Every Step I Take: Evaluating Stair Compliance At The UP Diliman Institute Of Civil Engineering Through Close-Range Photogrammetry

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Abstract

This study explores the application of Close-Range Photogrammetry (CRP) for the structural assessment and compliance evaluation of stairs at the UP Diliman Institute of Civil Engineering. The analysis was performed on multiple flights of stairs, where scaling was done using a reference object due to the absence of ground control points (GCPs). For each step, three measurements were taken for both tread and rise dimensions and the average was computed to represent the values for consistency. Additionally, the standard deviation (SD) for both tread and rise within each flight was calculated to assess variability and conformity to the National Building Code of the Philippines (NBCP) standards. The results revealed significant variability in both tread and rise dimensions across the stairs. Only two flights of stairs out of twelve satisfied the 5 mm SD limit for tread, while none for rise. Ninety-three point sixteen percent (93.16%) fell outside the recommended tread range of 250-280 mm. The largest observed SDs were 11.16 mm for tread and 19.41 mm for rise, indicating considerable inconsistency in the stair dimensions. In terms of accuracy, the study validated the CRP method by comparing photogrammetry with actual physical measurements of the stairs. The Root Mean Square Error (RMSE) and Margin of Error (MOE) were used, yielding favorable results. The first stair demonstrated high accuracy, while the second showed minor variations that still fell within the lower end of the observed range, highlighting the reliability and precision of the measurement methods employed.

1. Introduction

1.1. Background of the Study

Close-range photogrammetry (CRP) has emerged as a cost-effective and highly accurate method for capturing detailed geometric data in engineering (Vedantu, n.d.; GEAVIS, n.d.). This technology generates 3D models and point clouds from images taken with consumer-grade cameras, providing a non-invasive alternative to traditional measurement techniques (Robsan et al., 2011). CRP achieves accuracy within a few centimeters, making it comparable to conventional methods like tape-measuring, while remaining more accessible and affordable (Singh, Jain, & Mandla, 2013). Moreover, Studies have highlighted additional advantages of CRP. Yakar (2011) emphasized that it is more reliable, faster, and safer than traditional approaches, particularly in areas with limited accessibility. It also supports accurate structural assessments even without ground control points. Compared to conventional methods, CRP requires less equipment and shorter work time, as capturing photographs is both simpler and cheaper. The technique also records color information, and its portability makes it convenient—cameras and tripods can fit into small bags and weigh significantly less (Factum Foundation, n.d.).

Continuing, construction always considers safety measurements when it comes to buildings, and other features such as stairs. Stairs have been used since ancient times and are very common in buildings but also very hazardous hence stairs safety and compliance is important for buildings. In the United States, stairway accidents cause over 1 million injuries each year and lead to approximately 12,000 deaths annually (Tenge, 2023).

According to the National Building Code of the Philippines (RA 6541 and PD 1096), stair risers must not exceed 200 mm, and treads must range between 250–280 mm. Additionally, the variation between steps should not exceed 5 mm, ensuring consistency for safety. Stairways serving 50 or more occupants must also have a minimum width of 1.10 meters. Despite these standards, inconsistencies remain in practice—for example, the stairs at the UP Diliman Institute of Civil Engineering (ICE) Building, which have been visibly inconsistent. This concern has been echoed by students on platforms like Reddit and confirmed by the researchers' peers.

1.2. Research Problem

The primary issue addressed is the potential non-compliance of the ICE Building's stair dimensions with the National Building Code of the Philippines (RA 654) and Presidential Decree No. 1096. Inconsistent stair treads and risers pose significant safety risks, contributing to accidents such as trips and falls. While previous studies have assessed stair safety using 3D laser scanning, there remains a gap in literature regarding the application of close-range photogrammetry for this purpose.

1.3. Objectives

This study generally aims to explore the feasibility and applicability of close-range photogrammetry (CRP) as a tool for structural assessment and compliance evaluation in built environments. To support this general objective, the study aims to achieve the following specific objectives:

1. To assess the compliance of stairs at the UP Diliman Institute of Civil Engineering with the National Building Code of the Philippines standards using close-range photogrammetry.
2. To conduct detailed assessments of stairs for compliance.
3. To ensure the accuracy and efficiency of the digital close-range photogrammetry method employed in measuring the physical attributes of stairs by validating through the actual stair measurements.

1.4. Significance of the Study

This study has significant implications, particularly through the application of close-range photogrammetry (CRP) to assess stair compliance. CRP offers accurate and reliable measurements that surpass the consistency and detail of traditional inspection methods, while also providing a more convenient and accessible means of evaluation. The practical benefits extend to a wide range of stakeholders. For civil engineers, architects, and construction firms, the study promotes adherence to regulations and encourages better design practices. Building inspectors and safety officials benefit from more efficient verification of compliance with national building codes, especially those concerning accessibility and structural safety. At UP Diliman, the Facilities and Management Office can use the findings to better monitor and maintain heavily trafficked academic and administrative buildings. For the general public and campus community, the study raises awareness about stair compliance in the ICE Building, helping reduce accident risks and enhance well-being. Lastly, it contributes to the academic community by demonstrating CRP's potential in structural compliance assessments, offering valuable insights that can support future research and broader applications.

1.5. Scope and Limitations

This study is limited to the UP Diliman Institute of Civil Engineering (ICE) Building, which serves as the designated study area. The focus is confined to the geometric aspects of the stairs, specifically the rise and tread dimensions. Image acquisition for the photogrammetric analysis was carried out using a DSLR camera to ensure high-resolution and consistent photo quality suitable for measurement and modeling.

2. Methodology

2.1 Photo Capturing

In this study, two stairs of the ICE Building were examined, each divided into six flights, resulting in a total of 12 flights analyzed. At least 30 photos were captured for each flight from various angles and perspectives to ensure comprehensive coverage. The image-capturing process followed a specific route—starting from the bottom of the stair, moving upward, and then descending. A Canon SX40 HS DSLR camera was used to acquire the images, maintaining a 60–80% overlap between photos to support effective photogrammetric processing. To enable accurate measurement of the stair rise and tread dimensions, markers with known measurements such as an illustration board and bluebooks, were strategically placed along the stairs and included in every scene for reliable scaling. In the case of bluebooks, it is an unconventional material for a marker, but it is a well-known, commonly used, with known measurements, consistently sized notebook on the campus, suggesting familiarity with the material. To address the unconventionality of the marker, the blue book used was the same all throughout, and was also measured properly to confirm the actual measurement.

2.2 Camera Calibration

To ensure measurement accuracy from the 3D models, camera calibration was performed prior to processing. A printed checkerboard pattern was used for camera calibration. Then, a separate calibration code utilizing MatLab was used to estimate the camera's intrinsic parameters, including focal length, principal point, and lens distortion coefficients. These parameters were essential to correct lens-related distortions coefficients. These parameters were essential to correct lens-related distortions and ensure accurate spatial representation during 3D model generation.

The process followed a standard close-range photogrammetry workflow, utilizing images of a printed checkerboard pattern taken from multiple angles. Calibration results were then applied to the image set used in Agisoft Metashape to improve model geometry. Since the Canon SX40 HS DSLR camera is not a metric camera, calibration was a crucial step in enhancing measurement reliability.

Seen from Table 1 below are the intrinsic parameters derived from the calibration process:

Parameter	X-axis (pixels)	Y-axis (pixel)
Focal Length	4183.2837 ± 29.6463	4192.2078 ± 28.5620
Principal Point	1467.8549 ± 13.2597	829.6372 ± 13.3991
Radial Distortion	0.5969 ± 0.1504	0.3410 ± 0.1572

Table 1. Intrinsic Parameters of the DSLR Camera.

2.3 Data Processing

2.3.1 Dense 3D Point Cloud Generation: The images were first calibrated using the parameters obtained in Table 1. Using Agisoft, a 3D Point Cloud of the images was generated. The "benchmark" objects served as the puzzle piece for the point cloud generation. The benchmarks, in particular, were used as reference points for aligning the photos, a function available within the software. Furthermore, to enhance details and ensure the accuracy of the model, dense clouds were generated shown in Figure 1.

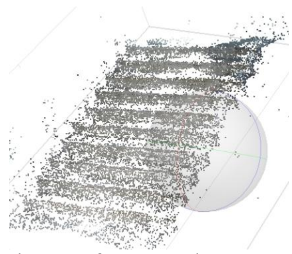

Figure 1. Sample image of generated Dense 3D Point Cloud.

2.3.2 Mesh Model Generation and Texturizing: Following the creation of the 3D point cloud, additional processing steps were performed to refine the results. Mesh generation and texture mapping were utilized to create a more realistic and detailed representation of the stair as shown in Figure 2. These processes involved leveraging the software's built-in algorithms to interpolate gaps and improve surface continuity.

Figure 2. Sample image of Texturized Mesh Model

2.4 Measurements and Statistical Methods

CloudCompare was employed for dimensional measurements of stair treads and risers. Results were validated against manual measurements using a straight metal ruler.

Both measurements through CloudCompare shown in Figures 3 to 5, and manual measurements shown in Figures 6 to 7 were done three times and averaged to lessen possible errors in measurements. Additionally, when scaling, a benchmark with known measurements was used, a standard University Blue Book. Also, the scaling measurements were measured thrice and the average was used, minimizing further errors.

Figure 3. Sample image showing the measurement of a benchmark with known dimensions.

Figure 4. Sample image of the measurement of the rise using CloudCompare.

Figure 5. Sample image of the measurement of the tread using CloudCompare.

Figure 6. Sample image of the actual rise measurements using a metal ruler.

Figure 7. Sample image of the actual tread measurements using a metal ruler.

Furthermore, statistical analyses, including Root Mean Square Error (RMSE), Margin of Error (MOE), and Standard Deviation (SD), were conducted to assess measurement accuracy. According to Bi et al. (2019), the Root Mean Square Error (RMSE) quantifies the average deviation between actual data points and predicted values, where each difference is squared to eliminate the offsetting effect of positive and negative values before being averaged. This provides a comprehensive measure of prediction accuracy. On the other hand, Frost (n.d.) explained that the Margin of Error (MOE) in a survey expresses the range within which the true population value is expected to lie, reflecting the precision of the survey estimates and the level of uncertainty due to sampling. Together with Standard Deviation (SD), which indicates how spread out the data values are from the mean, these statistical tools collectively provide a more complete analysis of both the accuracy and reliability of the measurements. Equations 1 and 2 below displays the equations used to carry out the statistical analyses.

$$RMSE = \sqrt{\frac{\Sigma(y_i - \hat{y}_i)^2}{n}} \quad (1)$$

Where, y_i = the actual observed value
$\hat{y}_i$ = the predicted value
n = the number of observations

$$MOE_{\gamma} = z_{\gamma} * \sqrt{\frac{\sigma^2}{n}} \quad (2)$$

Where, z_{γ} = is the z-score of the observed value
σ = the standard deviation of the dataset
n = the number of observations

3. Results and Discussion

3.1 Measurements from Cloud Compare

The tables below present the measurements of the tread and rise for each flight of stairs, obtained through photogrammetric analysis using CloudCompare. As ground control points (GCPs) were not employed to establish actual coordinates, scaling was performed using a reference object—a standard UP bluebook—with known dimensions of 15.2 cm by 22.7 cm. To minimize potential errors, three measurements were taken per dimension, and the average of these values was used as the representative measurement. In addition, the standard deviation of the tread and rise values within each stair was computed to assess the variability and consistency of the measurements.

After the measurement through CloudCompare, the standard deviation for tread and rise between each flight is determined. This was to find out whether the stair adheres to the standards set by the National Building Code. The following definition of terms were used to simplify the discussion of the table contents:

- *step*, pertains to the structure containing a rise and a thread;
- *flight,* refers to the set of steps, and there were 10-11 steps per flight;
- *stairs,* the set of flights, and there were 6, which are the flights from the first floor to the fourth floor. The ICE building has two stairs, one on the left side and one on the right side, hence pertaining as first and second stairs all throughout the discussion.

Tables summarizing the Cloud Compare measurements of the rise and thread of the six (6) flights for the two stairs are in the appendix section of the paper.

Table 2 below summarizes the standard deviations of the rise and thread of the six (6) flights for the two stairs.

Flight	Standard Deviation (mm)			
	First Stair		Second Stair	
	Tread	Rise	Tread	Rise
1st	8.17	6.52	11.16	8.13
2nd	5.65	6.64	4.86	7.02
3rd	5.65	8.38	6.62	7.82
4th	6.11	9.62	5.94	15.26
5th	5.15	9.97	3.7	19.41
6th	5.75	8.84	6.43	18.64

Table 2. Summarized Standard Deviations of the Treads and Rises for Each Flight.

As observed in Table 2, out of 12 flights, only two flights of stairs satisfied the 5 mm SD for the tread as stated in the National Building Code of the country, highlighted in green. While no flight satisfied the 5mm SD for the rise. Additionally, 93.16% of steps fell outside the recommended tread range (250-280 mm), with the largest SDs for tread and rise being 11.158 mm and 19.414 mm, respectively (see Table 4). The rise varied from 123.6 mm to 200.4 mm, indicating inconsistency. The biggest computed standard deviation for the rise was 19.41 mm. With this alone, it can be seen how big the difference between the smallest rise and tread from the largest rise and tread, thus already showing inconsistency. Table 3 and Table 4 below show the summary of findings per flight of each stair. Note that 'DNS' stands for 'Did Not Satisfy' and 'STD' stands for the Standard Deviation.

Flight	Standard Deviation (mm)			
	First Stair			
	Tread	Remarks	Rise	Remarks
1st	8.17	DNS	6.52	DNS
2nd	5.65	DNS	6.64	DNS
3rd	5.65	DNS	8.38	DNS
4th	6.11	DNS	9.62	DNS
5th	5.15	DNS	9.97	DNS
6th	5.75	DNS	8.84	DNS

Table 3. Summarized Findings for Stair 1.

Flight	Standard Deviation (mm)			
	Second Stair			
	Tread	Remarks	Rise	Remarks
1st	11.16	DNS	8.13	DNS
2nd	4.86	SATISFIED	7.02	DNS
3rd	6.62	DNS	7.82	DNS
4th	5.94	DNS	15.26	DNS
5th	3.7	SATISFIED	19.41	DNS
6th	6.43	DNS	18.64	DNS

Table 4**.** Summarized Findings for Stair 2.

3.2 Accuracy Assessment

Equations 1 and 2 were used to carry out the accuracy assessment. The tables below present the actual measurements of the tread and rise for selected steps within the stairs, obtained through manual measurement using a metal ruler. To minimize potential measurement errors, three readings were taken for each parameter, and the average was used as the final value. The differences between these actual measurements and those derived from CloudCompare are summarized in Table 5 and Table 6. In the tables, Segment A refers to the 2nd step, while Segment B corresponds to the 2nd to the last step of each flight. These two steps were chosen to be the reference for the actual measurements for accuracy assessment. The farthest from the photo center are distorted the most; hence points in the image that appear only at near image edges could be reconstructed with lower accuracy, justifying the intentional usage of the two steps.

The average actual measurements of the rise and thread; of segment A and segment B, of each flight in both stairs are in the appendix section of this paper.

Tables 5 and 6 summarise the comparison between the actual measurements and Cloud Compare measurements for all flights of both stairs. As mentioned previously, Segment A refers to the 2nd step, while Segment B corresponds to the 2nd to the last step of each flight.

Flight		Rise Measurement Comparison (mm)					
		First Stair			Second Stair		
		Actual	Cloud Compare	Difference	Actual	Cloud Compare	Difference
1st	A	187.7	188	0.3	188.5	185.3	3.2
	B	182.3	182.5	0.2	170.3	168.1	2.2
2nd	A	183.7	183.7	0	175.7	179.7	4
	B	181.7	181.9	0.2	164.3	178.5	14.2
3rd	A	162.3	152	10.3	162.7	166.9	4.2
	B	165	167	2	160	157.2	2.8
4th	A	139	130.3	8.7	136	128.1	7.9
	B	131.3	126.4	4.9	143.7	140.2	3.5

5th	A	164.3	154.9	9.4	162	145.7	16.3
	B	151.7	150.1	1.6	149	129.9	19.1
6th	A	131	128.3	2.7	140	139.7	0.3
	B	140.3	136.1	4.2	146.7	129.7	17
RMSE				5.2	RMSE		10.2

Table 5. Comparison of the Tread Measurements from Actual and CloudCompare of the First Stair.

Flight		Tread Measurement Comparison (mm)					
		First Stair			Second Stair		
		Actual	CC	Diff	Actual	CC	Diff
1st	A	291	292.7	1.7	327.7	337	9.3
	B	298.7	299.4	0.7	301	312.8	11.8
2nd	A	298	298	0.8	288.3	311.4	23.1
	B	289.3	289.4	0.1	285.3	299.1	13.8
3rd	A	299.3	302	2.7	319.5	303.1	16.4
	B	306.3	303.7	2.6	318.3	301	17.3
4th	A	289.3	287.5	1.8	298	299.8	1.8
	B	276	278.5	2.5	289.3	286.8	2.5
5th	A	323	325.1	2.1	314.8	312.2	2.6
	B	325	317.4	7.6	316.7	306.3	10.4
6th	A	297.3	294.5	2.8	314	304	10
	B	284.3	287.2	2.9	289	289.1	0.1
RMSE				3	RMSE		12

Table 6. Comparison of the Tread Measurements from Actual and CloudCompare of the First Stair.

As observed from Table 5 and Table 6, the first stair has an RMSE value less than 1cm for both rise and tread measures. While the second stair has an RMSE value greater than 1 cm. According to Bobbitt (2021), a good way to determine if the RMSE value obtained was ‘good’ is by normalizing it. This turns the obtained RMSE value into a value between 0 and 1; a value closer to zero indicates a ‘better’ RMSE. The formula to normalize the RMSE value is defined in Equation 3 below.

$$\widehat{RMSE} = \frac{RMSE}{max\ value - min\ value} \quad (3)$$

Where, $\widehat{RMSE}$ = is the normalized RMSE value

Staircase	Tread RMSE (mm)	Rise RMSE (mm)
First Stair	0.4	0.51
Second Stairs	0.52	0.55

Table 7. Normalized Tread and Rise RMSE Values for Both Stairs

As observed in Table 7, upon normalizing the RMSE values. The obtained values were in the middle of the range [0,1], with the largest value being 0.55 and the smallest value being 0.4. This suggests that the RMSE values are neither good nor bad.

The inconsistencies in the obtained measurements can be attributed to distortions in the image when forming the 3D model, scaling issues, and lighting issues. Especially since the images were obtained during the afternoon, and the stairs of the ICE building are located in a dim spot, especially stair 2, whose photos were taken when the sun was already setting, which is evident since it has a higher normalized RMSE compared to stair 1.

Moreover, the margin of error was calculated to determine the probable range of error due to measurement variances. From Equation 2, using the z-score of each measurement with respect to the respective mean value of each sample, the maximum margin of error calculated was $\pm\ 3.8024$ mm, with 651 out of 732 or 88.9344% of the measurements having a margin of error between ± 1 mm. Simply put, the margin of error represents the degree of uncertainty in the measurements or results. A larger margin of error indicates a greater potential deviation from the true or actual values (Zoho Survey, n.d). This suggests that the obtained values have a lower uncertainty, suggesting a smaller deviation from the actual measurements

Despite its effectiveness, the method showed accuracy limitations due to scaling methods and inconsistent measurement points. Using clear markers as measurement references in both actual and CloudCompare assessments is recommended to improve accuracy, efficiency, and reliability in similar applications.

4. Conclusion

The UP ICE’s building does not fully comply with RA 6541 and PD 1096, as multiple steps exceed the 5 mm variation standard for rise and tread. Additionally, 93.16% of steps fall outside the recommended tread range (250-280 mm), and one step exceeds the 200 mm rise limit

The study demonstrated that Close-Range Photogrammetry provides acceptable accuracy for stair assessment, with 79.16% of stairs showing less than a 1 cm difference between actual and CloudCompare measurements. Statistical analysis, including margin of error, standard deviation, and RMSE, confirmed measurement reliability. The maximum margin of error was ±3.8024 mm, with 88.93% of measurements within ±1 mm. RMSE values are closely aligned with mean values, with differences ranging from +0.0615 mm to +2.1337 mm. The normalized RMSE values for both stairs ranged from 0.4 to 0.55, indicating moderate accuracy. The inconsistencies were likely due to image distortions, scaling, and poor lighting conditions, particularly during the late afternoon for stair 2. Thus, Close-Range Photogrammetry is effective for similar studies, though further improvements are recommended.

Moreover, beyond accuracy, close-range photogrammetry (CRP) offers practical advantages, using consumer-grade cameras and accessible software, making it a cost-effective alternative to traditional surveying methods. Moreover, CRP allows the production of 3D models of structures, in this case a stair, which can be used for database purposes and for future studies. Its digital workflow allows for repeatability, easy data review through 3D models, and reduced physical effort during data collection.

CRP effectively identifies inconsistencies in stair dimensions such as riser height and tread depth, aiding in the early detection of non-compliant and potentially hazardous stairways. This promotes building safety, particularly in high-traffic areas like universities. The method supports proactive hazard mitigation by facility managers and inspectors and can be extended to assess other structural features like ramps and thresholds. Additionally, this study highlights stair non-compliance issues at the UP ICE building, raising awareness and encouraging action toward safer infrastructure.

References

Aussie Balustrading & Stairs, 2021. 3 Common staircase hazards and how to prevent them. *Aussie Balustrading & Stairs*. aussiebalustrading.com.au/3-common-staircase-hazards-and-how-to-prevent-them/ (21 October 2024).

Bi, L., Feleke, A. G., & Guan, C., 2019. A review on EMG-based motor intention prediction of continuous human upper limb motion for human-robot collaboration. *Biomedical Signal Processing and Control*, 51, 113–127. doi.org/10.1016/j.bspc.2019.02.011

Bobbitt, Z., 2021. What is considered a good RMSE value? *Statology*. statology.org/what-is-a-good-rmse/ (4 December 2024).

Bowman, R., Roys, M., & Davies, N., 2015. Use of 3D laser scanning stairway geometry data to better understand the risk of falls and enable improved stair regulations. *In Proceedings 19th Triennial Congress of the IEA* (Vol. 9, p. 14).

Canon. (2024, July 23). Support. *Canon*. support.usa.canon.com/ kb/s/article/ART112677 (21 October 2024).

Factum Foundation. (n.d.). *Close-range photogrammetry. Factum Foundation*. factumfoundation.org/technology/3d-digitisation/close-range-photogrammetry (17 August 2025).

Frost, J. (n.d.). Margin of error: Formula and interpreting. *Statistics by Jim*. statisticsbyjim.com/hypothesis-testing/margin-of-error/ (15 November 2024).

GEAVIS. (n.d.). *Advantages brought by trends in close-range photogrammetry*. geavis.si/en/2016/11/advantages-trends-close-range-photogrammetry/ (21 October 2024).

Government of Canada, Canadian Centre for Occupational Health and Safety, 2024. Stairways - fall prevention. *CCOHS*. ccohs.ca/oshanswers/safety_haz/stairs_fallprevention.html (20 October 2024).

Kot, B. C. W., Tsui, H. C. L., Chung, T. Y. T., Cheng, W. W., Mui, T., Lo, M. Y. L., Yamada, T. K., Mori, K., & Brown, R. A. L., 2020. Photogrammetric three-dimensional modeling and printing of cetacean skeleton using an Omura's whale stranded in Hong Kong waters as an example. *Journal of Visualized Experiments*, 163. doi.org/10.3791/61700

National Building Code of the Philippines | Department of Public Works and Highways. (n.d.). *DPWH*. dpwh.gov.ph/dpwh/references/laws_codes_orders /national_law (9 October 2024).

Robsan, S., Kyle, S., & Harley, I., 2011. Close range photogrammetry: Principles, techniques and applications. *Whittles.*

Singh Gurjar, S. P., Jain, K., & Mandla, V. R., 2013. Virtual 3D campus modeling by using close range photogrammetry. *American Journal of Civil Engineering and Architecture*, 1(6), 200–205. doi.org/10.12691/ajcea-1-6-9

Tenge, T., 2024. Stairway injury statistics and their hazards. *Tenge Law Firm LLC*. tengelaw.com/blog/2023/november/stairway-injury-statistics-and-their-hazards/ (15 October 2024).

Vedantu. (n.d.). Photogrammetry. *Vedantu*. vedantu.com/geography/photogrammetry (21 October 2024).

Yakar, M., 2011. Using close range photogrammetry to measure the position of inaccessible geological features. *Experimental Techniques*, 35(1), 54–59. doi.org/10.1111/j.1747-1567.2009.00583.x

Zheng, F., Wackrow, R., Meng, F., Lobb, D., & Li, S., 2020. Assessing the accuracy and feasibility of using close-range photogrammetry to measure channelized erosion with a consumer-grade camera. *Remote Sensing*, 12(11), 1706. doi.org/10.3390/rs1211170

Zoho Survey. (n.d.). What is margin of error in survey results? *Zoho Survey*. zoho.com/survey/margin-of-error.html (29 November 2024).

Appendix

This section presents the supplementary materials that support the research methodologies and findings discussed in this study.

The following tables summarize the average measurements of the rise and thread from Cloud Compare for each flight of both stairs.

Step	1st	2nd	3rd	4th	5th	6th
1	292.17	296.32	311.52	271.85	312.24	283.93
2	292.68	298.01	302.01	287.47	325.09	294.48
3	293.53	302.15	304.62	271.54	314.54	295.27
4	297.36	293.83	305.00	288.67	306.09	284.74
5	298.99	309.04	298.66	275.74	316.93	294.16
6	298.79	299.75	296.03	278.84	312.37	287.01
7	271.97	291.36	308.13	285.81	312.20	281.69
8	287.72	300.46	303.73	282.20	317.36	285.03
9	299.40	289.45	313.47	278.50	314.10	287.22
10	294.12	299.25		277.35		278.32
STD	8.17	5.65	5.65	6.11	5.15	5.75

Table 8. Average CloudCompare Tread Measurements of the Ten (10) Steps in Each of the Six (6) Flights of the First Stair in mm.

Step	1st	2nd	3rd	4th	5th	6th
1	165.34	190.20	176.26	144.15	178.30	134.61
2	187.98	183.68	151.97	130.28	154.87	128.27
3	185.43	177.37	149.53	132.92	155.32	137.48
4	185.46	170.45	161.81	130.98	151.47	135.67
5	189.64	170.97	162.55	142.45	144.81	125.48

6	180.49	177.67	157.71	128.72	152.51	135.94
7	179.23	166.69	148.56	127.23	152.39	128.66
8	185.14	177.28	158.97	144.72	140.45	126.12
9	179.73	181.01	167.03	126.04	150.12	130.99
10	182.47	181.87	160.04	126.42	149.97	136.07
11	184.42	179.01		154.93		157.55
STD	6.52	6.64	8.38	9.62	9.97	8.84

Table 9. Average CloudCompare Rise Measurements of the Eleven (11) Steps in Each of the Six (6) Flights of the First Stair in mm.

Step	1st	2nd	3rd	4th	5th	6th
1	338.73	313.23	309.31	282.03	316.55	283.54
2	337.02	311.38	303.08	299.75	312.24	304.03
3	317.98	307.00	298.97	292.16	315.93	285.09
4	309.35	303.22	299.26	293.40	305.71	289.30
5	320.19	314.82	298.23	284.47	311.83	286.42
6	314.66	304.18	304.36	298.00	310.72	284.19
7	318.77	304.30	297.39	295.24	309.52	281.96
8	303.38	308.68	295.13	287.86	306.33	285.97
9	312.83	299.11	301.04	286.85	311.77	289.09
10	315.76	307.08	284.15	286.79		293.20
STD	11.16	4.86	6.62	5.94	3.70	6.43

Table 10. Average CloudCompare Tread Measurements of the Ten(10) Steps in Each of the Six (6) Flights of the Second Stair in mm.

Step	1st	2nd	3rd	4th	5th	6th
1	191.53	185.73	179.38	180.63	200.41	195.33
2	185.33	179.69	166.85	128.13	145.67	139.67
3	185.19	171.56	169.24	123.60	141.62	130.05
4	182.56	171.57	171.32	127.47	152.34	136.70
5	173.24	164.99	171.63	146.11	145.35	132.62
6	169.97	172.69	163.30	132.53	150.18	143.10
7	176.40	161.85	161.52	137.22	135.37	133.49
8	173.43	165.22	174.22	139.38	145.87	131.40
9	165.84	175.01	153.13	136.18	129.95	139.09
10	168.06	178.50	157.21	140.22	138.96	129.68
11	178.06	173.25	172.40	141.04		146.49
STD	8.13	7.02	7.82	15.26	19.41	18.64

Table 11. Average CloudCompare Rise Measurements of the Eleven (11) Steps in Each of the Six (6) Flights of the Second Stair in mm.

Flight		Average Measurements (mm)			
		First Stair		Second Stair	
		Tread	Rise	Tread	Rise
1st	A	291	187.7	327.7	188.5
	B	298.7	182.3	301	170.3
2nd	A	298	183.7	288.3	175.7
	B	289.3	181.7	285.3	164.3
3rd	A	299.3	162.3	319.5	162.7
	B	306.3	165	318.3	160
4th	A	289.3	139	298	136
	B	276	131.3	289.3	143.7
5th	A	323	164.3	314.8	162
	B	325	151.7	316.7	149
6th	A	297.3	131	314	140
	B	284.3	140.3	289	146.7

Table 12. Summary of the Average Actual Rise and Tread Measurements of Segment A and Segment B of the Six (6) Flights of the Two Stairs.