



# **Masters in Scientific Instrumentation**

## **Optical Instruments**

### **Laboratory Report**

**on**

## **Principle and Application of Surveying Instruments**

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## 1. Introduction

Surveying is the process of measuring and mapping the physical features of a piece of land or property. This can include measuring distances, angles, and elevations to create detailed maps and plans.

Theodolite can determine horizontal and vertical angles, therewith you can calculate distances. A tachymeter is in principle a theodolite with an integrated distance measurement system. With the help of a tachymeter, it's possible to determine direction, distance, and height differences in one working step outgoing from a well-known location. By using a tachymeter, each point is described by its polar coordinates; the location of the instrument is the intersection point of the x and y axes. One can distinguish between a simple tachymeter, a double image reduction tachymeter, and an electro-optical tachymeter.

## 2. Preparatory

2.1. Calculate the required height  $h$  of a supporting bar B by using the known values  $a$ ,  $b$ ,  $\gamma_1$ , and  $\gamma_2$ . Please note, that you're able to reduce an angular distance to the appropriate horizontal distance. (See sketch below).

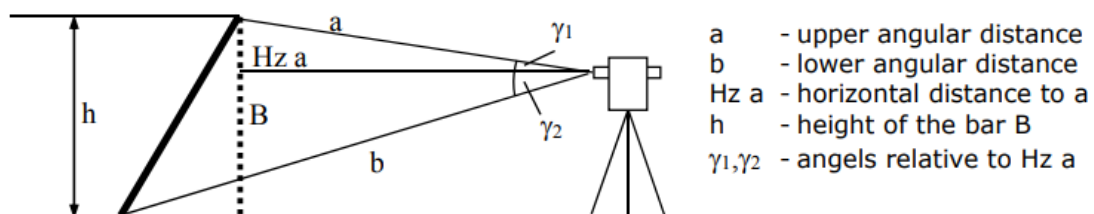
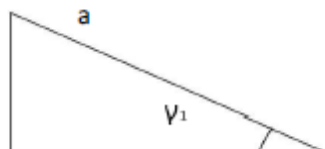


Figure 1 Preparatory problem

Let 'x' stand for the distance above the horizontal distance and ' $h-x=y$ ' for the distance beneath the horizontal distance.

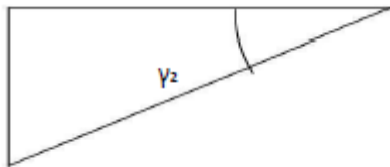
➔ Consider the upper right angle with angular distance,  $a$



$$\sin \gamma_1 = x/a$$

$$x = a \cdot \sin \gamma_1 \quad (1)$$

➔ Consider right angle triangle with a lower angular distance, b



$$\sin \gamma_2 = h-x/b$$

$$h - x = b \cdot \sin \gamma_2 \quad (2)$$

Solving (2) & (1)

$$h = x + b \cdot \sin \gamma_2$$

$$\mathbf{h = a \cdot \sin \gamma_1 + b \cdot \sin \gamma_2}$$

2.2. What are the differences between leveling instruments, tachymeters, and theodolites?

### Levelling Instruments

Leveling instruments are primarily used for determining relative heights and establishing horizontal lines or planes. Levels typically consist of a telescope mounted on a tripod, with a leveling bubble, and an electronic sensor to indicate horizontal alignment. They can be manually or automatically leveled using a compensator.

### Theodolites

The theodolite is an instrument to measure horizontal angles and vertical angles. Its main parts are horizontal, and a vertical graduated circle, a telescope that can be rotated around a horizontal axis and a vertical one, and elements to facilitate circle readings and leveling.

#### Advantages:

- It is very portable and can be carried anywhere without making much effort.
- It is generally easier to use than transit or the level and compass. This makes it ideal for small-scale surveying projects like construction sites, farms, and so on.
- Its basic parts are easy to understand and can be used with ease by anyone who knows the basics of surveying instruments in general.

#### Disadvantages:

- Errors due to leveling.
- Inaccurate centering of theodolite instrument over station mark point.
- Error due to slipping of the lower plate of the theodolite instrument.
- Taking reading wrong from the vernier scale.
- Errors occur due to parallax.
- Errors due to not holding the ranging rod vertically.

#### Tacheometer

All measuring methods with which the position and elevation of terrain points are determined from one station with an instrument providing direction, elevation difference, and distance are considered as a tachometer. Theodolites or compasses with a special optical device for distance measurement are called tacheometers, while electronic tacheometers contain an EDM. Tacheometer levels can only be used in flat and nearly plane terrain. In all other cases, stadia theodolites and compasses, also denoted as circle tacheometers, tacheometers with the base at the station, as well as equipment with a plane table and alidade for graphical mapping of points, can be used.

Each terrain points to be measured is described by polar coordinates, with the origin of the coordinate system being at the instrument station. The optically determined distances and elevation differences are reduced to horizontal, computationally for circle tacheometers, completely or partially automatically for self-reducing tacheometers, and either by computation or with an internal computer for electronically determined distances.

### Advantages

- High accuracy for precise measurements.
- Increased efficiency and time savings.
- Digital data integration and easy data management.
- Versatile for various surveying applications.
- Remote control and connectivity options for convenience.

### Disadvantages

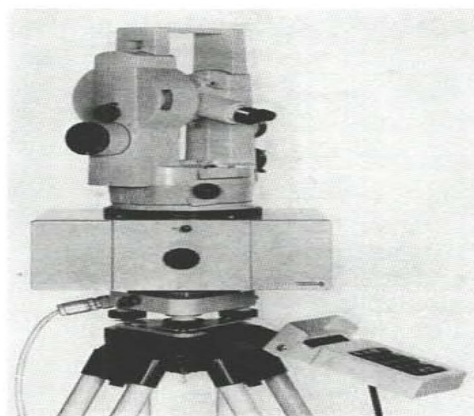
- Instrumental mistakes can result from inaccurate markings on the stadia rod or faulty modifications in the instrument.
- Errors can be caused by manipulation and sighting due to a lack of expertise or improper instrument centering and leveling.
- There are many natural sources of inaccuracies such as wind, unequal refraction, visibility, and asymmetrical expansion of instrument components.

### Electronic Tacheometer

Electronic tacheometers are instruments that combine theodolite and electro-optical distance measuring devices. One distinguishes between

1. electronic tacheometers with visual circle reading and EDM and recording electronic tacheometers (with automated angular and distance measurements)

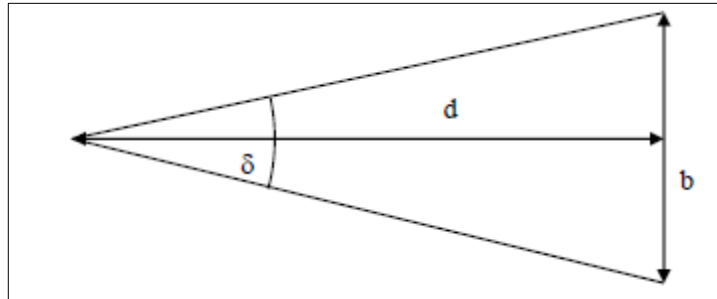
The operation of an electronic tacheometer with visual circle reading is also obtained by mounting an attachment for EDM onto a theodolite,



*Figure 2 Zeiss optical instrument in 1978*

## Trimble M3 Total Station

The measurement principle of optical distance measurement instruments is based on the measurement of the parallactic angle and of the length  $b$ , which is opposite to the instrument's location in the distance  $d$ .



*Figure 3 Principle of Tachometer*

The tachometer is the location of the base and the angle. We have instruments with a base in the location of the instrument as well as instruments, which use a base in the goal point. Otherwise, we have instruments with variable angles as well as instruments with solid angles.

Electro-optical tachymeter uses the measurement of phase shifting between the outgoing beam and the reflected beam from a retro reflector in the goal point.

Naturally, such instruments use modulated near IR for measurements.

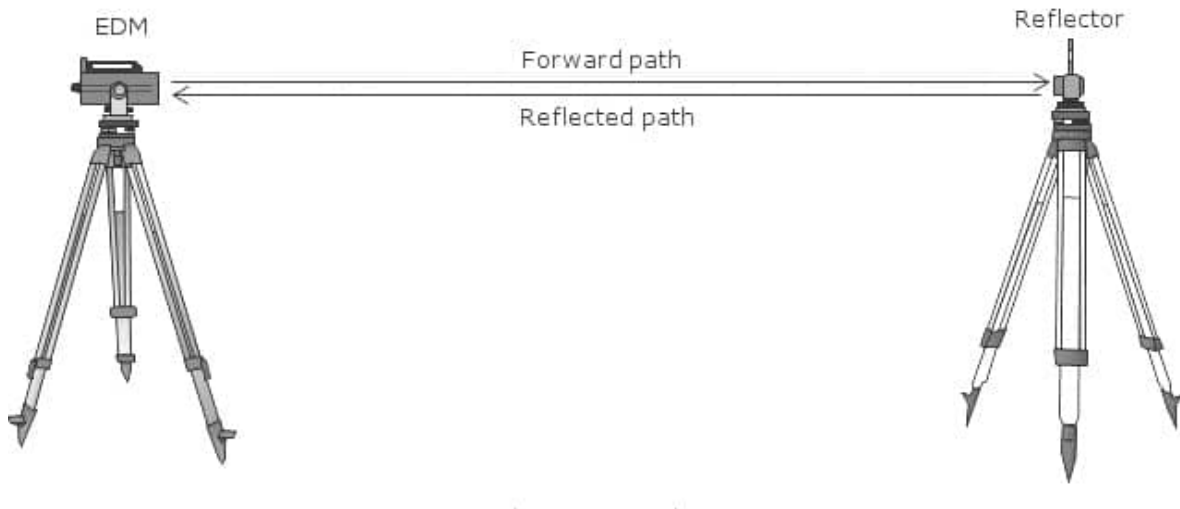
It works with an **870 nm laser diode**.

Measured angular distance it's necessary to determine the horizontal and the vertical angle, too. This measurement is done with the help of the pitch circle inside the instrument.

### 2.3. Explain the principle of electro-optical distance measurement.

The electromagnetic waves propagate through the atmosphere based on the equation. Mainly the waves that are propagated can be represented like a sine wave as shown in the figure below. Another property of wave called a phase of the wave is a very convenient method of a small fraction of wavelength during measurement in EDM.

From the transit time and known velocity, the distance can be easily measured. To solve the problem that arises due to difficulty in starting the timer a reflector can be



*Figure 4 Transit measurement arrangement with the help of an EDM and a reflector*

**Advantage:**

- Less susceptible to atmospheric conditions.
- Less expensive: only a single transmitter is needed.

**Disadvantages:**

- Shorter range.

### 3. Analysis

#### 3.1 Explain the measurement and the reduction of horizontal distances.

**Measurement of Horizontal Distance:**

- a. Setting up the instrument: The total station is properly set up on a stable tripod and leveled using the built-in bubble level.
- b. Target: for value approximation the prism is placed at the desired location where the distance is to be measured.
- c. Aim and measure: Look through the telescope of the instrument and use the onboard controls to aim at the prism.

After fixing the target point at the corner the horizontal angle is set to Zero as a set point (reference point). This process is done for the first set point and for other set points both the horizontal and vertical axis are taken for calculation.

The Trimble M3 Total Station accurately measures the distance and the angles by averaging 5 sets of values.

- d. Distance calculation: The total station measures the time it takes for the laser beam to travel to the prism and back. It calculates the horizontal distance between the instruments.

The value measured is calculated using the Law of cosine for finding the distance between two angles. For example, the value taken from the set point 1 to 2 with the help of angle the distance can be calculated.

Law of cosine:

The Law of Cosines is a function that relates the lengths of the sides of a triangle to the cosine of one of its angles. It can be used to calculate an unknown side length or angle in a triangle when the lengths of two sides and the included angle are known.

$$d = \sqrt{a^2 + b^2 - 2 \times a \times b \times \cos \beta}$$

The layout of the room is measured using the reference point of the distance between the instrument and the corner point. So, we have determined a total of 14 reference points with the different relative positions which cover the entire area of the room as mentioned in Figure 5.

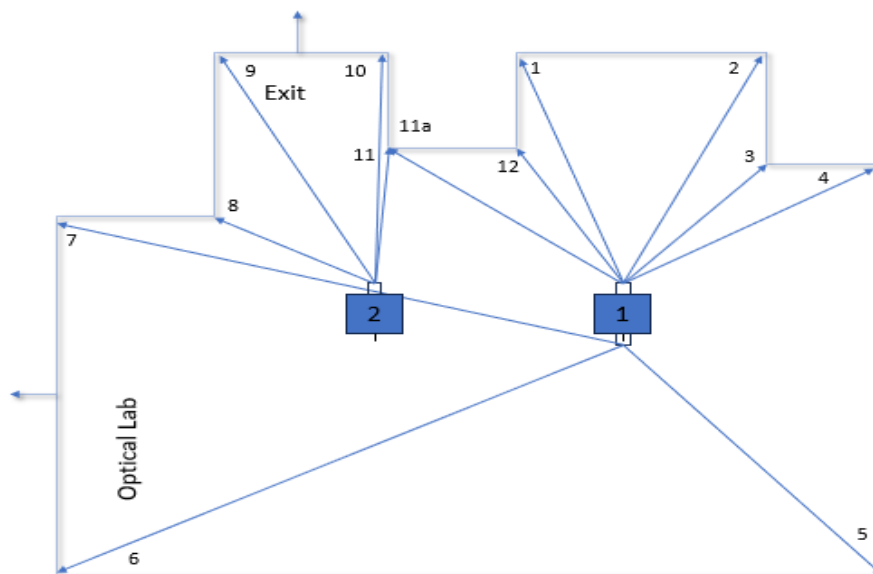
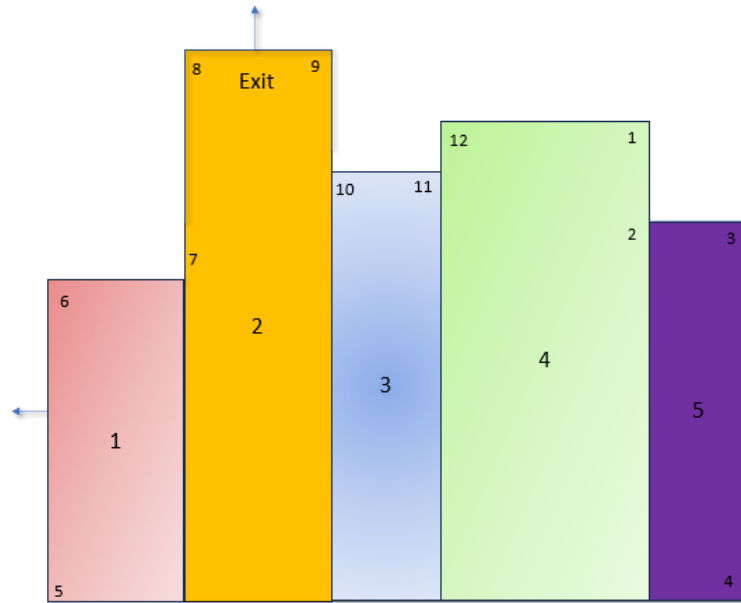


Figure 5 Area of the floor diagram

Area of room calculation:

To calculate the area of the room we need length and breath. So, the area is portioned into 5 which is shown in figure 6. By summing the portioned area, we can find the area of the room.



Position 1 → the Control point of position 1 with the distance of the points 1,2,3,4,5,6,7,10a,11, and 12 have been measured where the horizontal angle is zero at the beginning and it will gradually increase ( $\beta$ ) as we move from our first position point which determines the change in distance (d) and also the vertical angle of each point determines the total height of the point located.

POSITION 1	DISTANCE IN m	HORIZONTAL ANGLE ( $\beta$ )	HORIZONTAL ANGLE ( $\beta$ ) Decimal value	VERTICAL ANGLE
1	8.088	0°0'0"	0	84°59'24"
2	7.481	10°3'54"	10.065	85°36'40"
3	8.885	12°51'40"	12.8611	84°51'05"
4	8.809	41°4'42"	41.0783	87°33'15"
5	6.203	184°59'2"	184.983	84°17'27"
6	5.833	219°45'31"	219.7586	89°45'44"
7	4.533	223°9'15"	223.154	90°01'46"
10a	4.197	258°1'59"	258.033	90°44'40"
11	3.363	281°43'16"	281.721	90°01'46"
12	3.846	283°40'2"	283.667	91°27'50"

Table 1 Position 1 Measured reading for floor area calculations.

Position 2 → The range of the instrument is small. The position is changed, and all the set-up needs to be followed (reference – page 10 measurement of horizontal distance). Another set point is measured such as 7a,8,9,10. The values are shown in the below table.

POSITION 2	DISTANCE IN m	HORIZONTAL ANGLE (β)	HORIZONTAL ANGLE (β) Decimal value	VERTICAL ANGLE
7a	1.846	0°0'0"	0	89°50'33"
8	5.214	20°38'40"	20.644	82°50'30"
9	5.18	39°29'3"	39.484	82°50'34"
10	3.679	42°51'8"	42.852	86°49'45"

*Table 2 Position 2 Measured reading for floor area calculations.*

3.2 Make a drawing and write all the measurements into this drawing (Angles and lengths).

#### Calculation

To determine the distance  $d$ , the stretches  $A$  and  $B$  as well as the angle between them are measured.

$$d = \sqrt{a^2 + b^2 - 2 \times a \times b \times \cos \beta} \quad \dots \text{eq (1)}$$

$$z = (a \times b \times \sin \beta) / d \quad \dots \text{eq (2)}$$

$$\cos \alpha = z / a \quad \dots \text{eq (3)}$$

With the help of the following formulas as shown in equations (1), (2), & (3) can be used to calculate the unknown angle which helps in distance calculation as shown in Figure 5.

Location of Points	Length of component 1 in meters (a)	Length of component 2 in meters (b)	Angle Difference	Distance $d = \sqrt{a^2 + b^2 - 2ab \cos(\beta - \alpha)}$
1 to 2	8.088	7.481	10.07	1.494
2 to 3	7.481	8.885	2.80	1.459
3 to 4	8.885	8.809	28.22	4.314
4 to 5	8.809	6.203	143.91	14.296
5 to 6	6.203	5.833	34.77	3.614
6 to 7	5.833	4.533	3.40	1.335
7a to 8	1.846	5.214	20.64	3.547
8 to 9	5.214	5.18	18.84	1.701
9 to 10	5.18	3.679	3.37	1.523
10a to 11	4.197	3.363	23.69	1.753
11 to 12	3.363	3.846	1.95	0.498

Table 3 Distance calculation

Area calculations.

To calculate the area of the room we need length and breath. So, the area is portioned into 5 which is shown in the figure x. By summing the portioned area, we can find the area of the room.

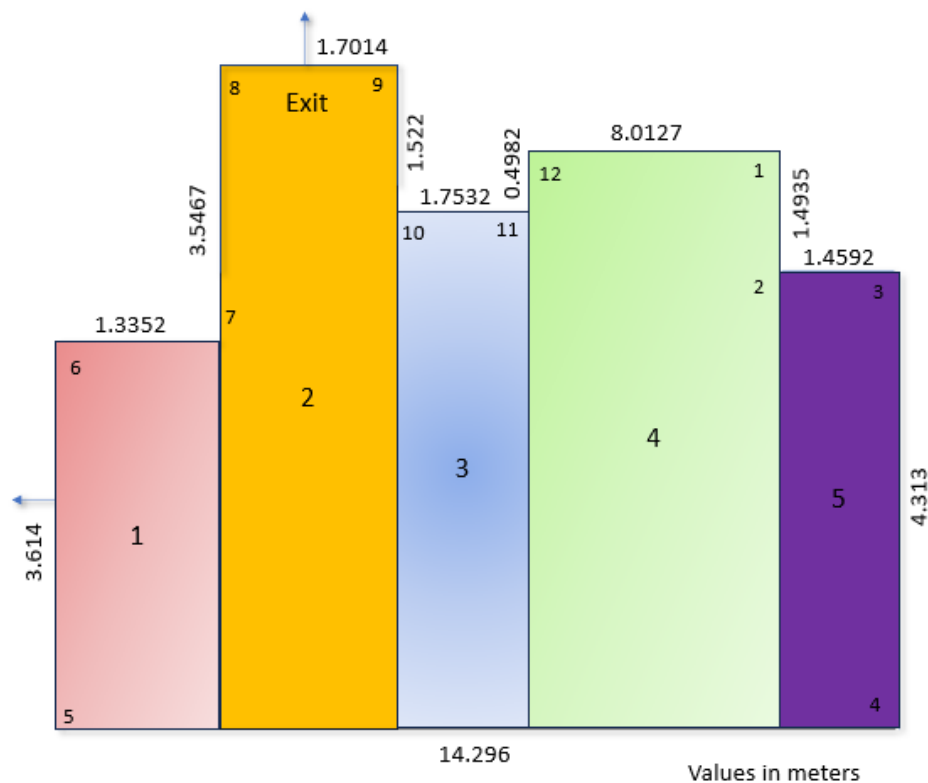


Figure 7 Area of the floor

Rectangular Number	Area (m <sup>2</sup> )
1	4.8254
2	12.1832
3	9.8857
4	46.5257
5	6.2935
Total	79.7135

*Table 4 area of the floor readings*

**The total area of the floor: 79.7135 m<sup>2</sup>**

3.3 Calculate the radius of curvature of the ceiling and explain how to do that.

The tachometer needs to be placed exactly 90 degrees with respect to the wall.

Calculating the perpendicular again the law of cosine comes into role.

The following law of cosine formulas is used to determine the angle needed to the tilting angle of the instrument.

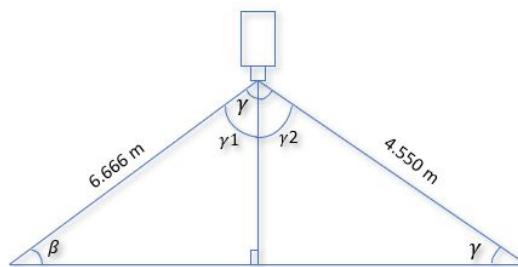
$$\frac{\sin \beta}{4.550} = \frac{\sin \gamma}{6.666}$$

$$\frac{\sin \beta}{4.550} = \frac{\sin 90^\circ}{6.666}$$

$$\beta = 52.9^\circ$$

After finding the angle ( $\beta$ ) of one side of the scalene triangle, the  $\gamma_1$  and  $\gamma_2$  can be determined.

$$\gamma_2 = 90^\circ - 52.9^\circ \quad \gamma_2 = 37.1^\circ$$



*Figure 8 formulation of the tachometer perpendicular to the wall*

The tachometer is adjusted with respect to the angle  $\gamma_2 = 37^\circ 1'$  as perpendicular to the wall.

Afterward, six value is measured from the point in the wall (ceiling) which is shown in the table below,

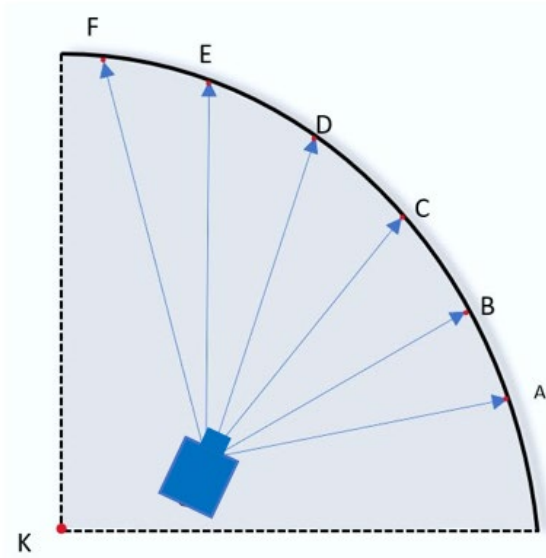


Figure 9 Vertical angle measurement

Measured values						
Point	Angle( $\alpha$ )	Vertical Angle	minute	second	Decimal	Distance (r)
A	$84^\circ 35' 16''$	84	15	16	84.25444	5.323
B	$83^\circ 46' 43''$	83	46	43	83.7786	5.261
C	$75^\circ 50' 58''$	75	50	58	75.8494	4.963
D	$69^\circ 01' 16''$	69	1	16	69.021	4.684
E	$59^\circ 07' 13''$	59	7	13	59.12	4.369
F	$38^\circ 03' 41''$	38	3	41	38.0613	4.007

Table 5 measured the value for the radius of curvature.

Point	Distance from the point O to the curvature of the wall (a)	Distance from the point O to the other point of curvature of the wall (b)	Vertical Angle ( $\beta$ ) Difference between the two points	Distance (m) $\sqrt{a^2+b^2-2ab\cos(\beta)}$
AOB	5.323	5.261	0.48	0.075996477
AOF	5.323	4.007	46.19	3.854976219
BOF	5.261	4.007	45.72	3.781123879
AOC	5.323	4.963	8.41	0.834914264
COF	4.963	4.007	37.79	3.042222963
AOD	5.323	4.684	15.23	1.469836108
DOF	4.684	4.007	30.96	2.409634692
AOE	5.323	4.369	25.13	2.305235031
EOF	4.369	4.007	21.06	1.571469789

Table 6 Distance calculation for the curvature

- Vertical Angle between points A and B =  $84.2544 - 83.776$   
 $= 0.48$  Values in decimal for calculation

$$\text{Distance of the chord, } \mathbf{AOB} = \sqrt{OA^2 + OB^2 - 2 * OA * OB * \cos(\beta)}$$

$$\mathbf{AOB = 0.0759 \text{ m}}$$

Considering Triangle	$\Delta AFB$	$\Delta AFC$	$\Delta AFD$	$\Delta AFE$
The angle of Chord AF ( $\varphi$ ) in decimal	166.22236	165.07623	166.71887	167.63746
The angle between the radius of curvature ( $\alpha$ ) in decimal $\alpha = 360^\circ - 2\varphi$	27.555281	29.847531	26.562255	24.725076
The radius of curvature R (meters) $R = \frac{s}{2\sin(\frac{\alpha}{2})}$	8.0934371	7.4844139	8.3902626	9.0028859

Table 7 Radius of curvature calculation

In  $\Delta ABF$ ,

Using law of cosines,  $\cos \varphi_1 = \cos AFB$

$$= \frac{AOB^2 + BOF^2 - AOF^2}{2 * AOB * BOF}$$

$$= \frac{(0.759)^2 + (3.781)^2 - (3.8549)^2}{2 \cdot 0.759 \cdot 5.452}$$

$$\varphi_1 = \cos^{-1}(-0.9712273)$$

$$\varphi_1 = 166.2236 \text{ Values in decimal}$$

$$\text{Mean Radius } R_{\text{mean}} = \frac{R_1 + R_2 + R_3 + R_4}{4}$$

$$R_{\text{mean}} = \frac{8.093471 + 7.4844139 + 8.3902626 + 9.0028859}{4}$$

$$= 8.24275 \text{ m}$$

### Result:

1. Total area of the Floor = 79.7135 m<sup>2</sup>
2. Radius of the curvature = 8.24275 m

3.4 Discuss the influence of environmental conditions on your results. Assume that you have done some measurements outside the building.

- Difficult to focus on the target because of bright sunlight and low light condition.
- Environment factor – temperature, atmospheric pressure, wind, vibrations.
- Strong wind can lose the balance and cause error.

### 4. Reference

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3. Gruber, O. v., Optische Streckenmessung und Polygonierung, 2. Auflage, Sammlung Wichmann, Band 11, Berlin 1955