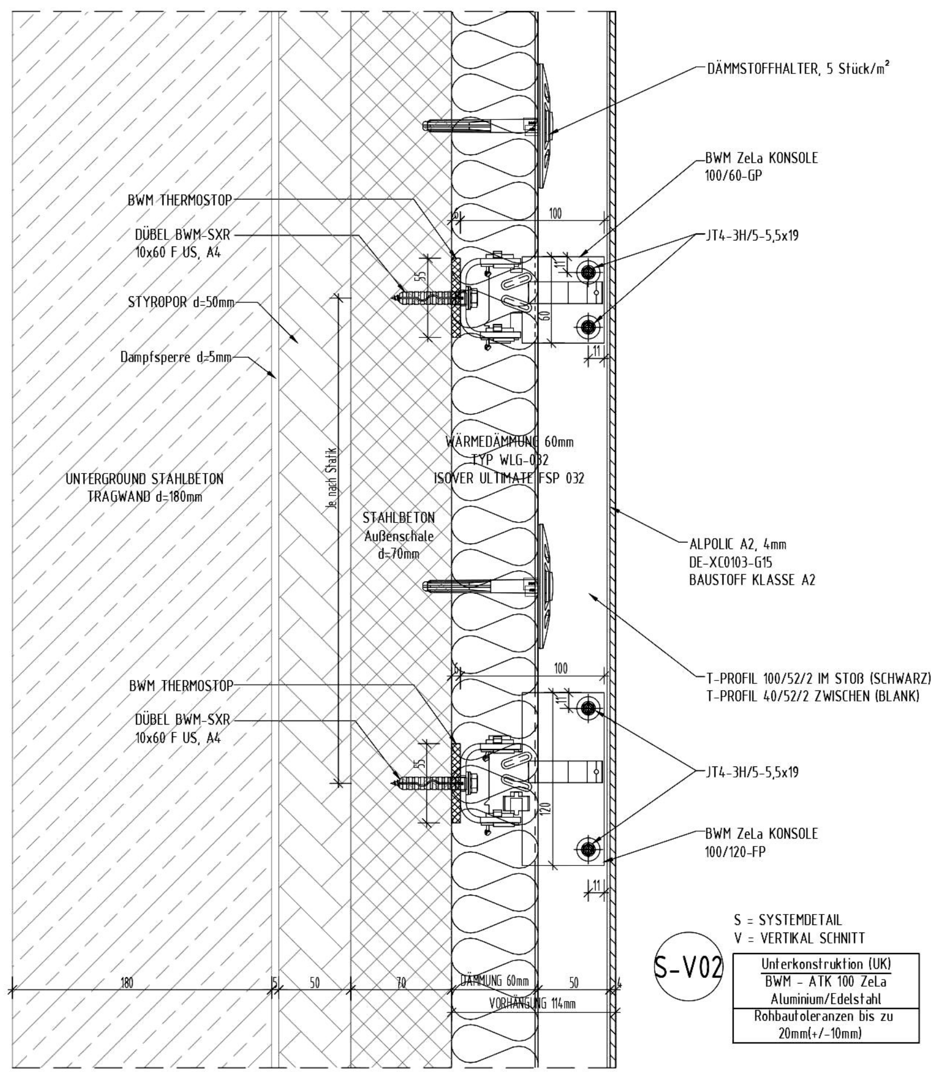

UNTERGROUND STAHLBETON
TRAGWAND d=180mm
Dampfsperre d=5mm
STYROPOR
d=50mm
DÜBEL BWM-SXR 10x60 F US, A4
STAHLBETON
Außenschale d=70mm
BWM THERMOSTOP
DÄMMSTOFFHALTER,
5 Stück/m²
BWM ZeLa
100X120
JT4-3H/5-5,5x19
(Je nach Statik)
BWM ZeLa KONSOLE
WÄRMEDÄMMUNG 60mm
TYP WLG-032
ISOVER ULTIMATE FSP 032
VORHÄNGUNG 114mm
DÄMMUNG 60mm
T-PROFIL 100/52/2
(SCHWARZ)
NIETE FARBLICH
PASSEND
ALPOLIC A2, 4mm
DE-XC0103-G15
BAUSTOFF KLASSE A2
S = SYSTEMDETAIL
H = HORIZONTAL SCHNITT
S-H03
Unterkonstruktion (UK)
BWM - ATK 100 ZeLa
Aluminium/Edelstahl
Rohbautoleranzen bis zu
20mm(+/-10mm)
BWM ZeLa
100X60
JT4-3H/5-5,5x19
T-PROFIL 40/52/2
(BLANK)
S-H04
FASSADE - LEGENDE:
BEKLEIDUNG: ALPOLIC A2, 4mm
BAUSTOFF KLASSE A2
FARBE: DE-XC0103-G15 Beige
FUGEN: 10mm
BEFESTIGUNG: Sichtbargenietet
VORHÄNGUNG: 114mm
SYSTEM UK: BWM - ATK 100 ZeLa Aluminium/Edelstahl
Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG: WÄRMEDÄMMUNG 60mm
TYP WLG-032
HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND: Stahlbeton-Außenschale



FASSADE - LEGENDE:	
BEKLEIDUNG:	ALPOLIC A2, 4mm BAUSTOFF KLASSE A2
FARBE:	DE-XC0103-G15 Beige
FUGEN:	10mm
BEFESTIGUNG:	Sichtbargenietet
VORHÄNGUNG:	184mm
SYSTEM UK:	BWM - ATK 100 ZeLa Aluminium/Edelstahl Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG:	WÄRMEDÄMMUNG 140mm TYP WLG-032 HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND:	Stahlbeton-Außenschale

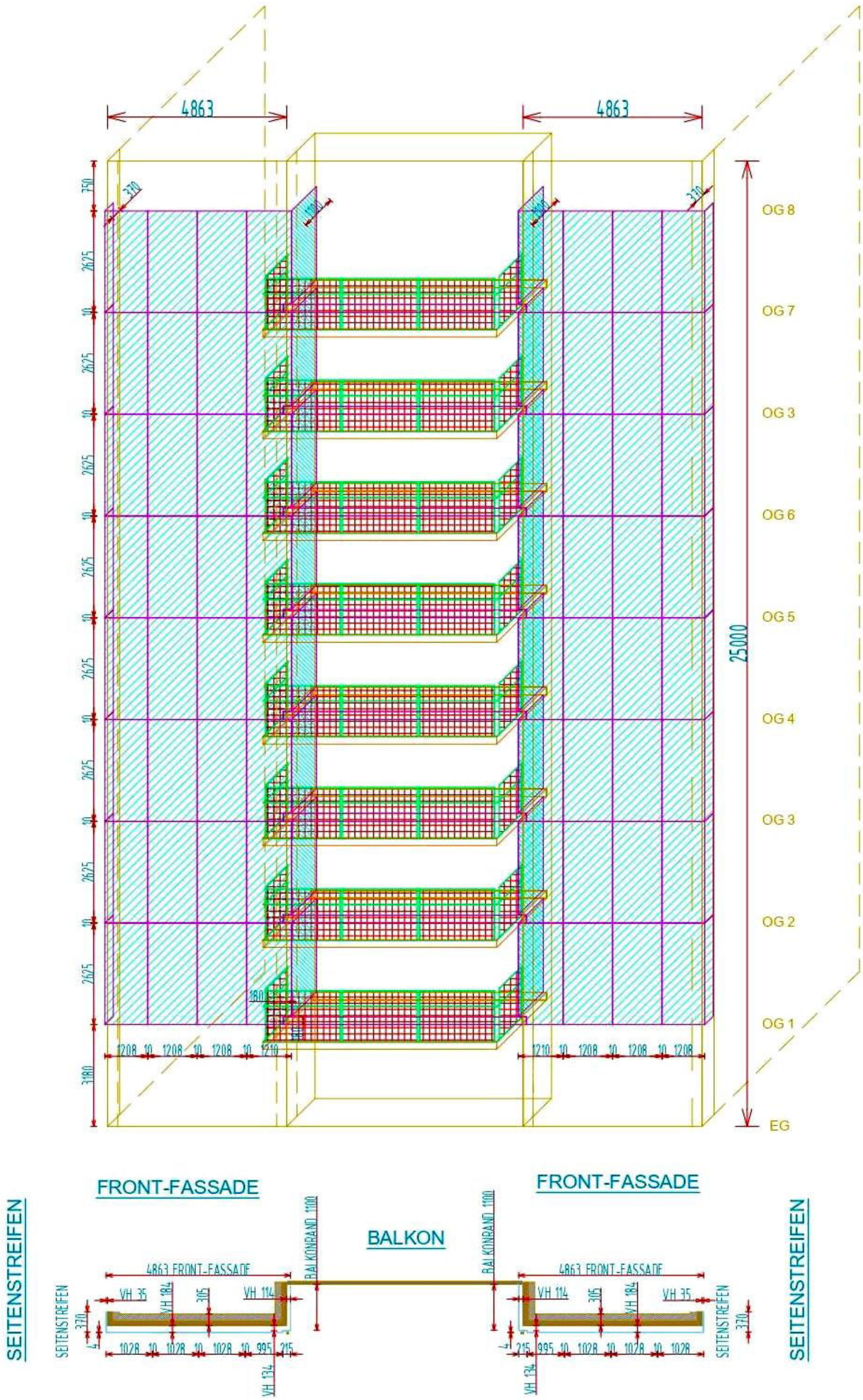
Author: Harikrishnan Ramanathan



FASSADE - LEGENDE:	
BEKLEIDUNG:	ALPOLIC A2, 4mm BAUSTOFF KLASSE A2
FARBE:	DE-XC0103-G15 Beige
FUGEN:	10mm
BEFESTIGUNG:	Sichtbargenietet
VORHÄNGUNG:	114mm
SYSTEM UK:	BWM - ATK 100 ZeLa Aluminium/Edelstahl Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG:	WÄRMEDÄMMUNG 60mm TYP WLG-032 HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND:	Stahlbeton-Außenschale

Author: Harikrishnan Ramanathan

Appendix B: Architectural drawings



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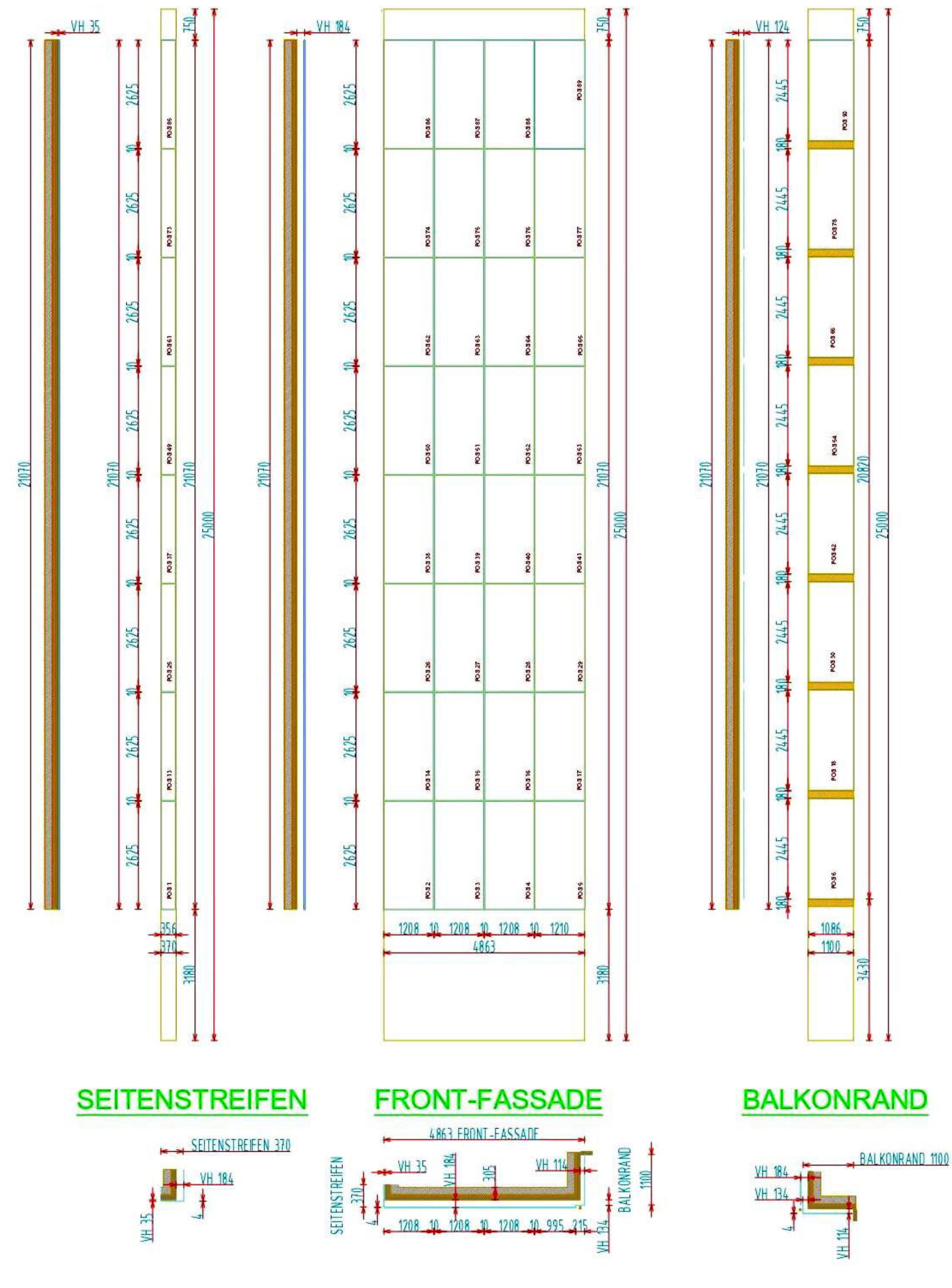
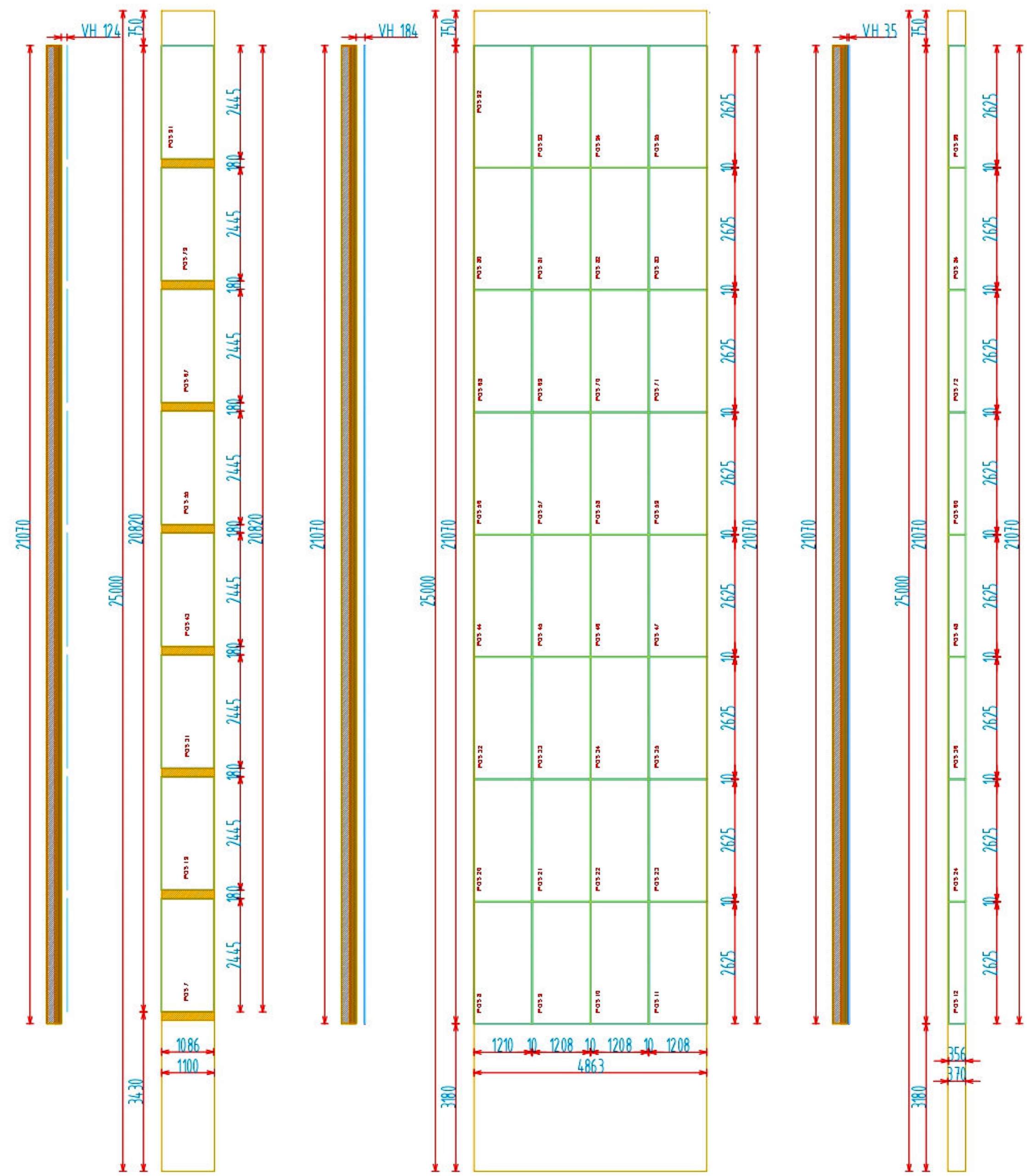
LINKS

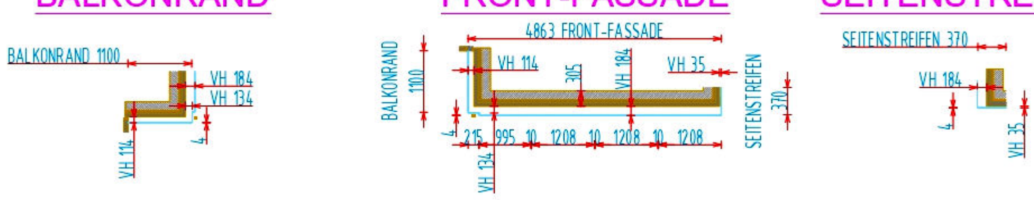


Author: Harikrishnan Ramanathan

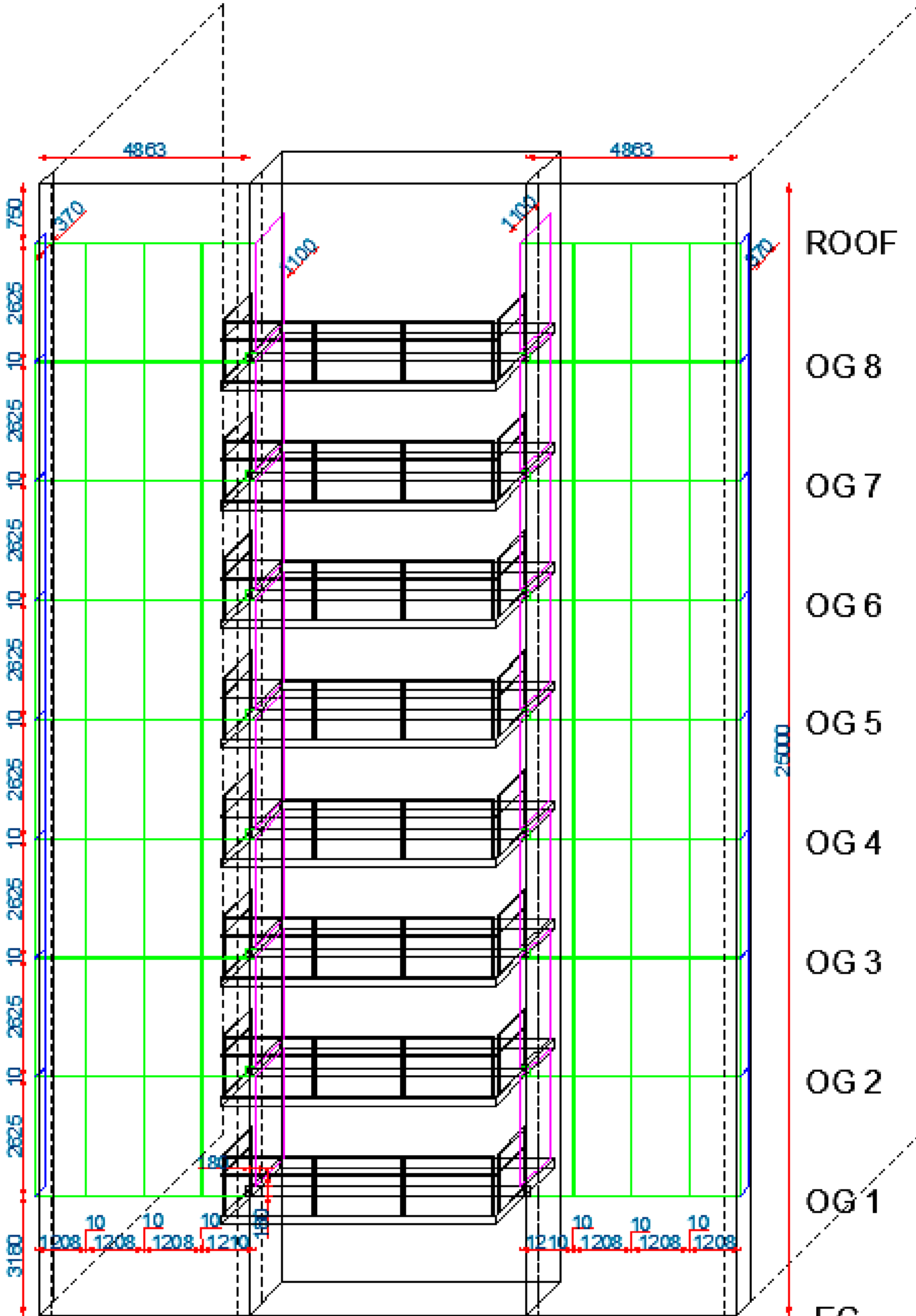
RECHTS



BALKONRAND FRONT-FASSADE SEITENSTREIFEN



Author: Harikrishnan Ramanathan



Detailed perspective view of south facade of the building

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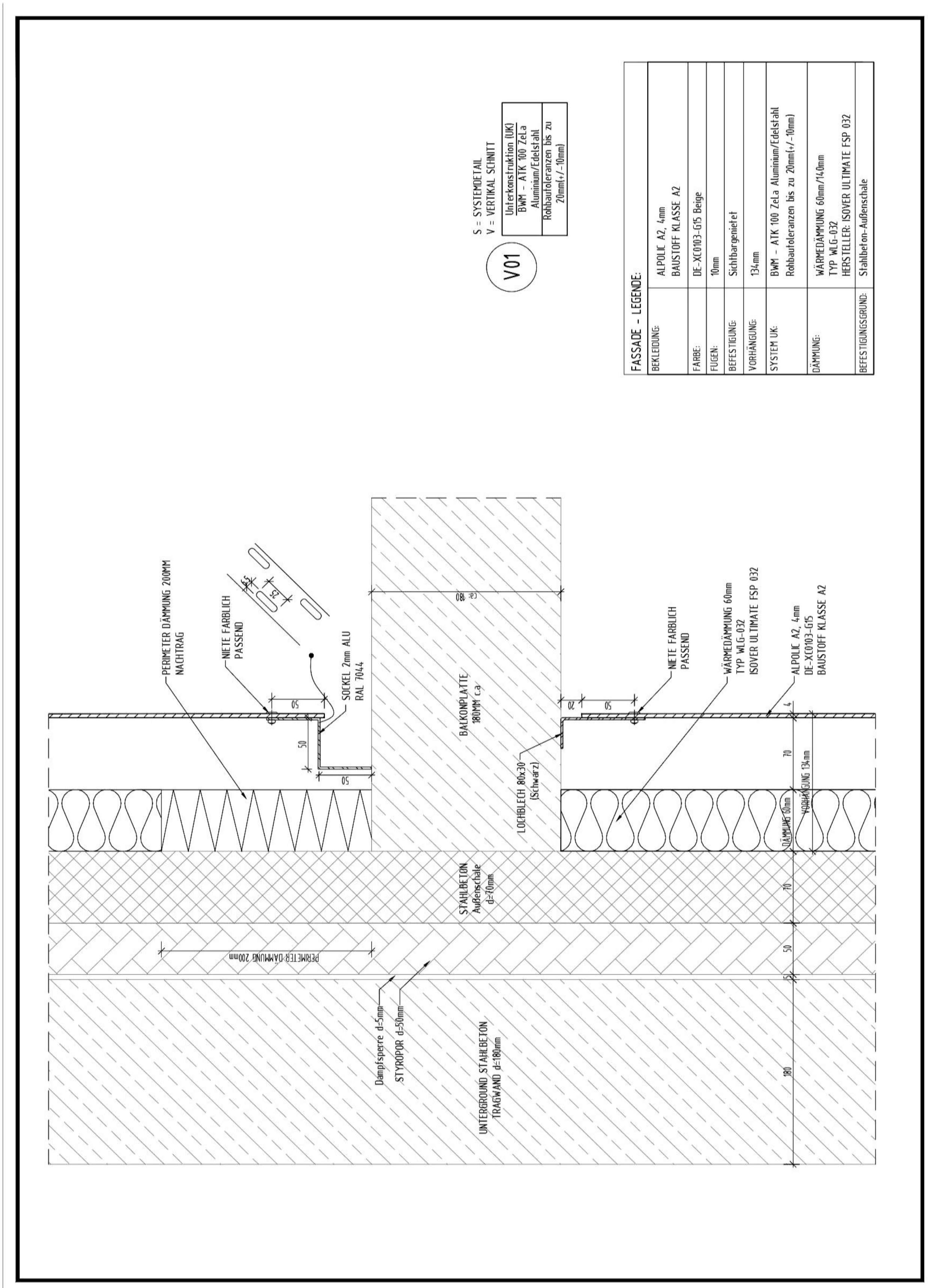
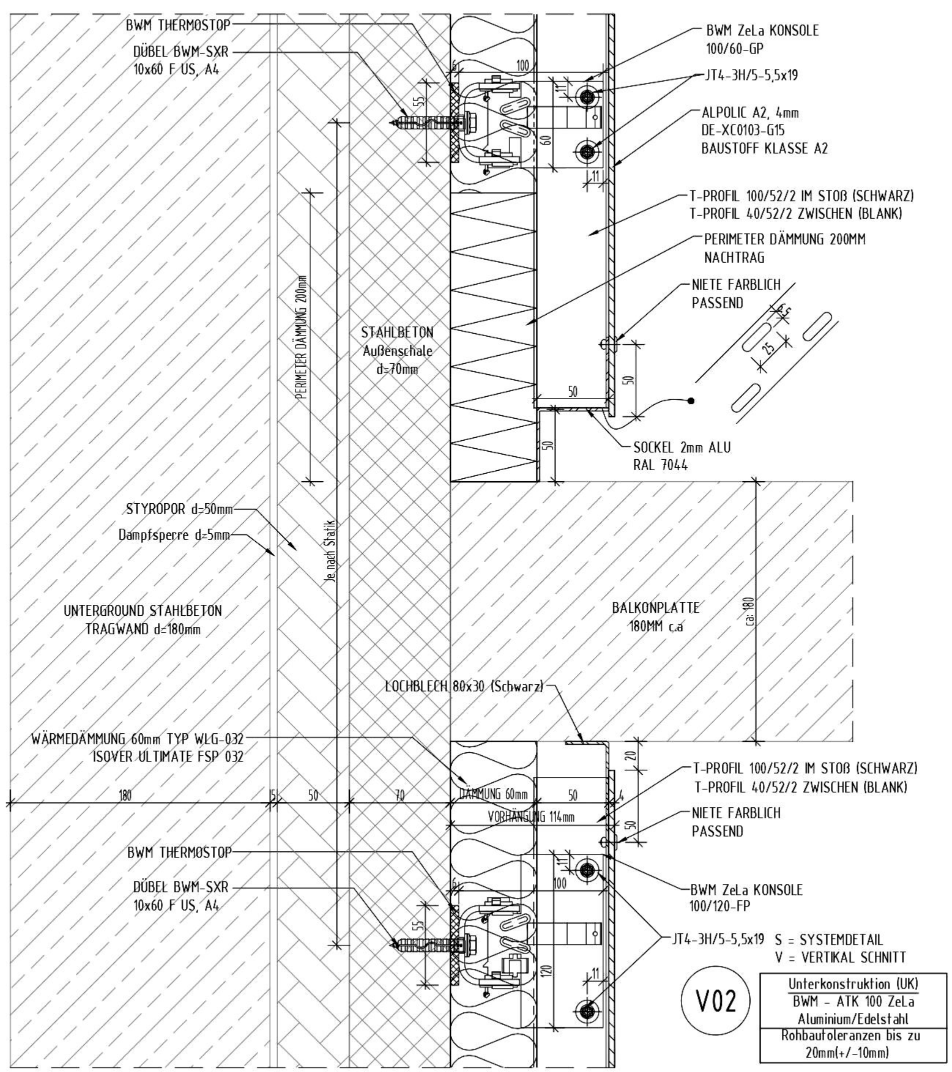
Appendix C: Corner parapet and critical details

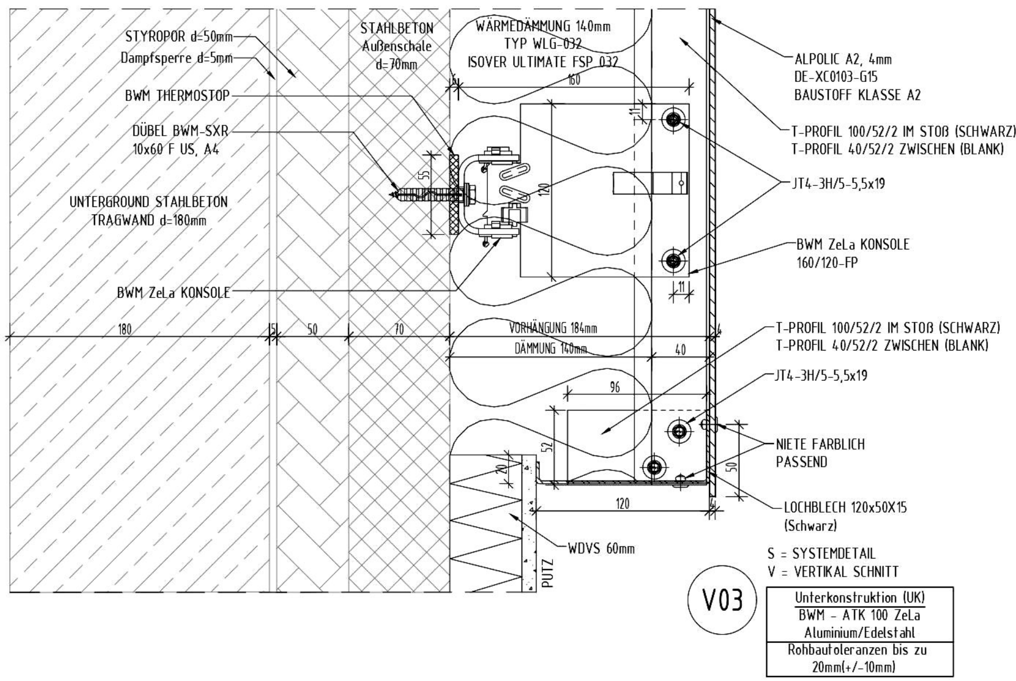


Author: Harikrishnan Ramanathan



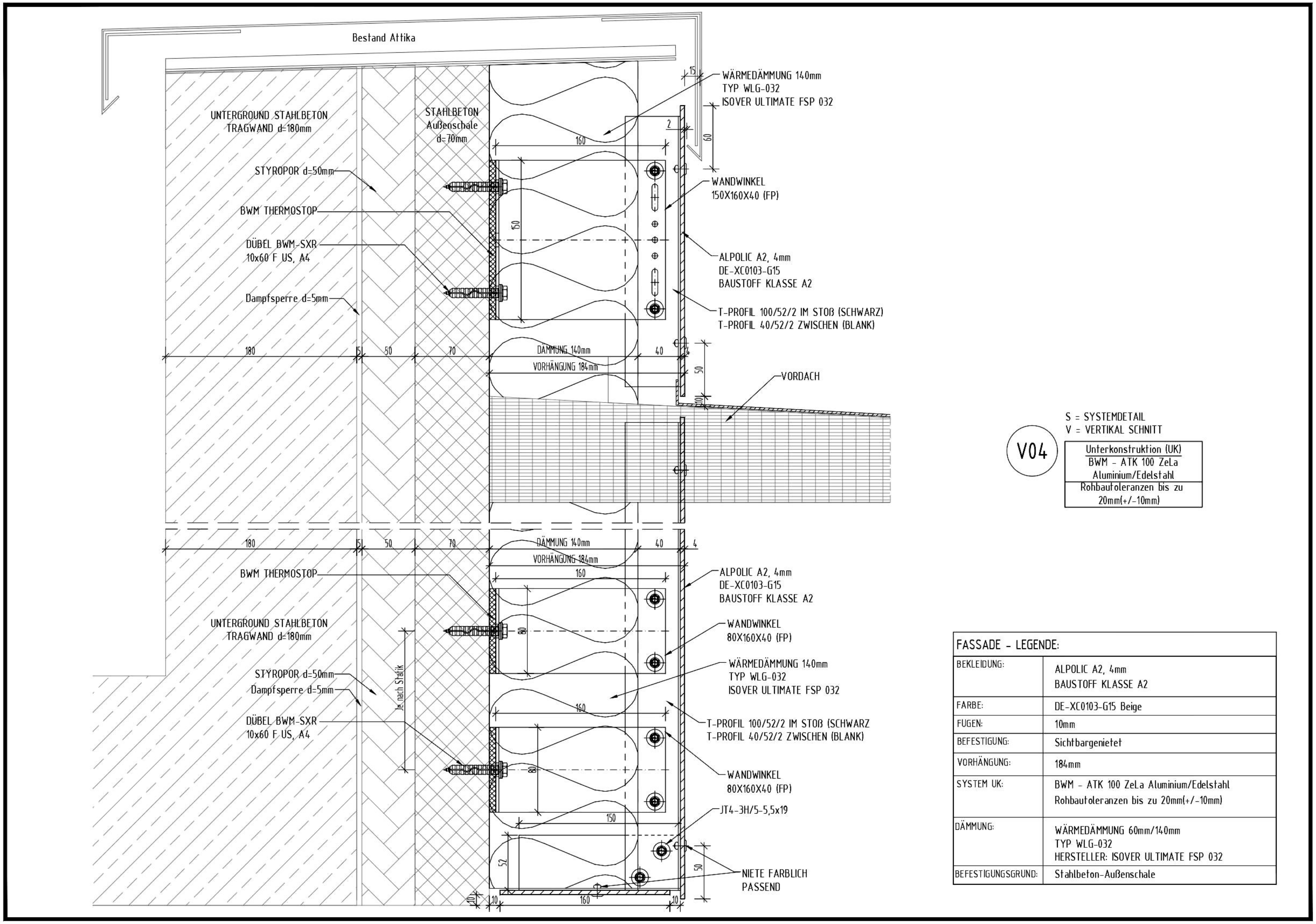
FASSADE - LEGENDE:	
BEKLEIDUNG:	ALPOLIC A2, 4mm BAUSTOFF KLASSE A2
FARBE:	DE-XC0103-G15 Beige
FUGEN:	10mm
BEFESTIGUNG:	Sichtbargenietet
VORHÄNGUNG:	114mm
SYSTEM UK:	BWM - ATK 100 ZeLa Aluminium/Edelstahl Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG:	WÄRMEDÄMMUNG 60mm/140mm TYP WLG-032 HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND:	Stahlbeton-Außenschale

Author: Harikrishnan Ramanathan

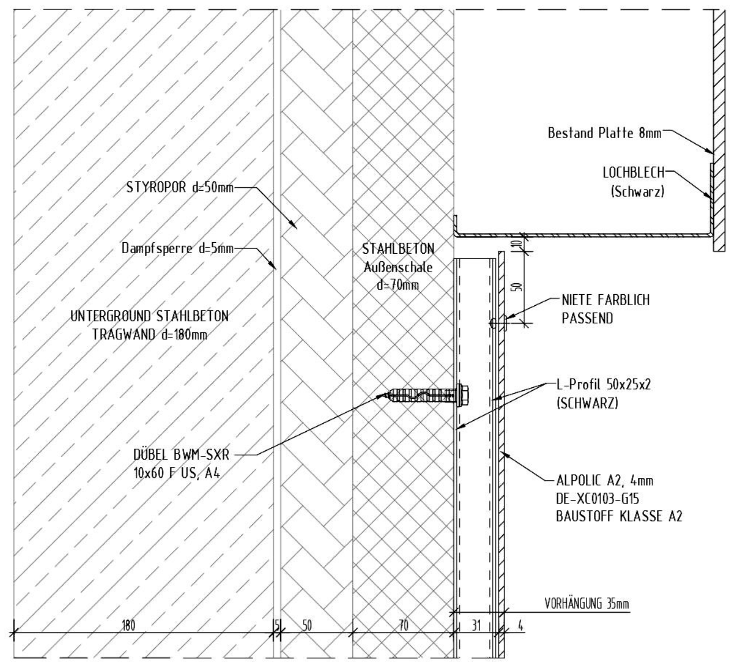


FASSADE - LEGENDE:	
BEKLEIDUNG:	ALPOLIC A2, 4mm BAUSTOFF KLASSE A2
FARBE:	DE-XC0103-G15 Beige
FUGEN:	10mm
BEFESTIGUNG:	Sichtbargenietet
VORHÄNGUNG:	184mm
SYSTEM UK:	BWM - ATK 100 ZeLa Aluminium/Edelstahl Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG:	WÄRMEDÄMMUNG 60mm/140mm TYP WLG-032 HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND:	Stahlbeton-Außenschale

Author: Harikrishnan Ramanathan



Author: Harikrishnan Ramanathan



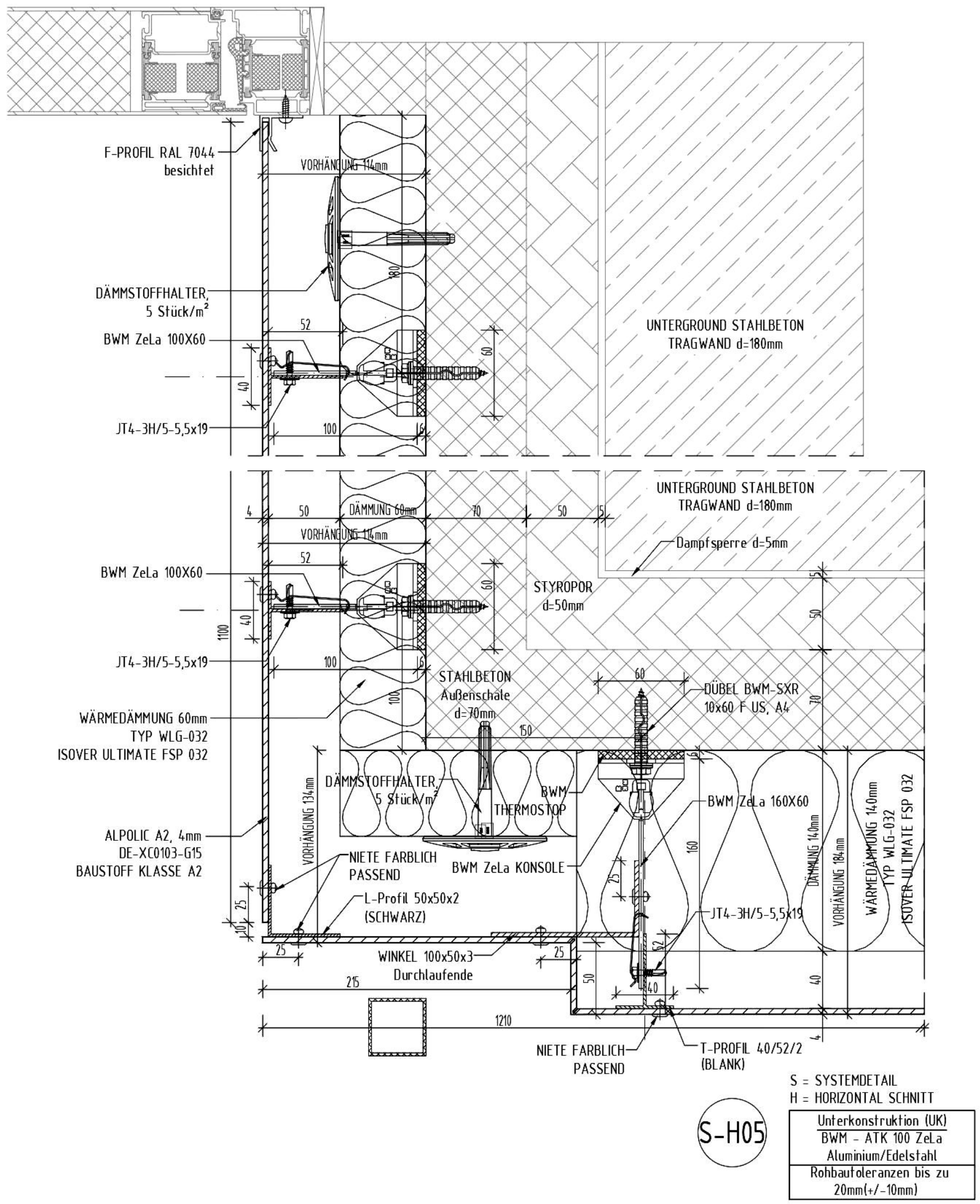
V05

S = SYSTEMDETAIL
V = VERTIKAL SCHNITT

Unterkonstruktion (UK) BWM - ATK 100 ZeLa Aluminium/Edelstahl
Rohbautoleranzen bis zu 20mm(+/-10mm)

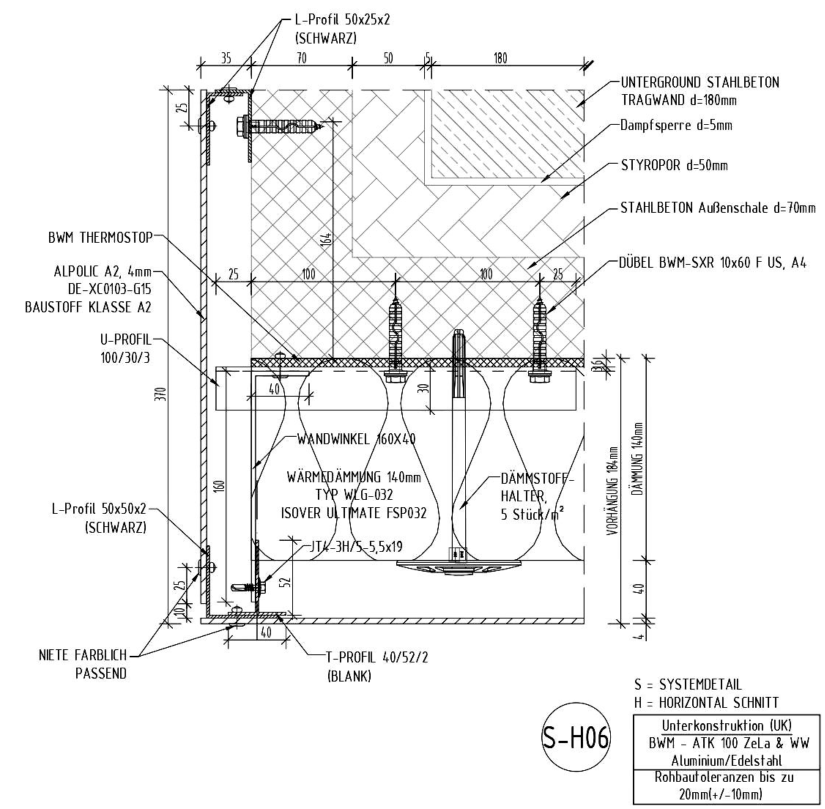
FASSADE - LEGENDE:	
BEKLEIDUNG:	ALPOLIC A2, 4mm BAUSTOFF KLASSE A2
FARBE:	DE-XC0103-G15 Beige
FUGEN:	10mm
BEFESTIGUNG:	Sichtbargenietet
VORHÄNGUNG:	35mm
SYSTEM UK:	BWM - ATK 100 ZeLa Aluminium/Edelstahl Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG:	WÄRMEDÄMMUNG 60mm/140mm TYP WLG-032 HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND:	Stahlbeton-Außenschale

Author: Harikrishnan Ramanathan



FASSADE - LEGENDE:	
BEKLEIDUNG:	ALPOLIC A2, 4mm BAUSTOFF KLASSE A2
FARBE:	DE-XC0103-G15 Beige
FUGEN:	10mm
BEFESTIGUNG:	Sichtbargenietet
VORHÄNGUNG:	114mm/184mm
SYSTEM UK:	BWM - ATK 100 ZeLa Aluminium/Edelstahl Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG:	WÄRMEDÄMMUNG 60mm/140mm TYP WLG-032 HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND:	Stahlbeton-Außenschale

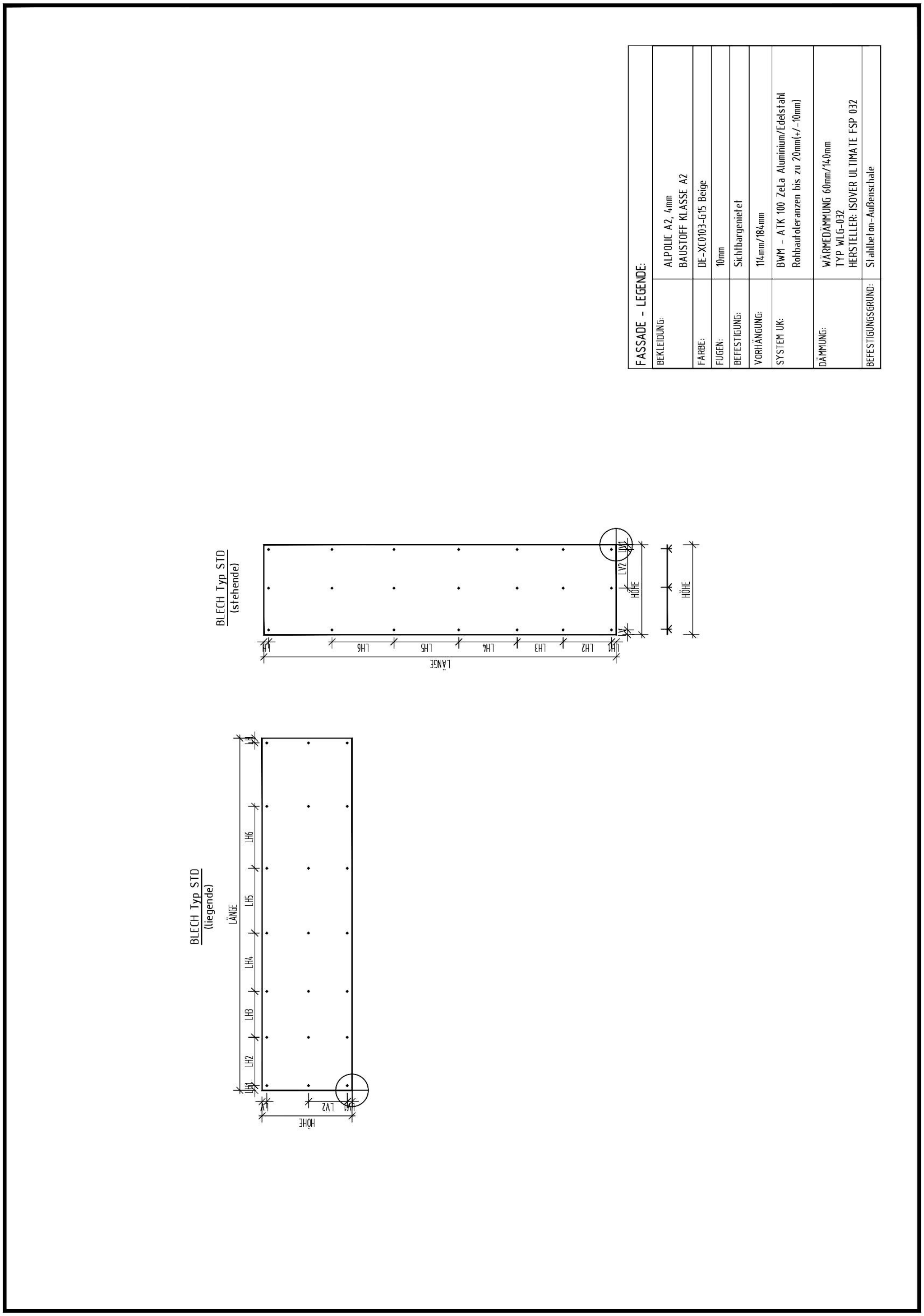
Author: Harikrishnan Ramanathan



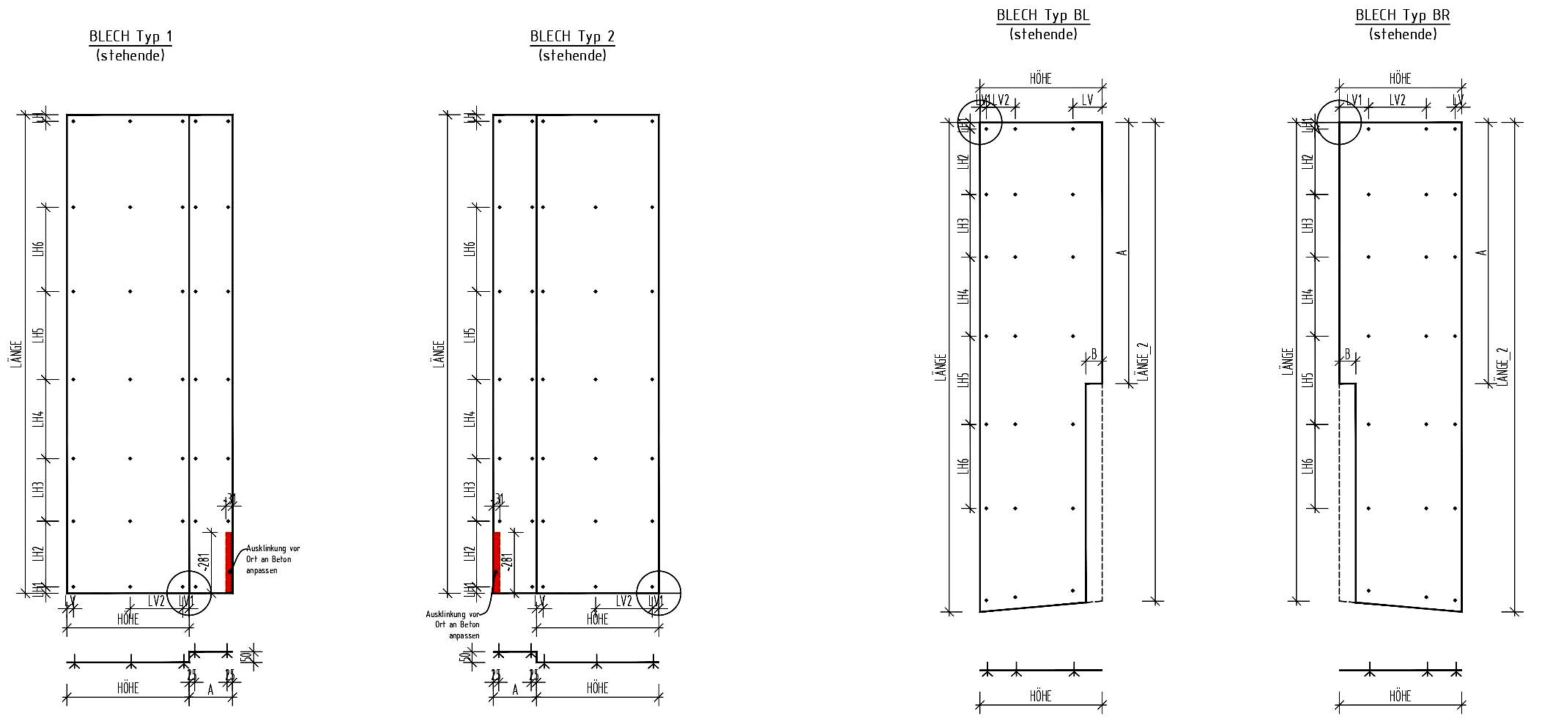
FASSADE - LEGENDE:	
BEKLEIDUNG:	ALPOLIC A2, 4mm BAUSTOFF KLASSE A2
FARBE:	DE-XC0103-G15 Beige
FUGEN:	10mm
BEFESTIGUNG:	Sichtbargenietet
VORHÄNGUNG:	184mm
SYSTEM UK:	BWM - ATK 100 ZeLa Aluminium/Edelstahl Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG:	WÄRMEDÄMMUNG 60mm/140mm TYP WLG-032 HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND:	Stahlbeton-Außenschale

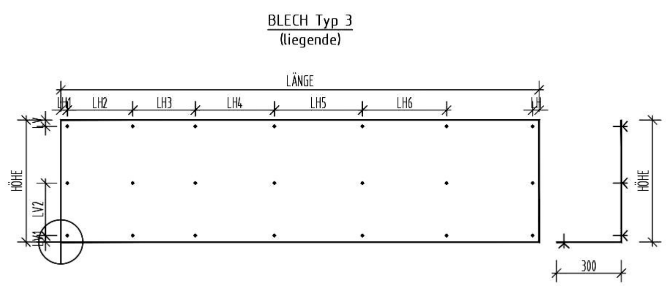
Author: Harikrishnan Ramanathan

Appendix D: Types of facade panels used in renovation project



Author: Harikrishnan Ramanathan





FASSADE - LEGENDE:	
BEKLEIDUNG:	ALPOLIC A2, 4mm BAUSTOFF KLASSE A2
FARBE:	DE-XC0103-G15 Beige
FUGEN:	10mm
BEFESTIGUNG:	Sichtbargenietet
VORHÄNGUNG:	114mm/184mm
SYSTEM UK:	BWM - ATK 100 ZeLa Aluminium/Edelstahl Rohbautoleranzen bis zu 20mm(+/-10mm)
DÄMMUNG:	WÄRMEDÄMMUNG 60mm/140mm TYP WLG-032 HERSTELLER: ISOVER ULTIMATE FSP 032
BEFESTIGUNGSGRUND:	Stahlbeton-Außenschale

Appendix E: Plate optimisation with SWIFTOPT V8.95

Parameter:

Schnittbreite mm : 10.0
Erste Schnittrichtung : frei
Komplexität : Level 4
Optimierungsart : intensiv
Kantenzuschlag mm : Keine

Plattenrand:

Links mm : 3
Rechts mm : 3
Unten mm : 3
Oben mm : 3

Platten:

Pos	Num.	Bedarf Stk	Länge mm	Breite mm	Di. mm	Material	Preis EUR/m2	Fläche m2	Struk
1	Alpolic	86	2650.0	1250.0	4.0	Alpolic	0.00	284.875	0

Plattenbedarf total m2 : 284.88
Plattenvolumen m3 : 1.140
Plattenkosten total EUR : 0.00
Schnittlänge total m : 685.25

Gesamtfläche Teile m2 : 260.30
Teilevolumen m3 : 1.041
Anzahl Teile total : 96
Kantenlänge total m : 698.944
Verschnitt total % : 8.63

Teile produziert:

Pos	Art.	Anzahl Stk	Länge mm	Breite mm	Di. mm	Material	Bezeichnung
1	POS 17	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
2	POS 26	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
3	POS 27	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
4	POS 14	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
5	POS 15	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
6	POS 16	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
7	POS 39	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
8	POS 40	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
9	POS 41	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
10	POS 28	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
11	POS 29	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
12	POS 38	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
13	POS 43	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
14	POS 55	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
15	POS 67	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
16	POS 7	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
17	POS 19	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
18	POS 31	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
19	POS 3	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
20	POS 4	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
21	POS 5	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
22	POS 79	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
23	POS 91	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
24	POS 2	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
25	POS 89	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
26	POS 6	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
27	POS 18	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
28	POS 86	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
29	POS 87	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
30	POS 88	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
31	POS 66	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
32	POS 78	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND

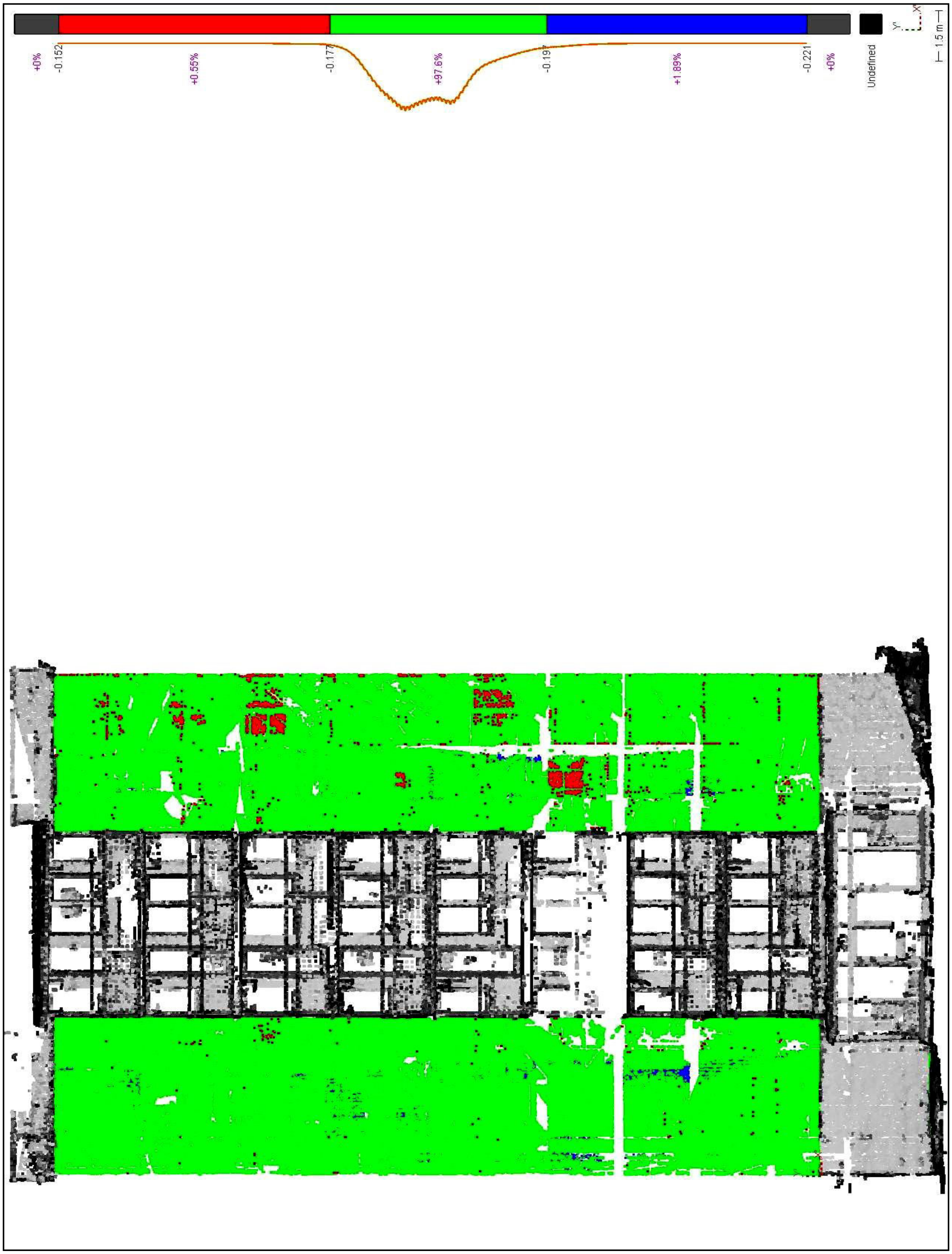
Seite 1

Pos	Art.	Anzahl Stk	Länge mm	Breite mm	Di. mm	Material	Bezeichnung
33	POS 90	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
34	POS 30	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
35	POS 42	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
36	POS 54	1	2445.0	1086.0	4.0	ALPOLIC	BALKONRAND
37	POS 53	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
38	POS 62	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
39	POS 63	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
40	POS 50	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
41	POS 51	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
42	POS 52	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
43	POS 75	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
44	POS 76	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
45	POS 77	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
46	POS 64	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
47	POS 65	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
48	POS 74	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
49	POS 20	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
50	POS 35	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
51	POS 34	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
52	POS 23	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
53	POS 22	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
54	POS 21	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
55	POS 46	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
56	POS 45	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
57	POS 44	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
58	POS 33	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
59	POS 32	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
60	POS 47	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
61	POS 37	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
62	POS 49	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
63	POS 61	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
64	POS 1	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
65	POS 13	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
66	POS 25	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
67	POS 10	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
68	POS 9	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
69	POS 8	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
70	POS 73	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
71	POS 85	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
72	POS 11	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
73	POS 92	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
74	POS 12	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
75	POS 24	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
76	POS 95	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
77	POS 94	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
78	POS 93	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
79	POS 72	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
80	POS 84	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
81	POS 96	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
82	POS 36	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
83	POS 48	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
84	POS 60	1	2625.0	356.0	4.0	ALPOLIC	SEITENSTREIFEN
85	POS 56	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE

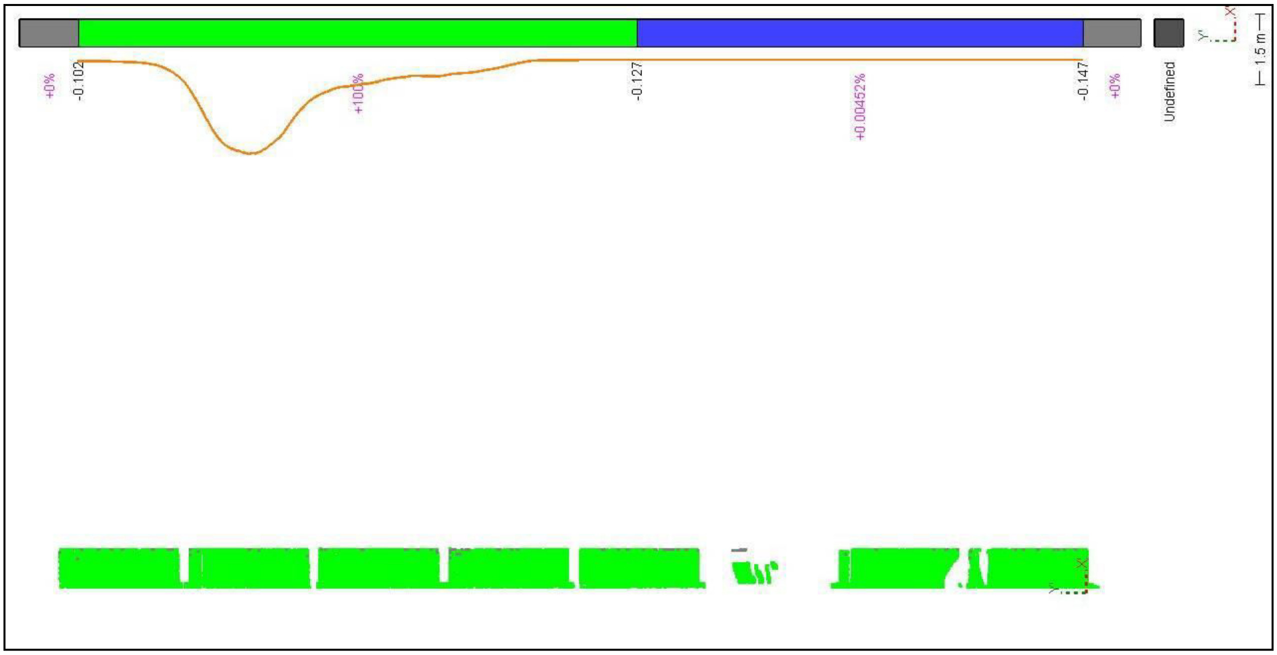
Pos	Art.	Anzahl Stk	Länge mm	Breite mm	Di. mm	Material	Bezeichnung
86	POS 71	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
87	POS 70	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
88	POS 59	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
89	POS 58	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
90	POS 57	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
91	POS 82	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
92	POS 81	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
93	POS 80	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
94	POS 69	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
95	POS 68	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE
96	POS 83	1	2625.0	1207.5	4.0	ALPOLIC	FRONT-FASSADE

Appendix F: Depth Analysis – 3D re-shaper

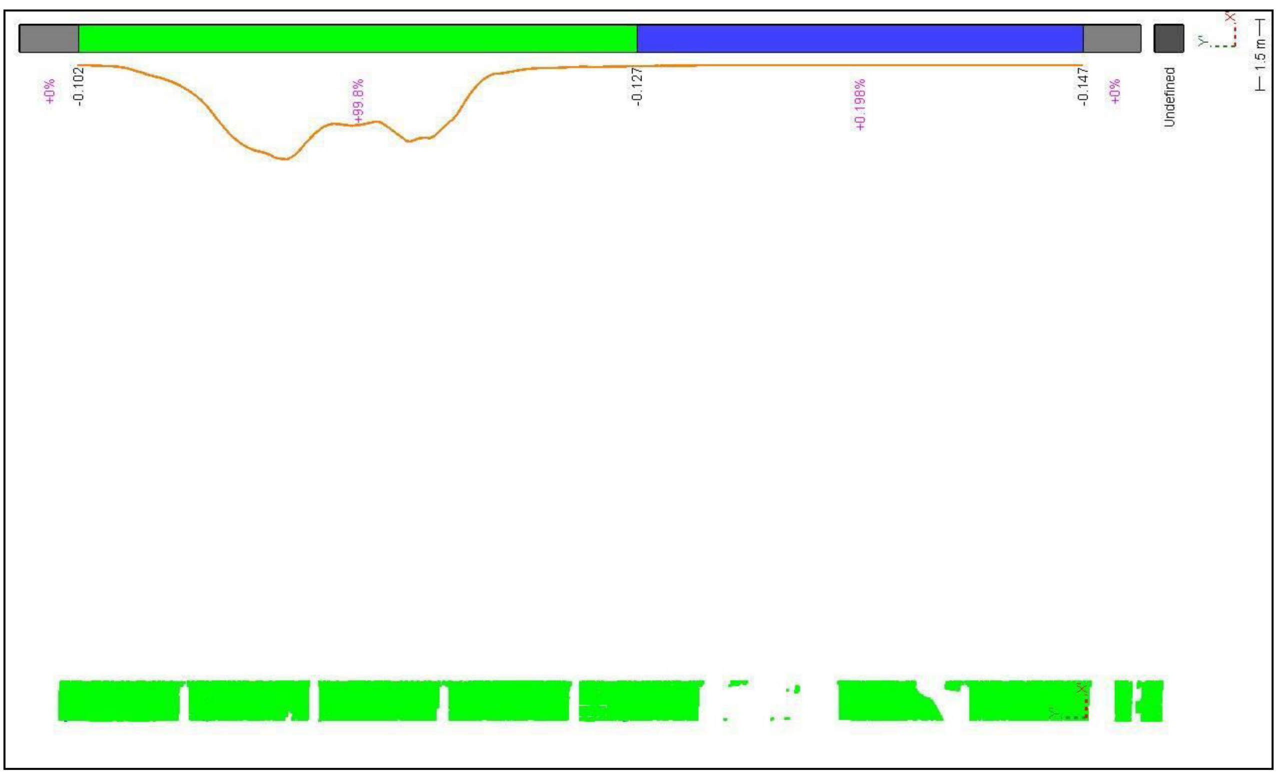
Front facade:



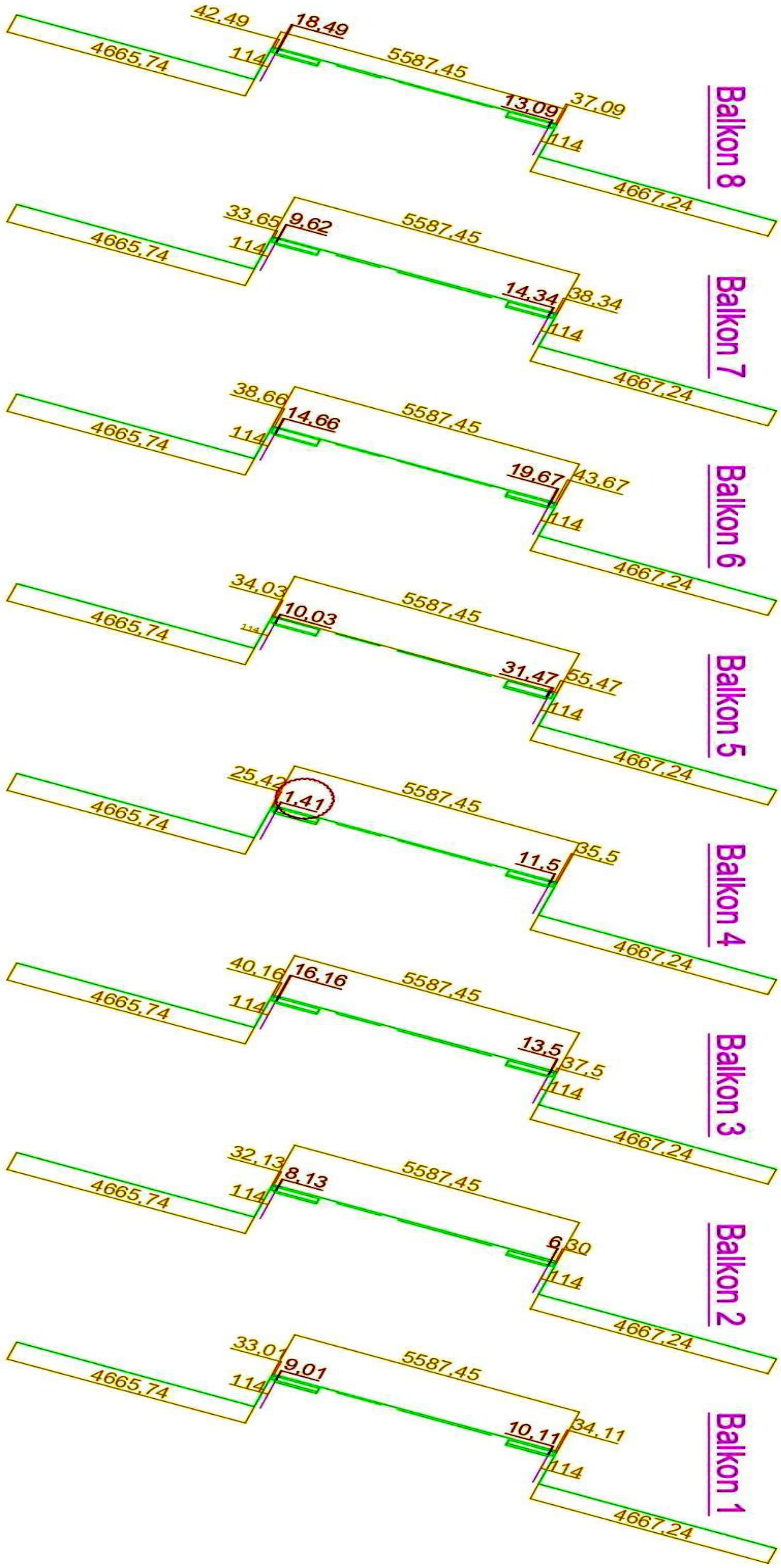
Balcony left side:



Balcony right side:

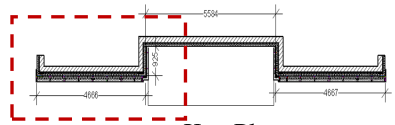


Appendix G: Check for Collision of facade panel in balcony

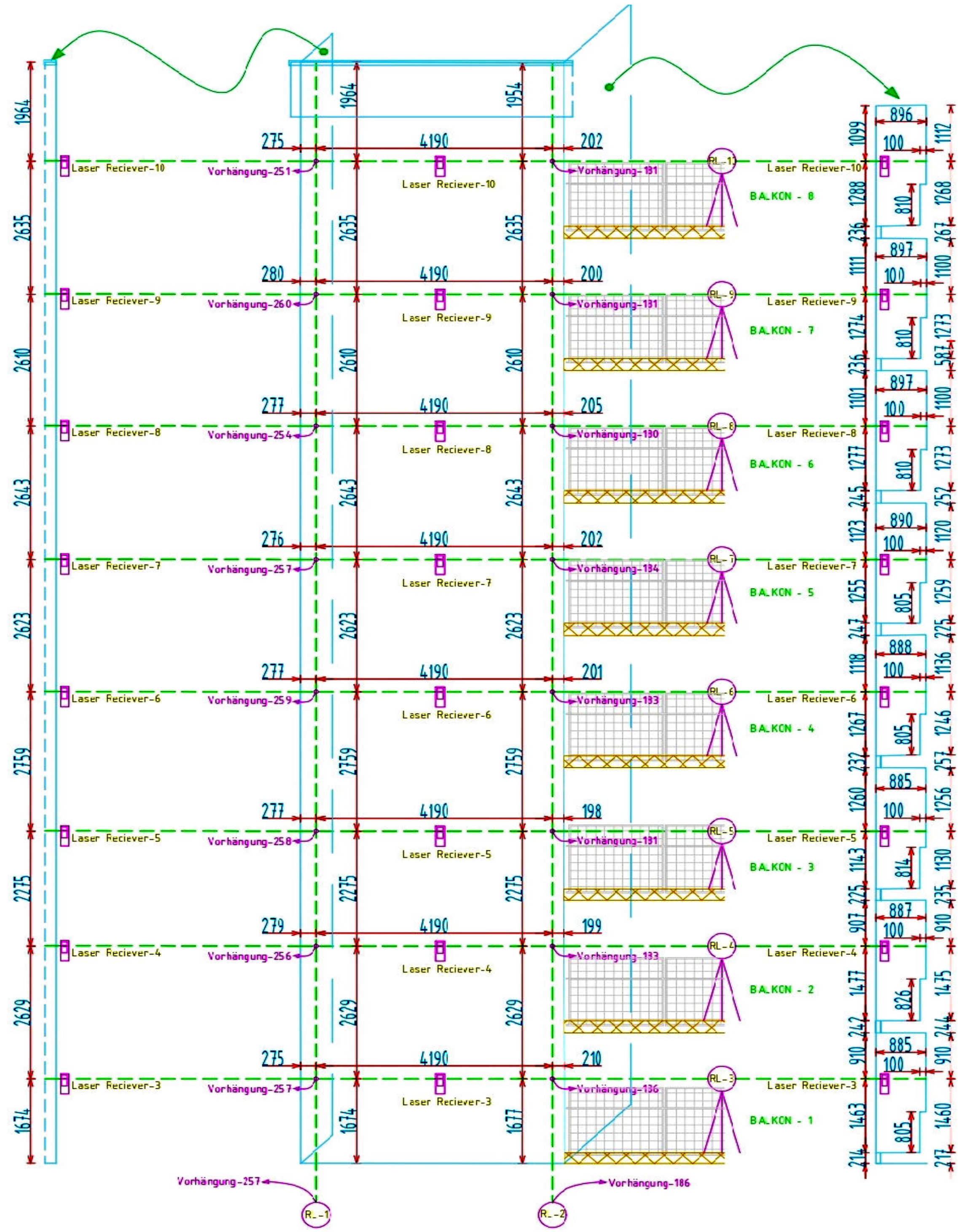


Author: Harikrishnan Ramanathan

Appendix H: Traditional surveying setup and meausurements



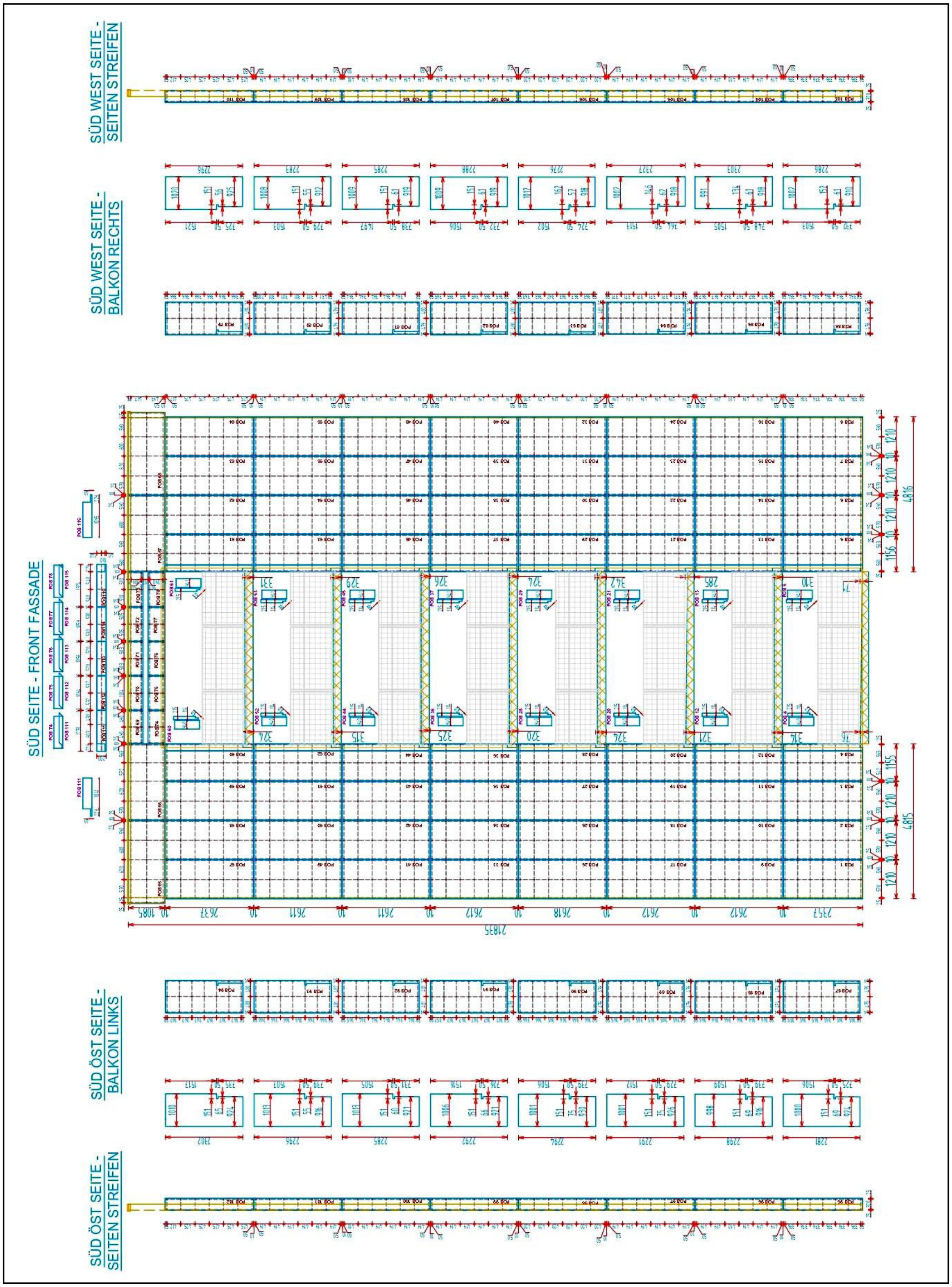
Key Plan



Front and balcony facade - left side

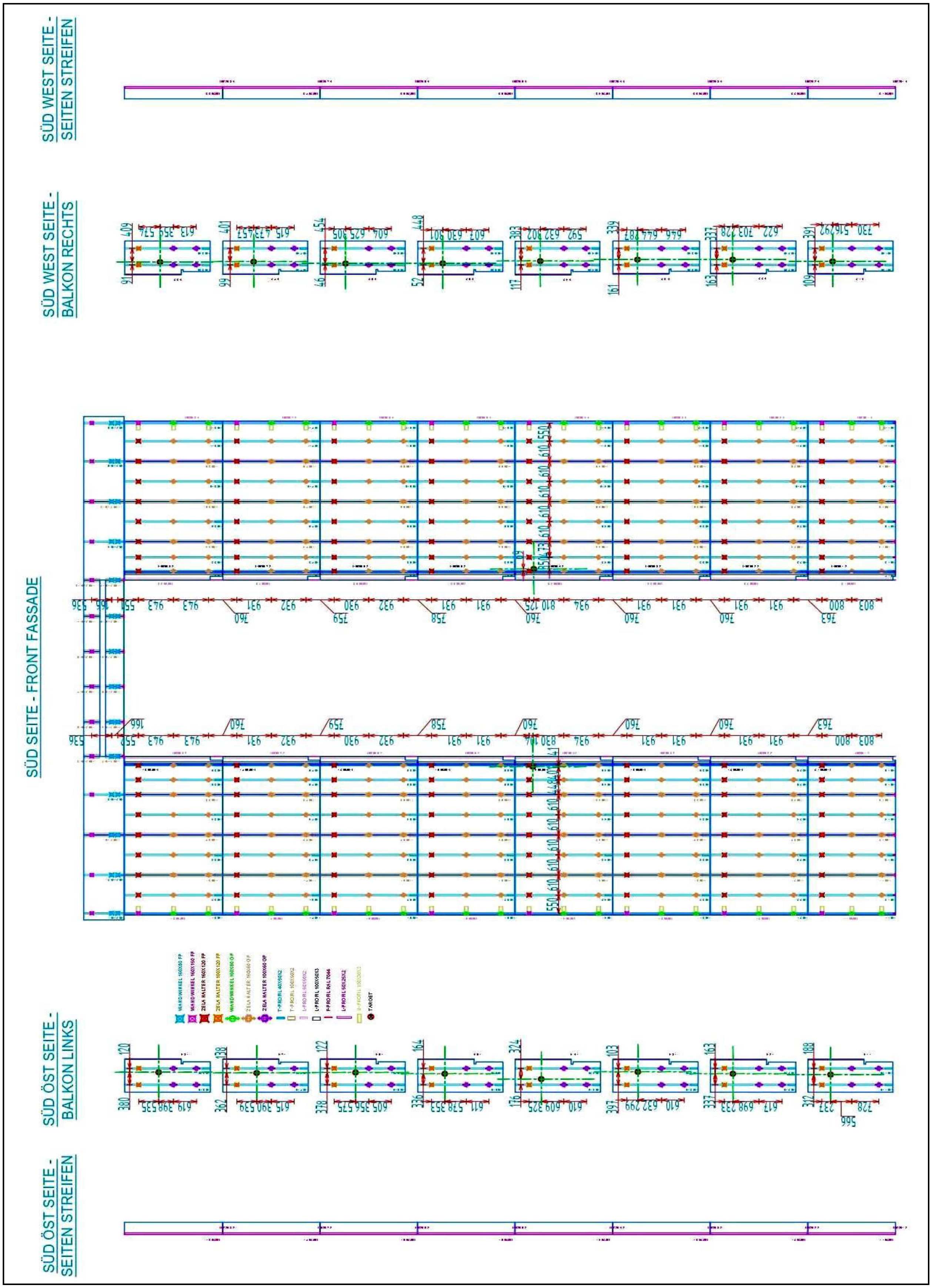
Author: Harikrishnan Ramanathan

Appendix I: Drawing for facade dimension and position



Author: Harikrishnan Ramanathan

Appendix J: Facade mounting plan with sub-construction details



Author: Harikrishnan Ramanathan

Appendix K: Excel for facade panel and drill hole dimensions

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 1	1	Alpolic	1064.0931	498.131	4	25	507.045	0	0	0	0	0	25	50	0	0	50	0	0	0	0
POS 2	1	Alpolic	2302.843	990.8807	4	50	367.166	367.17	367.17	367.166	367.17	0	50	25	470.5	0	25	0	50	0	0
POS 3	1	Alpolic	2612.0204	370	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	0	0	25	0	0	0	0
POS 4	1	Alpolic	2611.8219	370	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	0	0	25	0	0	0	0
POS 5	1	Alpolic	2612.0204	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 6	1	Alpolic	2357.049	1210	4	50	376.16	376.16	376.16	376.16	376.16	0	50	25	590	0	25	0	0	0	0
POS 7	1	Alpolic	2618.3573	940.78	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	562.5	0	25	0	50+215	0	0
POS 8	1	Alpolic	2611.1332	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 9	1	Alpolic	2611.8219	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 10	1	Alpolic	1056.107	498.131	4	25	503.055	0	0	0	0	0	25	50	0	0	50	0	0	0	0

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 11	1	Alpolic	2284.6677	1008.951	4	50	364.16	364.16	364.16	364.16	364.16	0	50	25	479.5	0	25	0	50	0	0
POS 12	1	Alpolic	2636.5776	1210	4	50	425	425	425	425	425	0	50	25	590	0	25	0	0	0	0
POS 13	1	Alpolic	2636.5776	1210	4	50	425	425	425	425	425	0	50	25	590	0	25	0	0	0	0
POS 14	1	Alpolic	2374.78	1084.82	4	25	570	620	572	563	0	0	25	50	492.5	0	75	0	0	0	0
POS 15	1	Alpolic	1030.7406	433.6119	4	25	490.37	0	0	0	0	0	25	50	0	0	75	0	0	0	0
POS 16	1	Alpolic	1064.0931	433.6119	4	25	507.045	0	0	0	0	0	25	50	0	0	75	0	0	0	0
POS 17	1	Alpolic	2636.5776	1210	4	50	425	425	425	425	425	0	50	25	590	0	25	0	0	0	0
POS 18	1	Alpolic	2636.5776	1210	4	50	425	425	425	425	425	0	50	25	590	0	25	0	0	0	0
POS 19	1	Alpolic	2575	1084.82	4	25	145	570	620	600	0	0	25	50	492.5	0	75	0	0	0	0
POS 20	1	Alpolic	2610.6157	370	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	0	0	25	0	0	0	0

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 21	1	Alpolic	2357.049	370	4	50	376.16	376.16	376.16	376.16	376.16	0	50	25	0	0	25	0	0	0	0
POS 22	1	Alpolic	2610.6157	370	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	0	0	25	0	0	0	0
POS 23	1	Alpolic	2302.2769	1010.048	4	50	367	367	367	367	367	0	50	25	480	0	25	0	0	0	0
POS 24	1	Alpolic	2612.0204	370	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	0	0	25	0	0	0	0
POS 25	1	Alpolic	2611.1332	370	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	0	0	25	0	0	0	0
POS 26	1	Alpolic	2612.425	370	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	0	0	25	0	0	0	0
POS 27	1	Alpolic	2611.1332	370	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	0	0	25	0	0	0	0
POS 28	1	Alpolic	2376.24	1084.82	4	25	543.24	593	600	0	0	0	25	50	492.5	0	75	0	0	0	0
POS 29	1	Alpolic	2575	1084.82	4	25	570	620	600	590	0	0	25	50	492.5	0	75	0	0	0	0
POS 30	1	Alpolic	2611.8219	370	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	0	0	25	0	0	0	0

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 31	1	Alpolic	2618.3573	370	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	0	0	25	0	0	0	0
POS 32	1	Alpolic	2291.1318	1001.072	4	50	365.166	365.17	365.17	365.166	365.17	0	50	25	475.5	0	25	0	0	0	0
POS 33	1	Alpolic	2285.3829	1012.71	4	50	364.16	364.16	364.16	364.16	364.16	0	50	25	481.5	0	25	0	0	0	0
POS 34	1	Alpolic	2636.5776	370	4	50	425	425	425	425	425	0	50	25	0	0	25	0	0	0	0
POS 35	1	Alpolic	2292.1341	1005.786	4	50	367	367	367	367	367	0	50	25	478	0	25	0	0	0	0
POS 36	1	Alpolic	2285.71	1001.621	4	50	364.33	364.33	364.33	364.33	364.33	0	50	25	476	0	25	0	50	0	0
POS 37	1	Alpolic	2357.049	370	4	50	376.16	376.16	376.16	376.16	376.16	0	50	25	0	0	25	0	0	0	0
POS 38	1	Alpolic	2612.425	370	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	0	0	25	0	0	0	0
POS 39	1	Alpolic	2297.9797	998.0426	4	50	366.33	366.33	366.33	366.33	366.33	0	50	25	474	0	25	0	0	0	0
POS 40	1	Alpolic	2636.5776	370	4	50	425	425	425	425	425	0	50	25	0	0	25	0	0	0	0

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 41	1	Alpolic	2294.4134	1001.152	4	50	365.66	365.66	365.66	365.66	365.66	0	50	25	475.5	0	25	0	0	0	0
POS 42	1	Alpolic	2295.9006	1012.71	4	50	366	366	366	366	366	0	50	25	481.5	0	25	0	0	0	0
POS 43	1	Alpolic	2281.2115	999.8472	4	50	365.33	365.33	365.33	365.33	365.33	0	50	25	475	0	25	0	0	0	0
POS 44	1	Alpolic	2618.3573	370	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	0	0	25	0	0	0	0
POS 45	1	Alpolic	2612.0204	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 46	1	Alpolic	2612.0204	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 47	1	Alpolic	2612.0204	940.78	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	562.5	0	25	0	50+215	0	0
POS 48	1	Alpolic	2612.425	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 49	1	Alpolic	2612.425	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 50	1	Alpolic	2612.0204	941.24	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	563	0	25	50+215	0	0	0

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 51	1	Alpolic	2618.3573	1210	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	590	0	25	0	0	0	0
POS 52	1	Alpolic	2618.3573	1210	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	590	0	25	0	0	0	0
POS 53	1	Alpolic	2618.3573	1210	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	590	0	25	0	0	0	0
POS 54	1	Alpolic	2612.0204	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 55	1	Alpolic	2612.0204	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 56	1	Alpolic	2612.0204	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 57	1	Alpolic	2612.425	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 58	1	Alpolic	2357.049	940.78	4	50	376.16	376.16	376.16	376.16	420.83	0	50	25	562.5	0	25	0	50+215	0	0
POS 59	1	Alpolic	2357.049	941.24	4	50	376.16	376.16	376.16	376.16	376.16	0	50	25	563	0	25	50+215	0	0	0
POS 60	1	Alpolic	2357.049	1210	4	50	376.16	376.16	376.16	376.16	376.16	0	50	25	590	0	25	0	0	0	0

POS	POS 61	POS 62	POS 63	POS 64	POS 65	POS 66	POS 67	POS 68	POS 69	POS 70
Count	1	1	1	1	1	1	1	1	1	1
Name	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic
Length	2357.049	2357.049	2357.049	2612.425	2612.425	2612.425	2357.049	2612.425	2612.425	2610.6157
Breadth	1210	1210	1210	1210	940.78	941.24	1210	1210	1210	1210
Thickness	4	4	4	4	4	4	4	4	4	4
LH1	50	50	50	50	50	50	50	50	50	50
LH2	376.16	376.16	376.16	418.66	418.66	418.66	376.16	418.66	418.66	418.5
LH3	376.16	376.16	376.16	418.66	418.66	418.66	376.16	418.66	418.66	418.5
LH4	376.16	376.16	376.16	418.66	418.66	418.66	376.16	418.66	418.66	418.5
LH5	376.16	376.16	376.16	418.66	418.66	418.66	376.16	418.66	418.66	418.5
LH6	376.16	376.16	376.16	418.66	418.66	418.66	376.16	418.66	418.66	418.5
LH7	0	0	0	0	0	0	0	0	0	0
LH	50	50	50	50	50	50	50	50	50	50
LV1	25	25	25	25	25	25	25	25	25	25
LV2	590	590	590	590	562.5	563	590	590	590	590
LV3	0	0	0	0	0	0	0	0	0	0
LV	25	25	25	25	25	25	25	25	25	25
LINKS	0	0	0	0	0	50+215	0	0	0	0
RECHTS	0	0	0	0	50+215	0	0	0	0	0
OBEN	0	0	0	0	0	0	0	0	0	0
UNTEN	0	0	0	0	0	0	0	0	0	0

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 71	1	Alpolic	2610.6157	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 72	1	Alpolic	2610.6157	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 73	1	Alpolic	2610.6157	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 74	1	Alpolic	2610.6157	940.78	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	562.5	0	25	0	50+215	0	0
POS 75	1	Alpolic	2610.6157	941.24	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	563	0	25	50+215	0	0	0
POS 76	1	Alpolic	2611.1332	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 77	1	Alpolic	2611.1332	941.24	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	563	0	25	50+215	0	0	0
POS 78	1	Alpolic	2611.1332	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 79	1	Alpolic	2611.1332	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 80	1	Alpolic	2611.1332	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 81	1	Alpolic	2611.1332	940.78	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	562.5	0	25	0	50+215	0	0
POS 82	1	Alpolic	2610.6157	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 83	1	Alpolic	2618.3573	1210	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	590	0	25	0	50	0	0
POS 84	1	Alpolic	2611.8219	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 85	1	Alpolic	2611.8219	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 86	1	Alpolic	2618.3573	941.24	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	563	0	25	50+215	0	0	0
POS 87	1	Alpolic	2618.3573	1210	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	590	0	25	0	50	0	0
POS 88	1	Alpolic	2618.3573	1210	4	50	419.66	419.66	419.66	419.66	419.66	0	50	25	590	0	25	0	50	0	0
POS 89	1	Alpolic	2611.8219	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0
POS 90	1	Alpolic	2611.8219	1210	4	50	418.66	418.66	418.66	418.66	418.66	0	50	25	590	0	25	0	0	0	0

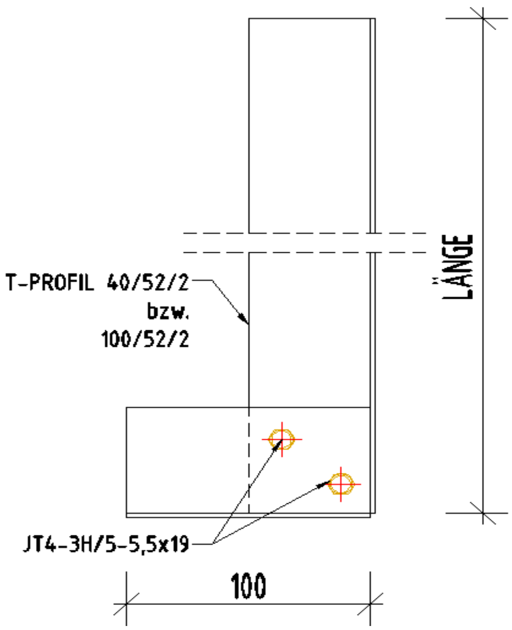
POS 100	POS 99	POS 98	POS 97	POS 96	POS 95	POS 94	POS 93	POS 92	POS 91	POS
1	1	1	1	1	1	1	1	1	1	Count
Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Name
1059.266	1324	1059	1056	1064	1270	2611.8219	2611.8219	2611.8219	2610.6157	Length
498.131	280	280	280	280	280	1210	941.24	940.78	1210	Breadth
4	4	4	4	4	4	4	4	4	4	Thickness
25	542	530	528	532	832	50	50	50	50	LH1
504.635	0	0	0	0	0	418.66	418.66	418.66	418.5	LH2
0	0	0	0	0	0	418.66	418.66	418.66	418.5	LH3
0	0	0	0	0	0	418.66	418.66	418.66	418.5	LH4
0	0	0	0	0	0	418.66	418.66	418.66	418.5	LH5
0	0	0	0	0	0	418.66	418.66	418.66	418.5	LH6
0	0	0	0	0	0	0	0	0	0	LH7
25	0	0	0	0	0	50	50	50	50	LH
50	140	140	140	140	140	25	25	25	25	LV1
0	0	0	0	0	0	590	563	562.5	590	LV2
0	0	0	0	0	0	0	0	0	0	LV3
50	0	0	0	0	0	25	25	25	25	LV
0	0	0	0	0	0	0	50+215	0	0	LINKS
0	0	0	0	0	0	0	0	50+215	0	RECHTS
0	0	0	0	0	0	0	0	0	0	OBEN
0	0	0	0	0	0	0	0	0	0	UNTEN

POS 110	POS 109	POS 108	POS 107	POS 106	POS 105	POS 104	POS 103	POS 102	POS 101	POS
1	1	1	1	1	1	1	1	1	1	Count
Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Alpolic	Name
1056.107	2282.5786	2296.0249	2326.679	2276.3092	2287.8957	1085.3133	1030.7406	1085.3133	1059.266	Length
433.6119	1008.383	1020.47	1001.96	1012.073	1009.169	498.131	498.131	433.6119	433.6119	Breadth
4	4	4	4	4	4	4	4	4	4	Thickness
25	50	50	50	50	50	25	25	25	25	LH1
503.055	380.5	366	371.166	362.66	364.66	517.65	490.37	517.65	504.635	LH2
0	380.5	366	371.17	362.66	364.66	0	0	0	0	LH3
0	380.5	366	371.17	362.66	364.66	0	0	0	0	LH4
0	380.5	366	371.166	362.66	364.66	0	0	0	0	LH5
0	380.5	366	371.17	362.66	364.66	0	0	0	0	LH6
0	0	0	0	0	0	0	0	0	0	LH7
25	50	50	50	50	50	25	25	25	25	LH
50	25	25	25	25	25	50	50	50	50	LV1
0	479	485	476	481	479.5	0	0	0	0	LV2
0	0	0	0	0	0	0	0	0	0	LV3
75	25	25	25	25	25	50	50	75	75	LV
0	0	0	0	0	0	0	0	0	0	LINKS
0	50	50	50	50	50	0	0	0	0	RECHTS
0	0	0	0	0	0	0	0	0	0	OBEN
0	0	0	0	0	0	0	0	0	0	UNTEN

POS	Count	Name	Length	Breadth	Thickness	LH1	LH2	LH3	LH4	LH5	LH6	LH7	LH	LV1	LV2	LV3	LV	LINKS	RECHTS	OBEN	UNTEN
POS 111	1	Alpolic	2636.5776	1210	4	50	425	425	425	425	425	0	50	25	590	0	25	0	0	0	0
POS 112	1	Alpolic	2636.5776	940.78	4	50	425	425	425	425	425	0	50	25	562.5	0	25	0	50+215	0	0
POS 113	1	Alpolic	2636.5776	941.24	4	50	425	425	425	425	425	0	50	25	563	0	25	0	0	50+215	0
POS 114	1	Alpolic	2611.1332	1210	4	50	418.5	418.5	418.5	418.5	418.5	0	50	25	590	0	25	0	0	0	0
POS 115	1	Alpolic	2636.5776	1210	4	50	425	425	425	425	425	0	50	25	590	0	25	0	0	0	0

Appendix L: Excel for quantity estimation of sub-construction

Type	Wall bracket	Symbol	Quantity	Screws	Per bracket	Quantity	Dowel	Per bracket	Quantity
1	ZeLa FP 100/120	F1	10	JT4-3H/5,5x19	2	20	SXR 10x60 F US	1	10
2	FP 80/150/40	F2	22	JT4-3H/5,5x19	2	44	SXR 10x60 F US	2	44
3	ZeLa FP 160/120	FP	144	JT4-3H/5,5x19	2	288	SXR 10x60 F US	1	144
4	ZeLa GP 100/60	G1	20	JT4-3H/5,5x19	2	40	SXR 10x60 F US	1	20
5	GP 80/80/40	G2	44	JT4-3H/5,5x19	2	88	SXR 10x60 F US	1	44
6	ZeLa GP 160/60	GP	288	JT4-3H/5,5x19	2	576	SXR 10x60 F US	1	288
					JT43H/5,5 x19:	**1056**		SXR 10x60 F US:	**550**



Foot + 100 T- Profile 40/52/2

Foot + 100 T- Profile 100/52/2

Type	Profile	Position	Quantity	Length	Unten	Oben
1	L100/50/3	L20	2	2575	-	-
2	L100/50/3	L21	2	2603	-	-
3	L100/50/3	L22	2	2598	-	-
4	L100/50/3	L23	2	2615	-	-
5	L100/50/3	L24	2	2600	-	-
6	L100/50/3	L25	2	2600	-	-
7	L100/50/3	L26	2	2602	-	-
8	L100/50/3	L27	2	2604	-	-
9	L50/25/2	L01	4	2575	-	-
10	L50/25/2	L02	4	2603	-	-
11	L50/25/2	L03	4	2598	-	-
12	L50/25/2	L04	4	2615	-	-
13	L50/25/2	L05	4	2600	-	-
14	L50/25/2	L06	4	2600	-	-
15	L50/25/2	L07	4	2602	-	-
16	L50/25/2	L08	4	2604	-	-
17	L50/50/2	L10	2	2575	-	-
18	L50/50/2	L11	2	2603	-	-
19	L50/50/2	L12	2	2598	-	-
20	L50/50/2	L13	2	2615	-	-
21	L50/50/2	L14	2	2600	-	-
22	L50/50/2	L15	2	2600	-	-
23	L50/50/2	L16	2	2602	-	-
24	L50/50/2	L17	2	2604	-	-
25	L50/50/2	L30	2	2295	-	-
26	L50/50/2	L31	2	2310	-	-
27	L50/50/2	L32	2	2304	-	-
28	L50/50/2	L33	2	2314	-	-
29	L50/50/2	L34	2	2305	-	-
30	L50/50/2	L35	2	2306	-	-
31	L50/50/2	L36	2	2308	-	-
32	L50/50/2	L37	2	2306	-	-
33	T-Profil 100/52/2	T01	6	2575	Foot +100	-
34	T-Profil 100/52/2	T02	6	2603	-	-
35	T-Profil 100/52/2	T03	6	2598	-	-
36	T-Profil 100/52/2	T04	6	2615	-	-
37	T-Profil 100/52/2	T05	6	2600	-	-
38	T-Profil 100/52/2	T06	6	2600	-	-
39	T-Profil 100/52/2	T07	6	2602	-	-
40	T-Profil 100/52/2	T08	6	2604	-	-
41	T-Profil 100/52/2	T09	2	920	-	-

Type	Profile	Position	Quantity	Length	Unten	Oben
42	T-Profil 40/52/2	T31	12	2575	Foot +100	-
43	T-Profil 40/52/2	T32	12	2603	-	-
44	T-Profil 40/52/2	T33	12	2598	-	-
45	T-Profil 40/52/2	T34	12	2615	-	-
46	T-Profil 40/52/2	T35	12	2600	-	-
47	T-Profil 40/52/2	T36	12	2600	-	-
48	T-Profil 40/52/2	T37	12	2602	-	-
49	T-Profil 40/52/2	T38	12	2604	-	-
50	T-Profil 40/52/2	T39	16	920	-	-
51	T-Profil 40/52/2	T40	1	2292	-	-
52	T-Profil 40/52/2	T41	1	2285	-	-
53	T-Profil 40/52/2	T42	1	2296	-	-
54	T-Profil 40/52/2	T43	1	2303	-	-
55	T-Profil 40/52/2	T44	1	2307	-	-
56	T-Profil 40/52/2	T45	1	2303	-	-
57	T-Profil 40/52/2	T46	1	2307	-	-
58	T-Profil 40/52/2	T47	1	2312	-	-
59	T-Profil 40/52/2	T48	1	2301	-	-
60	T-Profil 40/52/2	T49	1	2294	-	-
61	T-Profil 40/52/2	T50	1	2283	-	-
62	T-Profil 40/52/2	T51	1	2298	-	-
63	T-Profil 40/52/2	T52	1	2312	-	-
64	T-Profil 40/52/2	T53	1	2305	-	-
65	T-Profil 40/52/2	T54	1	2293	-	-
66	T-Profil 40/52/2	T55	1	2308	-	-
67	T-Profil 40/52/2	T56	1	2303	-	-
68	T-Profil 40/52/2	T57	1	2299	-	-
69	T-Profil 40/52/2	T58	1	2296	-	-
70	T-Profil 40/52/2	T59	1	2305	-	-
71	T-Profil 40/52/2	T60	1	2303	-	-
72	T-Profil 40/52/2	T61	1	2295	-	-
73	T-Profil 40/52/2	T62	1	2293	-	-
74	T-Profil 40/52/2	T63	1	2302	-	-
75	T-Profil 40/52/2	T64	1	2306	-	-
76	T-Profil 40/52/2	T65	1	2301	-	-
77	T-Profil 40/52/2	T66	1	2290	-	-
78	T-Profil 40/52/2	T67	1	2302	-	-
79	T-Profil 40/52/2	T68	1	2308	-	-
80	T-Profil 40/52/2	T69	1	2298	-	-
81	T-Profil 40/52/2	T70	1	2294	-	-
82	T-Profil 40/52/2	T71	1	2303	-	-