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Surface Waviness Evaluation of Two Different Types of Material of a Multi-Purpose Hall Using Terrestrial Laser Scanner (TLS)

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Abstract. The construction industry is rapidly integrating current technology and new construction techniques to increase productivity and efficiency in construction operations. Quality control and progress tracking are labour-intensive and time-consuming operations. Several surface waviness assessment methods have been created to alleviate the drawbacks of one assessment method over the other, focusing on measuring the quality of concrete slabs. Current methods of assessing waviness using one-dimensional (1D) survey lines produce inaccurate results and are prone to mistakes. It does not reflect the actual condition of the entire floor concerning waviness. Two objectives of this study are to 1) evaluate the feasibility of using Terrestrial Laser Scanner for surface waviness assessment using slope analysis of different types of material and 2) propose a valuate pattern and image for different slope surface analyses. Leica RTC 360 laser scanner was used to scan the floor of the Multi-purpose hall. The plan image of the floor slab and one of the 3D point clouds were recorded. Slope analysis shows a consistent pattern of slope distribution for floors with tiles. This is due to the tile used concrete screed during installation to have a smooth surface during construction. The distribution of slope analysis of tile surface mostly between 0 to 0.0625% while the slope analysis slope variation of laminated floor between 0% - 0.5%. The distribution shows that floor variation with the laminated wood surface is high, especially between 0 to 0.5%. From the result obtained, this method has the benefit of combining rich 3D data from TLS for fast and reliable surface waviness assessment during construction. This technology has massive potential in the construction sector because of its capacity to record as-built conditions consistently, fast, and accurately.

Keywords: Surface waviness assessment, terrestrial laser scanner, TLS, quality assurance and quality control

1. Introduction

Many industries are being transformed by emerging technologies focusing on improving product quality, increasing production rates, and lowering long-term costs. The construction industry is rapidly integrating current technology and new construction techniques to boost productivity and efficiency in construction operations. The construction industry's digitisation is being accelerated by incorporating these tools and technologies into construction operations. Project field engineers can track the progress of construction work using accurate as-built data received from ongoing construction projects.

Quality control and progress tracking are labour-intensive and time-consuming operations. Failure to communicate project performance with all involved parties effectively and timely leads to delays and cost overruns in construction work [1]. Furthermore, data produced manually for progress tracking may not be readily available for analysing project performance. It may be inferred that traditional tracking techniques in projects are unreliable and prone to error. Quickly identifying any differences enables necessary actions to reduce the impact of a delay on the building workflow.

Dimensions Quality Control (QC) ensures that items are manufactured to the prescribed dimensional tolerances. As-built dimensions of cast-in-place concrete elements often differ from those specified initially in as-designed plans [2]. The failure to detect the imperfections in newly constructed surfaces during the earlier stages of construction causes delays in carrying out necessary repair works [3]. The repair, demolition, removal, and replacement of defective concrete elements entail additional costs that could amount to as much as 12% of the project contract value [4-7]. It is critical to conduct prompt inspections after the completion of concrete elements, especially in terms of flatness and waviness.

Several surface waviness assessment methods have been created to alleviate the drawbacks of its practical use, focusing on measuring the quality of concrete slabs. The F-number approach, for example, was created to address the drawbacks of the Straightedge method, while the Waviness Index (WI) method was created to address the drawbacks of the F-number method. The lack of data linked with each of these methods makes it difficult to have a clearer picture of how elevations and undulations vary over time. Current methods of assessing waviness using one-dimensional (1D) survey lines may not accurately reflect the actual state or waviness of the entire floor. Bosché and Guenet [8] proposed integrating BIM and TLS to capture as-built elements that comply with the specified surface flatness tolerances using 3D point clouds obtained using TLS and data from BIM. Two objectives of this study are to:

- Evaluate the feasibility of using TLS for surface waviness assessment using slope analysis of different types of material, and

- Proposed a valuate pattern and image for different slope surface analyses.

2. Dimensional Quality Control in the Construction Industry

When it comes to concrete slabs, various elements influence the dimensional quality of cast-in-place concrete slabs, including hot temperatures, location, and finishing procedures used during construction. Waviness in concrete slabs causes problems that are not only unsightly but also hinder the efficiency of machineries such as lift trucks or very narrow aisle (VNA) vehicles. It is also affecting the health and safety requirement of sports facilities such as futsal and basketball court. The waviness of concrete slabs in industrial facilities, such as large warehouses, must be thoroughly examined because failure to detect waviness and deviations from specified tolerances can significantly impact the operational activities that the floor is designed to handle [9]. The effect of abnormalities in the floor on the stability of VNA vehicles is depicted in figure 1. Static lean (s) of VNA trucks are caused by differences in elevation between the left and right wheels (d). Because of the waviness of concrete slabs, the static lean can rise by ten times [10].

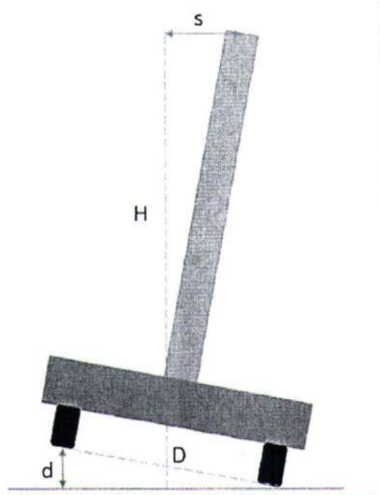
2.1. Current Methods of measuring concrete slab waviness

Surface imperfections are divided into two categories: "abrupt" and "gradual." Offsets and fins generated by displaced or misaligned formwork, loose knots, and other faults in formwork materials are examples of abrupt abnormalities that must be checked by direct measurement. Gradual imperfections must be verified using a straight template for level surfaces or a suitable counterpart for curved surfaces, measuring 3.0m for unformed surfaces and 1.5m for formed surfaces. A 3mm deviation from a 1.5m straight edge placed in any position on a presumably planar surface is commonly specified as a flatness tolerance. The existing methods for detecting concrete slab waviness in the construction sector require extensive human interaction, are labour intense and time-consuming. The Straightedge method puts a 3.0-meter Straightedge across a survey line on the floor and uses a stainless-steel slip gauge to measure the distance between the Straightedge and the floor [11]. The procedure of laying out the Straightedge over vast surface areas is time-consuming and results in random measurement mistakes [12]. This time-consuming method only offers information on the variances between as-built and as-designed locations at a few measured places.

The F-numbers approach was introduced to eliminate random mistakes in measurements by using devices that allow for the measurement of elevation changes at fixed intervals, resulting in more accurate findings. The F-number approach produces flatness numbers (Floor Flatness (FF) and Floor Levelness (FL) values) that are difficult to interpret. It gives two numbers to work that is FF and FL. The flatness of the measured floor surface point is described by FF, whereas FL describes the levelness of the measured floor surface point. The measurements are taken at 1-ft intervals along each survey line, as stated in the ASTM E1155-14 standard [13]. The values obtained from many survey lines are statistically processed to provide FF and FL figures that represent the conditions of the whole floor surface.

The WI method identifies different periods of floor undulation between 1.0 and 3.0 meters, which correlate to periods of surface undulation that affect forklift operation [15][16]. The WI method produces results that are expressed in inches and are therefore easier to interpret. Despite having a significant advantage over the Straightedge and F-number approaches, the WI method suffers from the same limitations. Because these procedures entail manually moving measurement equipment around the floor's surface, the findings are prone to human error. Inaccuracies in measurements are exacerbated by random errors, which can result from carelessness when handling measurement tools. The primary methodologies' significant limitation is the difficulty of recovering consistent results across multiple measurement sessions.

$$\frac{d}{D} = \frac{s}{H} \rightarrow s = \frac{d \cdot H}{D}$$



s - Static lean of a VNA truck in mm for D=1.2 m		d - Difference in elevation between the left and right wheels of a fork lift truck [mm]									
		3	4	5	6	7	8	9	10	11	12
H - height of racking [m]	6	15	20	25	30	35	40	45	50	55	60
	7	18	23	29	35	41	47	53	58	64	70
	8	20	27	33	40	47	53	60	67	73	80
	9	23	30	38	45	53	60	68	75	83	90
	10	25	33	42	50	58	67	75	83	92	100
	11	28	37	46	55	64	73	83	92	101	110
	12	30	40	50	60	70	80	90	100	110	120
	13	33	43	54	65	76	87	98	108	119	130
	14	35	47	58	70	82	93	105	117	128	140
	15	37	50	63	75	87	100	113	125	137	150
	16	40	53	67	80	93	107	120	133	147	160
	17	42	57	71	85	99	113	128	142	156	170
	18	45	60	75	90	105	120	135	150	165	180

Figure 1. The effect of the difference in elevation between the wheels on the static lean for a VNA [10]

2.2. Emerging technology for measuring concrete slab waviness

Accurate project as-built information is required for dimensional quality control measurements so that timely choices can be made. TLS is a modern surveying technology that is gaining traction in the construction industry. The adaptability of Terrestrial Laser Scanning (TLS) technology has been put to the test in a variety of construction industries applications. TLS has been used, for example, to analyse the conditions of remote sites where human access is difficult or risky [17], to create BIMs that represent the as-built conditions of building facilities [18], and to monitor construction progress.

TLS is gaining popularity for dimensional QC because of its ability to quickly give as-built data in the form of dense and accurate 3D point clouds (with accuracy ranging from sub-mm to mm) [19]. TLS overcomes accuracy and repeatability issues and allows for capturing data representing the geometry of finished surfaces, overcoming the data sparsity restrictions of traditional surveying methods. TLS provides an effective technique for gathering dense as-built data spanning the entire slab surface compared to existing measurement equipment used in current standard flatness measurement methods. Fuchs et al. [20] and Shafer and Weber [21] developed deformation monitoring methods to discover the differences in positions of TLS data points concerning a reference surface when processing TLS data for QC. In [22], a colour map generated from TLS data was used to analyse the flatness of multi-story building facades. Tang et al. [23] devised three techniques for determining the difference in elevation of points in a point cloud concerning a plane derived from a Building Information Modelling (BIM) model or a user-specified plane. The method described in [24] employed an elevation map with different colours representing different height intervals. This method displayed each point's height concerning a reference plane derived from a BIM model. These methodologies and current approaches identified areas with varying degrees of deviation, but they failed to quantify the waviness or duration of surface undulations.

3. Method

As summarised in figure 2, the proposed methodology was used to test the applicability of the proposed framework to dimensions and surface QC of surface flatness. The input is a raw point cloud that may result from the scanning process's co-registration of numerous scans. The registered point cloud data noise is removed using a commercial point cloud processing software's capability, leaving a clean point cloud of the area of interest (i.e. concrete slab). The slab surface's pre-processed point cloud is aligned (parallel) to the XY plane, which is most likely already the case. As a result, z coordinates represent each point's elevation, making subsequent analysis more manageable. The raw 3D point cloud comprises data points from a floor area and its immediate surroundings and structures. Several laser scans are often co-registered using a conventional target-based approach to create the point cloud. The raw point cloud is first pre-processed to isolate the area of interest, the concrete slab, from the rest of the data. The next stage is to create a depth map representing the undulating zones corresponding to several undulations types. A Leica RTC 360 laser scanner was used to scan the warehouse building's floor slab. After putting up the scanner's tripod, an in-situ floor slab from UPNM's multi-purpose hall was scanned. At 50 metres, the scanner's 3D position accuracy is 3 mm, and at 100 metres, it is 10 cm.

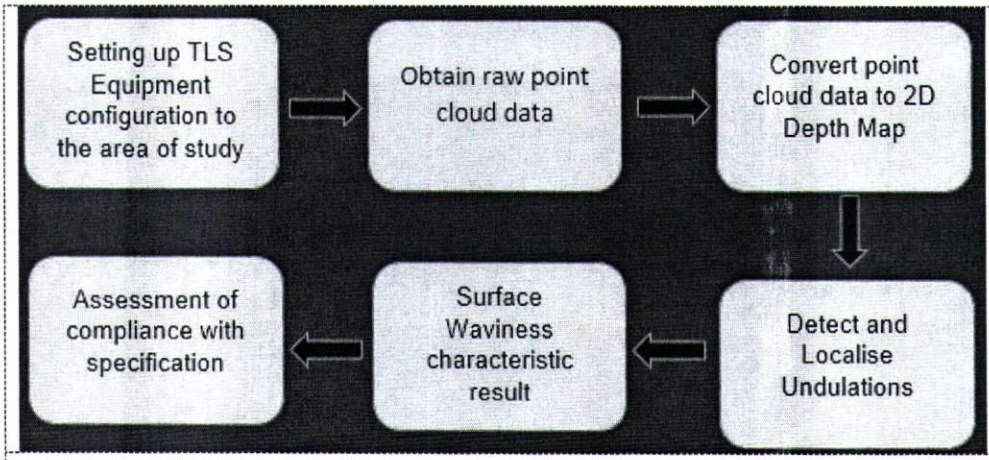


Figure 2. Overview of the research methodology.

4. Result and discussion

A Leica RTC 360 laser scanner was used to scan the floor of the hall. The plan image of the floor slab and one of the 3D point clouds recorded are shown in figure 3. In both the plan view and the point cloud, the region of interest with a surface area of roughly 100 m^2 is marked. To make the point cloud registration process more manageable, six targets were set at various points around the facility. The entire scanning process took around 45 minutes, including setup, scanning, dismantling, and relocating. The raw point clouds, which included noise from laser scans, were initially loaded into commercial point cloud processing software. There were approximately 100,000,000 points in the point cloud corresponding to the slab region of interest. Figure 4 shows the data analysis process using Cyclone Register 360 and Cyclone 3DR.

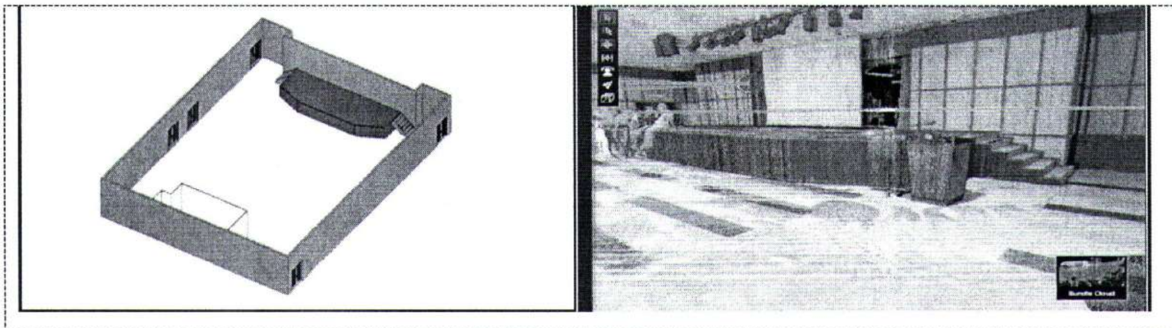


Figure 3. The plan view and the 3D point cloud view of the study area. The stage consists of the laminated wood floor, while the rest uses a tile surface.

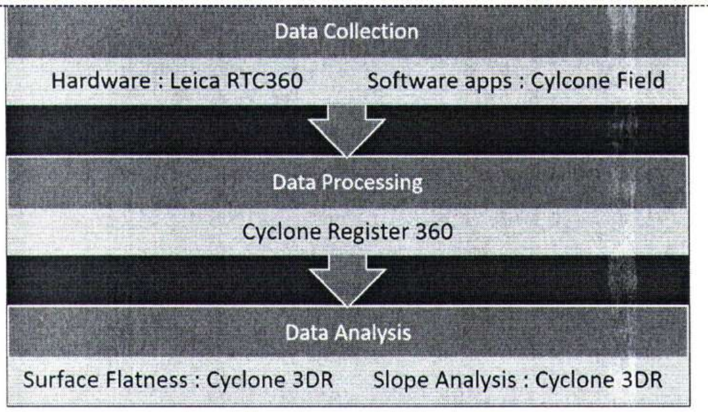


Figure 4. Hardware and software used for data processing and data analysis

The resulting slope analysis is shown in figures 5 and 6. Both surfaces were analysed for 1.0% and 0.5% slope to see the surface flatness using the cyclone 3DR software. Figure 5(a) shows result for floor with tile surface with slope variation between 0% to 1% while figure 5(b) shows area slope variation between 0% - 0.5%. Both slope analysis shows a consistent pattern of slope distribution. The traditional tile installation methods relied on secondary mortar beds placed over underlying concrete slabs to provide a level and smooth profile for ceramic tile installations. The slope percentage for tile surface is mostly between 0 to 0.0625%, which is well in the specification for concrete flatness (not more than 6mm for every 1500mm).

Figure 6(a) shows the result for the floor with the laminated wood surface with slope variation between 0% to 1%, while figure 6(b) shows area slope variation of laminated wood surface between 0% - 0.5%. The distribution shows that variation of the wood surface is high, especially between 0 to 0.5%. The installation of the laminated wood does not have any material to cater to the waviness of the concrete surface. From the result obtained, this method has the benefit of combining rich 3D data from TLS.

According to the testing results, the suggested approach provides efficient colour-coded deviation maps to depict the flatness information of construction surfaces or component surfaces. When comparing the two experimental results, it becomes clear that the construction surface of a wood-laminated floor requires further investigation. The proposed method demonstrates an efficient method for quickly locating areas with large deviations or places that deviate from the as-designed model. Because concrete surface waviness quality control is critical for construction, there is a rising need to present an automated waviness evaluation method to replace the time-consuming existing human testing methods.

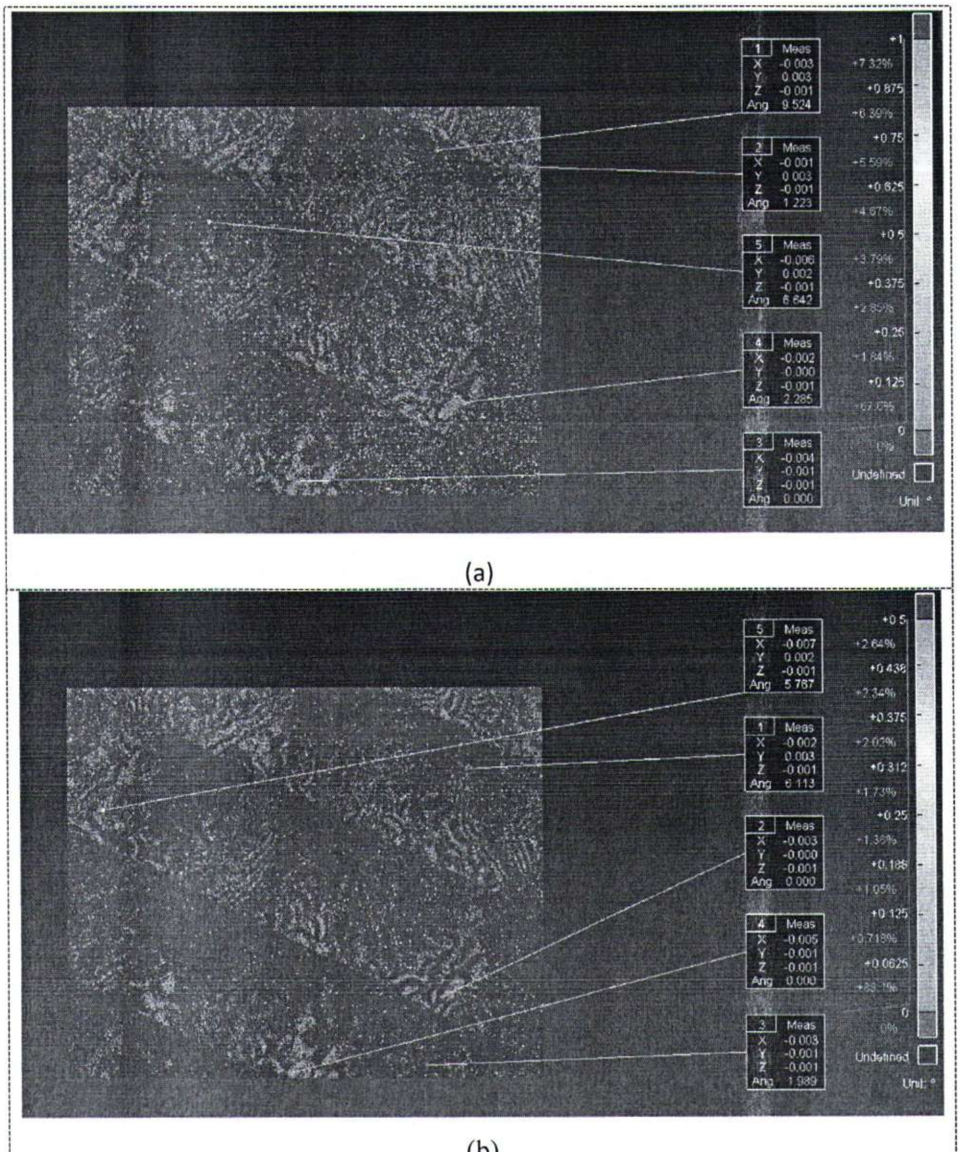
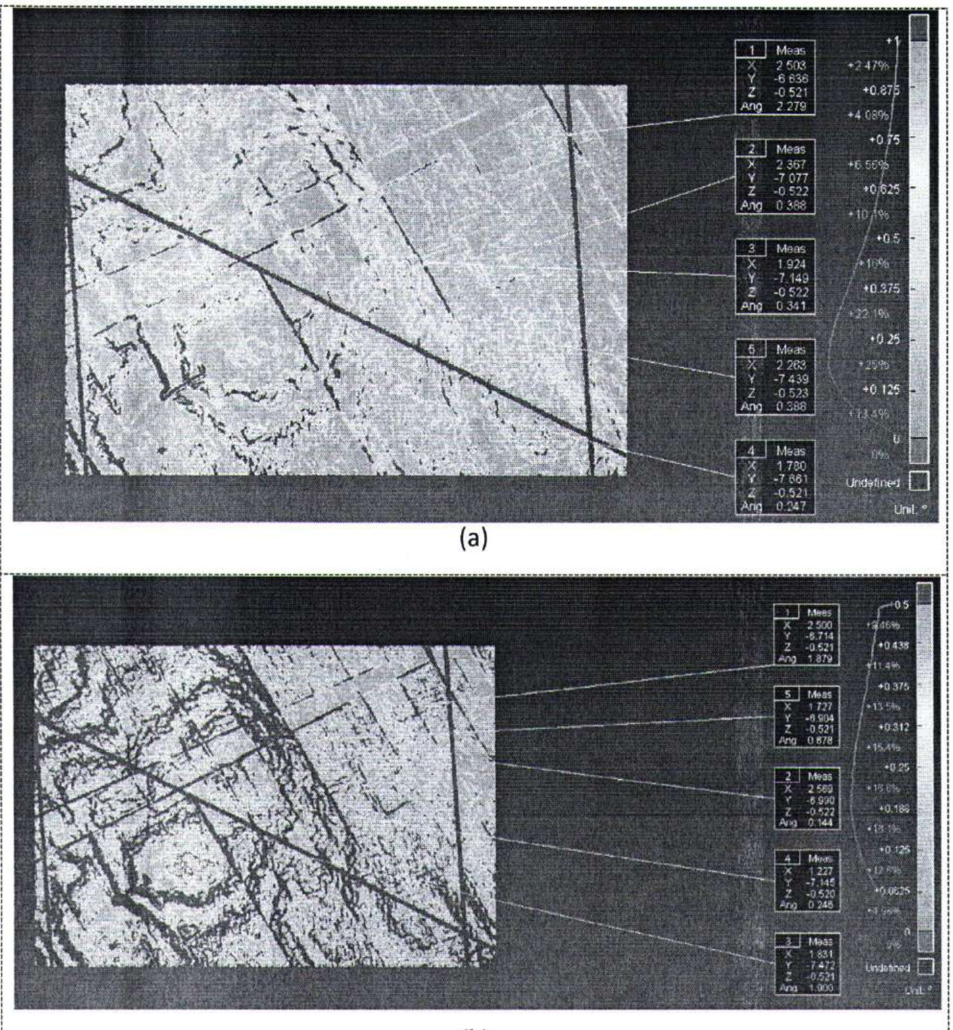


Figure 5. Slope analysis for floor with tile (a) 1% slope and (b) 0.5% slope.



(a)

(b)

Figure 6. Slope analysis for floor with laminated wood (a) 1% slope and (b) 0.5% slope.

5. Conclusions

Because of its capabilities to capture and record as-built elements quickly and accurately, TLS has considerable potential in the construction sector. One such area is dimensional quality control. The dimensional QC analysis provides versatility when looking at surface undulations with a wide range of distinct periods. The distribution of deviations on each surface can be easily analysed, quickly locating the area at the actual location on the surface. In particular, the area with high deviations often appears near the adjacent edges of two surfaces localisation in compliance evaluation and corrective work planning by highlighting regions on the surface. Future research efforts should focus on enhancing the practicality of using laser scanning to measure the waviness of surfaces. This paper proposed a method for automatically evaluating concrete surfaces and precast concrete component surfaces. To illustrate the distribution of waviness information of surfaces, a colour coded deviation map is provided. The technology suggested in this paper can visualise undulations according to various characteristic periods on site.

References

[1] J.D. Owolabi, L.M. Amusan, C.O. Oloke, O. Olusanya, P.F. Tunji-Olayeni, O. Dele, N.J. Peter, I.O. Omuh, "Causes and effect of delay on project construction delivery time," International Journal of Education and Research, vol. 2, no. 4, pp. 197–208, 2014.

[2] D. K. Ballast, Handbook of Construction Tolerances, Second. John Wiley & Sons, 2007.

[3] H. P. Gillette, C. S. Hill, C. T. Murray, H. B. Kirkland, and S. C. Hadden, Engineering and Contracting, no. v. 39. Gillette Publishing Company, 1913.

[4] McKinsey Global Institute, "Reinventing Construction: A Route to Higher Productivity," 2017.

[5] U. S. Census Bureau., "Value of construction put in place at a glance," 2013.

[6] J. L. Burati and J. J. Farrington, "Costs of quality deviations in design and construction," Bureau of Engineering Research, the University of Texas at Austin, 1987.

[7] Patterson and W. B. Ledbetter, "The cost of quality: A management tool," in Excellence in the Constructed Project, 1989, pp. 100–105.

[8] F. Bosché and E. Guenet, "Automating surface flatness control using terrestrial laser scanning and building information models," Automation in Construction, vol. 44, pp. 212–226, 2014.

[9] F. Bosché and B. Biotteau, "Terrestrial laser scanning and continuous wavelet transform for controlling surface flatness in construction – A first investigation," Advanced Engineering Informatics, vol. 29, pp. 591–601, 2015

[10] F. R. Neal, Concrete Industrial Ground Floors. Thomas Telford, 2002.

[11] D. K. Ballast, Handbook of Construction Tolerances, Second. John Wiley & Sons, 2007.

[12] B. M. Phares, G. a. Washer, D. D. Rolander, B. a. Graybeal, and M. Moore, "Routine Highway Bridge Inspection Condition Documentation Accuracy and Reliability," Journal of Bridge Engineering, vol. 9, no. 4, pp. 403–413, 2004.

[13] American Society for Testing and Materials (ASTM), "Standard Test Method for Determining F F Floor Flatness and F L Floor Levelness Numbers (Metric) 1," ASTM, vol. 96, no. Reapproved 2008, pp. 7–14, 2015.

[14] American Society for Testing and Materials (ASTM), "Standard Test Method for Determining Floor Tolerances Using Waviness, Wheel Path," ASTM vol. 04, no. November 1998, pp. 1–12, 2004.

[15] C. N. Ytterberg, "Using the Waviness Index To Improve Floor Flatness," 1996.

[16] R. E. Loov, "Is the F-number system valid for your floor?" Concrete International, 123 vol. 12, no. 1, pp. 68–76, 1990.

[17] G. S. Cheok, W. C. Stone, R. R. Lipman, C. Witzgall, and J. Uisod, "Lidars for construction assessment and update," vol. 9, no. 5, pp. 463–477, 2000.

[18] H. Son and C. Kim, "Advanced Engineering Informatics Semantic as-built 3D modelling of structural elements of buildings based on local concavity and convexity," Advanced Engineering Informatics, vol. 34, no. August, pp. 114–124, 2017.

[19] M.C. Amann, T. Bosch, M. Lescure, R. Myllyla, and M. Rioux, "Laser ranging: a critical review of usual techniques for distance measurement," Optical Engineering, vol. 40, no. 1, pp. 10–19, 2001.

[20] P. A. Fuchs, G. A. Washer, S. B. Chase, and M. Moore, "Applications of LaserBased Instrumentation for Highway Bridges," Journal of Bridge Engineering, vol. 9, no. 6, pp. 541–549, 2004.

[21] T. Schafer and T. Weber, "Deformation measurement using terrestrial laser scanning at the hydropower station of Gabcikovo," in INGEO 2004 and FIG Regional Central and Eastern European Conference on Engineering Surveying, FIG, Copenhagen, Denmark., 2004.

[22] M. C. Israel and R. G. Pileggi, "Use of 3D laser scanning for flatness and volumetric analysis of mortar in facades," vol. 9, no. 1, pp. 91–106, 2016.

[23] P. Tang, B. Akinci, and D. Huber, "Characterisation of three algorithms for detecting surface flatness defects from dense point clouds," IS&T/SPIE Electronic Imaging, vol. 7239, p. 72390N–72390N, 2009.

[24] N.J. Shih and P.-H. Wang, "Using point cloud to inspect the construction quality of wall finish," Proceedings of the 22nd eCAADe Conference, no. October, pp. 573–578, 2004.128