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Critical Evaluation of Time and Cost of Terrestrial Laser Scanning for Construction automated QA analysis

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Critical Evaluation of Time and Cost of Terrestrial Laser Scanning for Construction automated QA analysis

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Abstract– Many governments agencies and private owners are demanding up-to-date information related to the current conditions of their facilities. Conventional QA is time-consuming and inefficient; thus, 3D terrestrial laser scanning (TLS) technology has been adopted due to the fast speed and high accuracy in acquiring data. Automated QA analysis can reduce the labour and time needed, reduce the costs, and improve the overall project efficiency. However, very few research efforts have been made to study the benefits of the automated QA analysis in a quantitative way. The process of the TLS-based geometric QA based in an automated data analysis process is described and the data is collected from a case study. It is analysed the performance between the approach with the verity software using a RCP file and the approach with the verity software using a LGS file. The results show for QA time that TLS based QA automated analysis approach with verity software using a LGS file is slightly more efficient (E_t is 1.464 m^2/h) than using verity software using a RCP file (E_t is 1.398 m^2/h). For QA cost, the results show that TLS based QA automated analysis using TLS approach with verity software using a RCP file and LGS file tended to have the same cost efficiency E_c. With the increase of GFA values the E_c is higher on the purchase than the rental of TLS equipment. Variations of the cost of QA automated analysis are affected by the fluctuation of the labour cost, equipment cost and software cost. New costs can easily input into the proposed model developed in this study for further analysis.

Keywords – Building Information Modelling (BIM); Construction automated quality assurance (QA); Terrestrial laser scanning (TLS); Digital technologies.

I Introduction

Many governments agencies and private owners are demanding up-to-date information related to the current conditions of their facilities (Anil, Tang, Akinci, & Huber, 2013) to ensure the success of construction projects, quality assessment (QA) is implemented to avoid potential problems from occurring (Guo, Yuan, & Wang, 2020).

The deviation analysis method as a way of assessing the quality of as-is BIMs generated from the laser scan point cloud data based on certain quality requirements will not only minimize the safety-related risk of construction but also guarantee the duration of service life and economic value of the project (Guo et al., 2020). This method classifies and analyses the deviations between the as-designed and the as-is BIM geometries (Anil et al., 2013). The process of geometric quality assessment (QA) can be separated into three main steps: QA data collection, QA data processing and QA data analysis (Anil et al., 2013). The QA data collection aims to obtain the as-built geometry of the elements on-site. Then, the QA data processing organizes and manipulates the raw data into a standardized format that can be used for comparison with the as-design geometry. In the end, the QA data analysis is conducted to identify the deviations between the as-built and as-designed geometries that could be performed manually or could be automated with software support (Guo et al., 2020).

Conventional QA is time-consuming and inefficient as all process is executed manually (Chalhoub, Ayer, & Mccord, 2021; Liu, Chen, Kayacan, Tiong, & Maruvanchery, 2015; Mellado, Wong, Amano, Johnson, & Lou, 2020) and can be subjective and unreliable because depends on a skill level of the operator (M.-K. Kim, Cheng, Sohn, & Chang, 2015; Phares, Washer, Rolander, Graybeal, & Moore, 2004; Wang, Kim, Cheng, & Sohn, 2016). In recent years, 3D terrestrial laser scanning (TLS) technology has been adopted due to the fast speed and high accuracy in acquiring data (Guo et al., 2020; Wang, Kim, Cheng, et al., 2016) and some studies have been demonstrated that is more time-efficient and cost-beneficial to use this technology in the long term (Guo et al., 2020; Tang, Wang, Wang, Guo, & Zhang, 2022).

Regarding to the restricted functions of the current software available, construction companies used to compare manually the as-design model with the as-built scan data with BIM coordination tools (e.g. Autodesk Navisworks) for QA data analysis (M.-K. Kim, Sohn, & Chang, 2014). Nevertheless, such manual approach is time-consuming and relies on the accuracy of manual matching skills of the operator (Guo et al., 2020).

There have been several articles that demonstrated the automated QA analysis can reduce the labour and time needed, reduce the costs, and improve the overall project efficiency. However, very few research efforts have been made to study the benefits of the automated QA analysis in a quantitative way. The aim of this research is to quantitatively study the time and cost of TLS-based geometric QA based on automated data analysis in the Irish AEC industry.

Section 2 of this paper will critically review the literature of the previous research efforts on the implementation and the benefits of 3D TLS in the construction sector. It will also be reviewed the time and cost for digital information technologies and the TLS hardware models available and lastly it will critically review the algorithms and software developed for TLS-based QA analysis.

In Section 3, the methodology is described in detailed. Section 4 describes the case study and time and cost information. In Section 5, an analysis of the results is conducted and presents a further discussion.

II LITERATURE REVIEW

a) The implementation and the benefits of 3D TLS in the construction sector

The TLS applied in construction industry have been investigated and become mature in the recent years (Wang & Kim, 2019). These days a sets of geometric coordinates information can be generated by 3D point clouds obtained from TLS to create the as-built model with high efficiency and accuracy (Wang, Tan, & Mei, 2020; Wu, Yuan, Tang, & Tian, 2022).

Bosché (2010) automatically recognised the 3D CAD model elements for calculating the as-builts poses of the objects. It revealed the potential of this approach in as-built dimension calculation and control. Demiralp et al. (2012) analysed how investment of automated data collection technologies would be shared among different parties through a case study. Dai et al. (2013) led a qualitative comparison of the accuracy, quality, time efficiency, and cost of the image-based approach and the TLS based approach for the 3D reconstruction of infrastructure and demonstrated that imaged based approach have a lower cost than TLS though only creates medium accuracy quality.

Anil et al. (2013) presented a method for assessing the quality of as-is BIM's generated from point cloud data by analysing the patterns of geometric deviations between the model and the point cloud data. Yen at al. (Yen, Lasky, & Ravani, 2014) presented a cost-benefit analysis of adopting a mobile TLS for highway infrastructure applications considering the asset management, preservation, maintenance, and operational planning. Seven options of deployment of mobile TLS were analysed including different accesses (e.g., purchase and rent) at different levels of partial ownership of equipment.

Further, Wang et al. (2016) presented an automated technique for precast elements, to estimate the dimensions with geometry irregularities based on point cloud data and a reference BIM model. Kim et al. (2016) proposed a BIM and laser scanning based quality inspection to automatically and precisely assess the key quality checklist of full-scale precast concrete elements, which achieved a measurement accuracy of around 3.0 mm for dimension and position estimation.

Ham and Lee (2018) proposed a structural safety diagnosis method with TLS and BIM technologies, which saved four months in construction time and 125 man-months in manpower. The results show that the proposed method would reduce 50% of the cost compared with the traditional approach. Nonetheless, the investment cost of the equipment and software, and cost-saving effect of the technology were not analysed.

Kim et al. (2020) used TLS to capture geometric and position information of prefabricated components in the process of bridge assembly and construction. Chalhoub et al. (2021) used immersive AR to identify the deviations from BIM in a ceiling plenum space and indicated that in instances where the accuracy is more important the reality capture technologies should be used.

Tan et al. (2020) developed an automated geometric quality inspection technique for prefabricated housing units using building information modelling (BIM) and light detection and ranging (LiDAR). The experiments also showed that the proposed technique greatly improves the inspection efficiency regarding time and labour.

Honti et al. (2020) studied the automated verification geometry of building components using BIM models and point clouds and proposed an algorithm to use in the verification process.

Guo et al. (2020) conducted a quantitative analyses of the time and cost benefits of TLS-based geometric QA/QC for structural columns after structural works are completed. Three geometric QA/QC approaches were compared, including the conventional approach, two TLS-based approaches with manual data analysis and automated data analysis, respectively. The equipment purchase and rental were both considered. However, only dimensional deviations of the structural columns were studied, without the other components and the QA automated data analysis was performed using a pre-developed program in Autodesk Dynamo, not using the commercial software.

Most recently Zhao et al (2022) conducted an inspection for installation quality of high formwork using TLS technology and suggested that the proposed method is superior to other common techniques for obtaining the required data needed to measure accurately the overall structure dimensions, regarding the accuracy of the data, time, and cost. Tang et al. (2022) provided a quantitative analysis of the time and cost benefits of TLS-based geometric QA/QC of buildings in comparison with the conventional approach. The results show that the TLS-based QA/QC approach is more efficient than the conventional due to reduce data collection time and regarding the cost the TLS-based QA/QC approach with rented TLS has a lower cost in a single project and a purchase TLS-based approach is the most economical choice in a company for a long term.

b) Time and Cost review of digital information technologies

Previous researchers have been making efforts with the aim of evaluating the adoption of digital information technology tools in the construction sector from quantitative and qualitative perspectives.

For example Barlish and Sullivan (2012) studied the benefits of the BIM implementation by comparing BIM and non-BIM case studies. It was reported a case study containing large industrial settings where analogous projects were evaluated through the developed cost or investment metrics to reflect the economic benefit or return.

Further, Love et al. (2013) in facility management and Bryde et al. (2013) both take into consideration the return investment (ROI) on adopting BIM and integrating intangible benefits and indirect costs. Grau et al. (2009) evaluated the impact of material tracking technologies across a massive field trial, demonstrating that this technology could considerably enhance craft labour productivity. Jang and Skibniewski (2009) conducted a cost-benefit analysis to explain the labour savings based on a comparative study with manual materials tracking with sensor-based materials tracking. Flanagan and Marsh (2000) analysed the range of IT available for construction companies, the level of uptake, and the barriers of organizations in applying IT.

Later, Kim and Kim (2011) quantified the process of cost of IT-based quality inspection. The method of time-driven activity-based costing was used to conduct the cost analysis of IT-assisted quality inspection and showed its efficiency. Vaughan et al. (2013) implemented a case study research to compare the distribution of time spent in various tasks of a construction IT system, and this study separated the cost into purchasing cost and implementation cost to analyse the benefits.

Some other researchers studied innovative modern equipment-based IT. For example, Bohn and Teizer (2010) analysed the benefits and barriers of high-resolution automated cameras by ranking the importance degree of different work tasks including duration, budget and stories based on interviews and surveys. Irizarry and Costa (2016) presents a case study that identifies potential applications of visual assets obtained from UASs for construction management tasks and performed a cost analysis of the construction projects. Based on a case study, Garcia de Soto et al. (2018) performed a time-cost analysis of robotic fabricated walls to measure the productivity.

c) *3D TLS Models*

The good performance of TLS enhances the feasibility of the TLS-based construction QA process. There are four most common commercial TLS models with similar specifications. The FARO Focus S150, Leica RTC360, Trimble TX8, and RIEGL VZ-400i. These are compared in terms of range, speed, field of view and scanning time in Table 1.

The maximum measurements ranges of FARO Focus S150, Leica RTC 360 and Trimble X8 are similar (120 m to 150 m) while the REIGL-VZ-440i is capable of 250 m. The range of the maximum speed is between 500,000 points per second and 2,000,000 points per second. The minimum ranges off all models have a few variation (0,5 m or 0.6. m). The horizontal field of view of 360° is shared among all the models, while the vertical fields of view of all models are approximate 300° with the exception for REIGL-VZ-440i which is 100°. All the models share the same minimum scan time approximately 1 min. In terms of price vary from 50,000 € to 110,000 €, these prices are influenced on the vendor and the country/region. It is important to mention that FARO Focus S150 model operates with a phase-shift based technology while the Leica RTC 360 and Trimble X8 uses a time-of-flight capturing technology.

Yan et al. (2019) incorporated a laser scan with a robot facilitating the automation of the quality inspection and assessment of building defects. TLS equipment normally is fixed on a tripod during the performance of the scans but recently innovative devices as robots are used to fix the TLS enabling the mobility of the hardware. Recently, the 3D TLS hardware have been integrated with the Boston Dynamics Spot Mobile Robot allowing construction scans to be automated (Rubenstone, 2020).

Table 1: Technical specifications of 3D TLS models

TLS model	**Speed (points per second)**	**Range (m)**	**Minimum Scan time**	**Field of view (horizontal/vertical)**	**Price (€)**
Leica RTC 360	2,000,000	[0.5–130]	<2 min	360°/300°	50,000
FARO Focus S150	976,000	[0.6–150]	1 min	360°/300°	60,000
Trimble TX8	1,000,000	[0.6–120]	1 min	360°/317°	70,000
RIEGL VZ-440i	500,000	[0.5–250]	1.5 min	360°/100°	110,000

d) *Algorithms and Software developed for TLS-based QA analysis*

Over the last few years, the development of algorithms that enhances the automated and semiautomated geometric QA analysis has been investigated by several researchers. The surface and dimensional proprieties of the building components have been analysed by these algorithms. Bosché and Guenet (2014) examined the floor flatness with the Straightedge and F-numbers methods from TLS data. Bosché and Biotteau (2015) evaluated the flatness of planar surfaces based on the continuous wavelet transform algorithm. Yan et al (2019) assessed the vertically alignment of the walls by calculating the angle between the planes after planes were automatically extracted from TLS data. An automatic algorithm to measure the surface distortion of the precast concrete elements using TLS was analysed by Wang et al. (2016). Truong-Hong et al. (2012) introduced an algorithm that detects building boundaries and features and converts the point cloud data into a solid model allowing to measure the length, width, and opening dimensions of the elements. Tan et al. (2020) proposed an automated geometric quality inspection technique for prefabricated housing units comparing the as-designed BIM and the 3D laser scan data. Tran et al. (2021) developed a new framework for geometric quality assessment of as-built prefabricated facades based on comparison between as-designed BIM and the as-built created from the 3D laser scan data.

For the time being, commercial software programmes have been launched for TLS-based construction QA analysis enabling the automation of the QA process. FARO BuiltIT Construction and Geomagic Control X are specifically developed for QA and can inspect elements such as dimensions, flatness/evenness/levelness, and vertically/squareness and export quality inspections reports (3dsystems, 2022; FARO, 2022).

Rithm Inspector and Rithm for Navisworks tools are mostly used to create heatmaps and inspection reports of the surface flatness and levelness (ClearEdge3D, 2022) while Verity for Navisworks and Verity powered by Jetstream are software compare the TLS data of as-builts elements against the as-designed BIM model, measure the deviations and produce QA reports of the variance (ClearEdge3D, 2022)

III Experimental Research

a) Methodology

To study the time and cost of TLS-based geometric QA based in an automated data analysis quantitatively in the Irish AEC industry is necessary to provide a comparative study between the different ways of implementing the automated deviation analysis with the software available. The commercial software that can calculate the deviations of the TLS data of as-builts against the as-designed BIM model is Verity developed by ClearEdge3D. The Verity software can use any structured scan data that can be loaded into ReCap Autodesk file (RCP) or use a structure data that be loaded in Leica Geosystem file (LGS).

To perform time and cost analysis, this study is organized in the following four steps based on a case study. The detail process for TLS QA is first defined, which include QA preparation, QA data collection, QA data processing and QA data automated analysis. The QA process is defined based on a case study and interviews. The case study is to understand the general process of TLS QA based in automated analysis. The time and cost information of each task is collected from the case. Then, the collected raw information is processed to facilitate further analysis. Finally, time and cost analysis are performed with the processed data considering different gross floor areas (GFA) of a project. The TLS-based method with automated data analysis includes four steps: QA preparation, QA data collection, QA data processing, and QA data analysis.

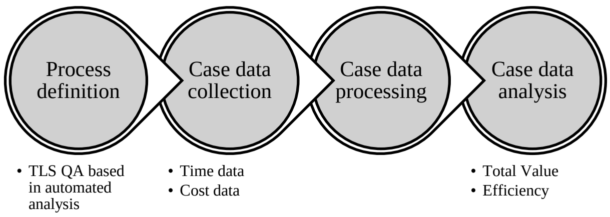


Figure 1 – Methodology process workflow.

a) TLS-based geometric QA based in an automated data analysis process

The TLS-based method starts with creating a scanning plan based on the drawings. Because each scan can only cover a certain area, multiple scans are needed to cover the entire site. Therefore, scanning plan is to determine the locations and sequence of scans, and determine the scanning parameters. The other preparation work is to identify three ground control points to facilitate the alignment between the scan data and BIM model (modelled with Autodesk Revit). Each control point is positioned by paper-made checkerboard, which is squared-shape and divided into black and white quarters. The checkerboards should be stuck onto the ground or reference points at the specific locations. After the preparation works, QA data collection is conducted to collect the laser scan data of the elements of the site according to the scanning plan. The TLS should be set up before conducting scanning at the very beginning, and then moved to the next location for each scan, the transportation between the construction site and the headquarter office are not considered in the process.

In QA data processing, the collected data are processed in the data processing software provided by the TLS vendor (Program Leica Cyclone Register 360 and Publisher Pro). The registration process initiates when the scan data collected from all scanning locations are filtered to remove noise data and to produce a single point cloud for the entire site. From the QA data processing two structure scan data files are produced to use in Verity software: the RCP and LGS files. Lastly, in QA data analysis, the obtained as-is scan data are automatically analysed against the as-designed model using Verity software developed by clear Edge 3D.

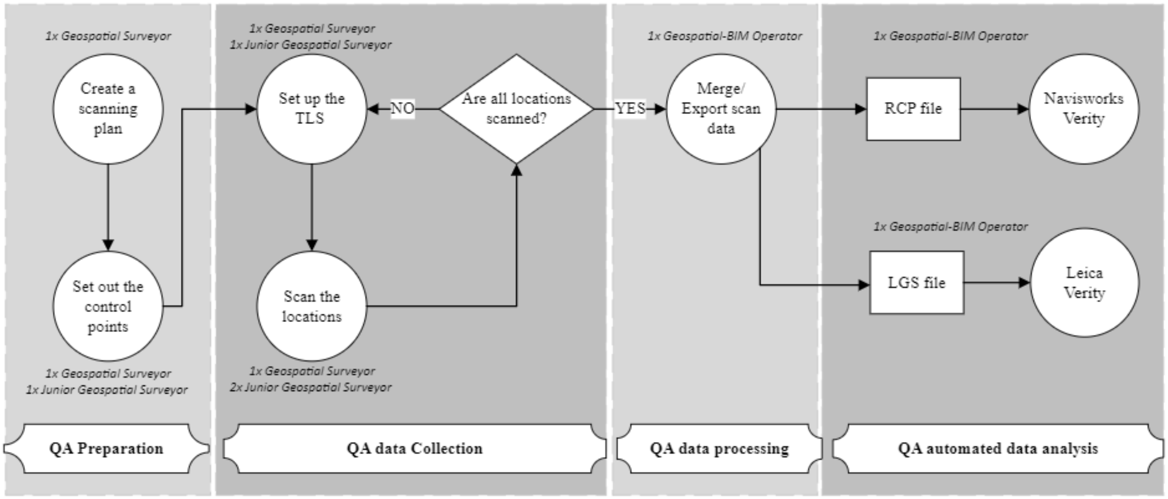


Figure 2 – TLS geometric based QA automated process workflow

b) Case data collection

This step aims to collect time and cost data for the method described. The time data are collected with the duration records. The duration records are utilized in tasks in QA preparation, QA data collection and QA data processing, where a stopwatch is available to calculate the duration of each task. While in QA automated data analysis tasks the report includes the processing time of each task. The elements analysed in the verity software against the as-builts laser scan data were the modelled architectural floors, architectural walls, structural columns, structural walls, and structural columns. The tasks were performed in a device with Windows 10 pro, 64-bit operating system, 32.0 GB RAM and an Intel (R) Core(T) i9 -10980 HK @ 2.40Ghz 3.10 GHz processor.

On the other hand, cost data are collected according to three categories: equipment, software, and labour. Note that only the cost items that are directly involved in geometric QA process are calculated. For equipment cost, the purchase and rental costs of the equipment are obtained through quotes from local supplier by inquiry on website. Note that both purchase and rental of TLS are considered in this study but only purchase of the total station is considered because it is a commonly used equipment in constructions firms. The software cost is calculated based on subscriptions in the website supplier. As for labour cost, the number, and types of workers for each task are identify first in Figure 2 and the salary of each type is obtained based on the average salary in the local industry of Ireland (Glassdoor, 2022)

c) Case data processing

This stage aims to process the raw data so that the case data can be extended to a more general scenario. The QA time and QA cost is processed on a project level. For QA time of a project is determined by the project GFA because a higher GFA often contains more elements to inspect and requires more QA time. Besides, because the durations of all tasks are depended on the project GFA, it is also assumed that the tasks durations are proportional to GFA, and the time per unit area is denoted as T_v (h/m^2). Therefore, the total QA time T (h) of a project is calculated as:

$$T = T_v \times GFA \qquad (1)$$

For the QA cost on project level, the total cost includes both fixed and variable costs. The fixed cost C_f (€) does not change when the project GFA changes while the variable cost is heavily determined by the project GFA. When considering the QA cost on project level, all software is regarded as single-use and exclusive to this project, therefore the cost of which are defined as fixed cost. As for labour cost, the classification of labour cost for certain task is consistent with the classification of time data for the same task. Thus, since the classifications of time for all tasks are variable, the labour costs are variable costs, which is proportional to the project GFA. For such variable cost, the cost per unit area is denoted as $C_{v1}(€/m^2)$. Regarding the equipment, the cost is classified as fixed cost when the equipment is accessed by purchase and exclusive to this project. With purchased equipment, the total cost C^pcan be calculated as Eq. (2.1.). While if the equipment is rented for the project, the cost becomes variable cost because the rental term depends on project GFA. However, the rental cost of TLS is not exactly proportional to GFA because is rented daily. Instead, the rental cost is calculated based on a daily rental cost C_{v2}(€/day) and the rental term N (day). Here, the rental term D is calculated based on the project GFA and is rounded up to the next integer.

The values of C_f , C_{v1} and C_{v2} are calculated by the summation of the cost of corresponding items. Therefore, the total QA cost C^p (€) of a project when the TLS is accessed by rent is calculated as Eq. (2.2).

$$C = \begin{cases} C_f + C_{v1} \times GFA, & if\ purchase\ a\ TLS \\ C_f + C_{v1} \times GFA + C_{v2} \times N, & if\ rent\ a\ TLS \end{cases} \qquad (2)$$

d) Case data analysis

According to the corresponding equations and data, the total time and cost of different QA approaches are predicted and calculated. In addition, to measure the degree of time and or cost efficiency with the change of GFA (or number of projects), auxiliary indicators to calculate time efficiency E_t (m^2/h) and cost efficiency E_c (m^2/€) are calculated as follows:

$$E_t = \frac{Q}{T},$$

$$E_c = \frac{Q}{C},$$

Where Q is the total project GFA, T is the total QA time and C is the total QA cost. Therefore, the lower the total time or cost for a specific GFA, the higher the efficiency.

IV CASE STUDY

a) Case description

The project chosen was undertaken at a construction site of a residential complex in Dublin with 12,600 m^2. As the project has a large-scale dimension, it was chosen as case study a sample of the basement with approximately 750 m^2. The TLS device used in this project was a Leica RTC360 and medium scan resolution 6mm point spacing at 10m was adopted.

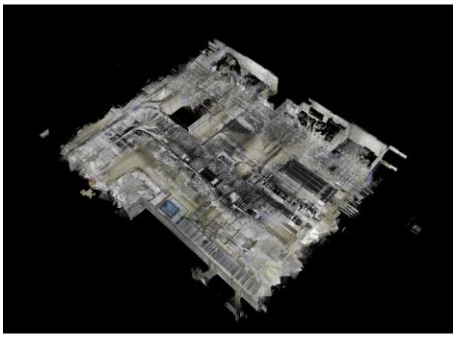


Figure 3 – Point cloud of the basement sample.

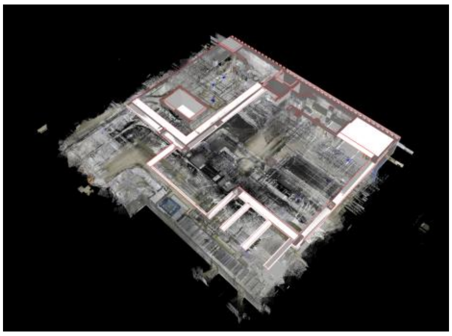


Figure 4– Point cloud and as-designed model overlayed of the basement sample.

b) Case data collection

a) Time data

The formulation of a scanning plan took approximately 0.5h and the duration of setting out control points was 0.1h. For data collection, it took 0.5 min to set up the scanner before each scan, and it took 2 min for each scan. Regarding the number of scans, to ensure enough data quality (e.g. accuracy and resolution). Based on the basement room sample 35 scans were conducted to effectively scan the entire area. The total time for scanner set-up was 2 min (0.033h) and the total time for conducting scanning was 70 min (1.16h), as shown in Table 2. Then QA data were registered and analysed with the software Leica Cyclone Register 360 and Publisher Pro. As it was analysed two different types of files the QA data processing took 2.67h to complete for the RCP file and 2.33h to complete for LGS file. For QA automated data analysis using the Verity software for Navisworks took on 0.929 h for the RCP file and using the Leica Verity software 0.993 h for the LGS file.

Table 2 – Time data

Process	Task	Time (h)
QA preparation	Create a scanning plan	0.500
	Set out the control points	0.100
QA data collection	Set up the scanner	0.033
	Conduct scanning	1.167
QA data processing	Merge scan data and Export:	
	RCP file	2.67
	LGS file	2.33
QA data analysis	Automatic analysis the data and generate a report:	
	RCP file	0.929
	LGS file	0.993

b) Cost data

The cost types and detailed cost items were present in Table 3. After creating the scanning plan, the geospatial surveyor instructed a junior geospatial surveyor to set out control points. Next during the data collection, the

TLS was moved to the location according to the scanning plan by the junior geospatial surveyor, and the reference sphere set was placed by the geospatial surveyor. Following, the data were transferred to geospatial BIM operator for processing and analysis. It should be noted that the same software geospatial BIM operator oversaw data processing and analysis.

Table 3 – Cost types and items

Process	Task	Cost type	Cost item
QA preparation	***Create a scanning plan***	Labour	1 geospatial surveyor
	Set out the control points	Labour	1 geospatial surveyor and 1 junior geospatial surveyor
		Equipment	1 laser scan and reference sphere set
QA data collection	***Set up the scanner***	Labour	1 geospatial surveyor and 1 junior geospatial surveyor
		Equipment	1 laser scanner and reference sphere set
	Conduct scanning	Labour	1 geospatial surveyor and 1 junior geospatial surveyor
		Equipment	1 laser scanner and reference sphere set
QA data processing	***Merge scan data and Export:***		
	RCP file	Labour	1 geospatial BIM operator
		Software	Program Leica Cyclone Register 360 and Publisher Pro
	LGS file	Labour	1 geospatial BIM operator
		Software	Program Leica Cyclone Register 360 and Publisher Pro
QA data analysis	***Automatic analysis the data and generate a report:***		
	RCP file	Labour	1 geospatial BIM operator
		Software	Program Leica Verity Powered by JetStream & Cloudworks for Navisworks
	LGS file	Labour	1 geospatial BIM operator
		Software	Program Verity for Navisworks

According to this, costs of these required items were collected through interview and investigation, which is summarized in Table 4. For equipment, the electronic total station costed 25,000€, and the TLS with reference sphere costed 50,000€ if purchased, while it costed 500 €/day if TLS was rented. The maintenance cost of TLS was 2,500€ after first year's warranty. For software, the subscribe cost for Leica Cyclone Register 360 and Publisher Pro was 4,750€/year, Autodesk Navisworks Manage was 1,283 €/year. For the verification software programme, the subscription cost for Verity for Navisworks was 4,250 €/year and the Leica Verity Powered by JetStream and Cloudworks for Navisworks costed 5,500 €/year. For the cost labour, the hourly salary for a junior geospatial surveyor was 16.83 €/hour while a geospatial was 24.04 €/hour and the hourly salary geospatial BIM operator was 24.04 €/h.

Table 4 – Cost data

Cost type	Cost item	Cost Category	Unit	Value
Equipment	*Electronic total station*	*Purchase*	*€*	*€25,000.00*
	TLS and reference sphere set	*Purchase*	*€*	*€50,000.00*
		Rental	*€/day*	*€500.00*
		Maintenance	*€/year*	*€2,500.00*
Software	*Autodesk Autocad*	*Subscribe*	*€/year*	*€557.00*
	Autodesk Navisworks	*Subscribe*	*€/year*	*€1,283.00*
	Program Verity for Navisworks	*Subscribe*	*€/year*	*€4,250.00*
	Program Verity Power by JetStream and Cloudworks for Navisworks	*Subscribe*	*€/year*	*€5,500.00*
	Program Leica Cyclone Register 360 and Publisher Pro	*Subscribe*	*€/year*	*€4,750.00*
Labour	*Junior geospatial surveyor*	*Salary*	*€/h*	*€16.83*
	Geospatial surveyor	*Salary*	*€/h*	*€24.04*
	Geospatial-BIM Operator	*Salary*	*€/h*	*€24.04*

c) *Case data processing*

a) *Time data*

As discussed in section b) a) case data analysis, time is calculated as the time per unit area. As time per m^2 could be extremely small. This study takes 100 m^2 as the unit area. Therefore, the variable time was computed in hours per 100 m^2. The values of T_v using a RCP file and Verity for Navisworks was 0.720 h/100m^2 and using a LGS file and Leica Verity was 0.683 h/100m^2.

b) *Cost data*

Based on this single project and on the collected cost data in Section b) c) the cost data is summarized in Table 5 . Fixed costs were in € while variable costs are defined in €/100m^2 or €/day. Because of the duration of the rental TLS was calculated in days, the number of renting days was estimated based on 8 hour a day. Because some software and equipment were used in two or more than two tasks, the cost of the corresponding item was only calculated for the first time if it is a fixed cost. Therefore, some cost items were zero.

Table 5 – Cost data for QA automated analysis process

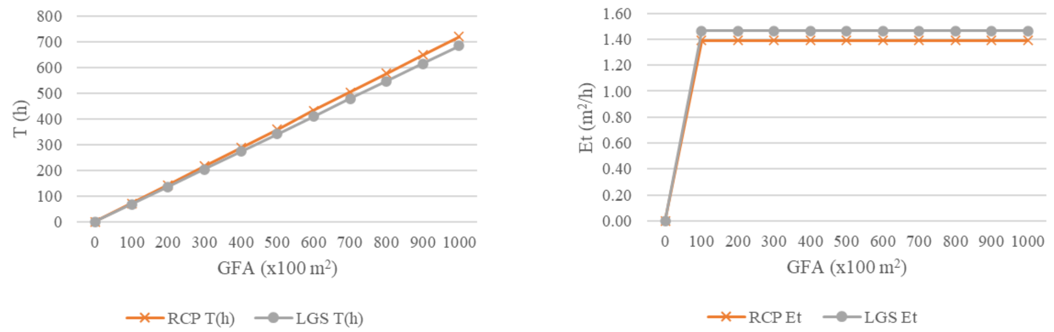
Process			**Purchase**			**Rent**		
	Task	***Cost Type***	***Cost Classification***	***Unit***	***Cost***	***Cost Classification***	***Unit***	***Cost***
QA preparation	Create a scanning plan	Labour	Variable	€/100m^2	1.603	Variable	€/100m^2	1.603
	Set out the control points	Labour	Variable	€/100m^2	0.545	Variable	€/100m^2	0.545
QA data collection	Set up the scanner	Labour	Variable	€/100m^2	0.254	Variable	€/100m^2	0.254
		Equipment	Fixed	€	50,000.000	Variable	€/day	500.000
	Conduct scanning	Labour	Variable	€/100m^2	8.974	Variable	€/100m^2	8.974
		Equipment	Fixed	€	0.000	Variable	€/day	0.000
QA data processing	***Merge scan data and Export:***							
	RCP file	Labour	Variable	€/100m^2	8.547	Variable	€/100m^2	8.547
		Software	Fixed	€	€4,750.00	Fixed	€	4750
	LGS file	Labour	Variable	€/100m^2	7.479	Variable	€/100m^2	7.479
		Software	Fixed	€	€4,750.00	Fixed	€	4750
QA data analysis	***Automatic analysis the data and generate a report:***							
	RCP file	Labour	Variable	€/100m^2	2.978	Variable	€/100m^2	2.978
		Software	Fixed	€	5533.000	Fixed	€	5533.000
	LGS file	Labour	Variable	€/100m^2	3.183	Variable	€/100m^2	3.183
		Software	Fixed	€	6783.000	Fixed	€	6783.000

V RESULT AND ANALYSIS

In this section it is compared the QA automated data analysis using the LGS and the RCP file by considering different GFA and is calculated the time efficiency E_t and cost efficiency.

a) *Time analysis*

The figure 5 (a) represents the total QA time for the automated analysis between the RCP and LGS file and Figure 5 (b) shows the comparison of the time efficiency between the RCP and LGS file. The maximum GFA was set to 100,000 m^2. The results reveal that, it was more time-saving and time efficient to choose the LGS file than the RCP. Figure 5 (b) demonstrated that the time efficiency of the two files has steady values at 1.389 m^2/h for the RCP and 1.464 m^2/h for the LGS file.

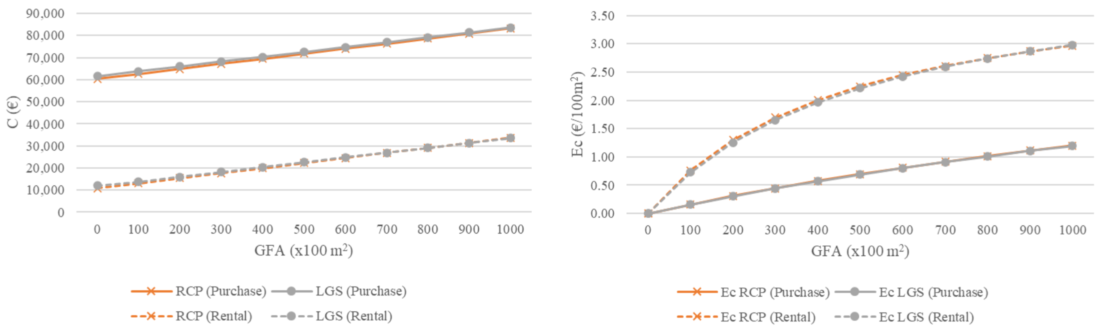


(a) (b)

Figure 5 – (a) Total time for QA automated data analysis using the RCP and LGS file , and (b) time efficiency for QA automated data analysis using the RCP and LGS file.

b) Cost analysis

The Figure 6 (a) and (b) represents the total costs and cost efficiencies for the QA automated analysis between the RCP and LGS file considering both purchase and rental of TLS. The cost of using the QA automated analysis with purchase TLS had the highest costs due to elevated TLS purchase cost and the lowest costs when the TLS is rented. Therefore, it can be concluded that the rental approach is considered the most cost-efficient. With the increase of GFA, cost efficiency E_c using for rental-based and purchase base tended to be the same 4.36 €/ 100m^2 using RCP file and around 4.53 €/100m^2 using the LGS file.



(a) (b)

Figure 6 – (a) Total cost for QA automated data analysis using the RCP and LGS file , and (b) cost efficiency for QA automated data analysis using the RCP and LGS file.

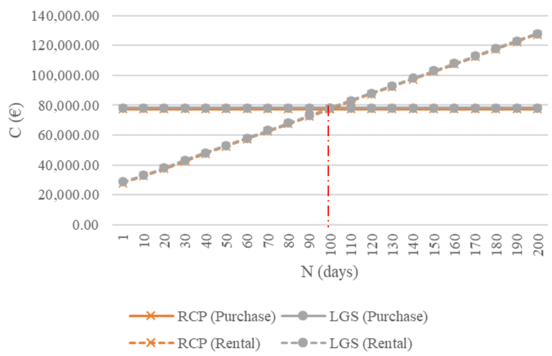


Figure 7 – Total cost for QA automated data analysis using the RCP and LGS file.

The Figure 7 shows the total cost for QA automated data analysis for both RCP and LGS file using the purchase and rental TLS for a fixed GFA value of 750 m^2. The difference between the RCP file and LGS file QA automated analysis costs is a steady value of 602.75 € for both purchase and rental TLS options. For N values approximately below 100 days it is observed that is more cost beneficial to rent the TLS equipment, while for N value greater than 100 days the cost of purchase of the TLS equipment option is lower.

VI CONCLUSIONS

This study researched quantitatively the time and cost of the TLS based QA automated analysis by comparing the performance between the approach with the verity software using a RCP file and the approach with the verity software using a LGS file. A case study was presented to collect time and cost data through time duration records and through quotes from local supplier by inquiry on website. The processed of these two approaches are identified and tasks are described. Then, a case study is presented to acquire the time and cost data. The collected data were then analysed to calculate the time and cost with varying GFA and N values. Additionally, both purchase and rental of TLS were studied for the cost analysis.

For QA time, the results show that TLS based QA automated analysis approach with verity software using a LGS file is slightly more efficient (E_t is 1.464 m^2/h) than using verity software using a RCP file (E_t is 1.398 m^2/h). The difference between both efficiencies is 0.075 m^2/h, it is considered residual and means that both have an identical time efficiency value.

For QA cost, the results show that TLS based QA automated analysis using TLS approach with verity software using a RCP file and LGS file tended to have the same cost efficiency E_c. With the increase of GFA values the E_c is higher on the purchase than the rental of TLS equipment. For fixed value of GFA of 750 m^2 for N values approximately below 100 days it is observed that is more cost beneficial to rent the TLS equipment.

Nevertheless, it is necessary to mention that the comparisons are based on certain assumptions that affect the time and cost of the QA automated analysis. First variations of the cost of QA automated analysis are affected by the fluctuation of the labour cost, equipment cost and software cost. Therefore, new costs can easily input into the proposed model developed in this study for further analysis. Second the technology advancements can further improve the performance of the TLS and the commercial software contributing for time and cost benefits. In this case study is assumed that all workers have been training and able to perform all the tasks, the time and cost need of training are not considered and impact the time and cost analysis.

In this study it is considered that the QA tasks are performed in a completed project. It would be interesting to perform QA tasks during the construction phase while the project progresses particularly for tracking inspections. Future research is required on the integration of immersive technologies in the process developed. A limitation of this study is that it only provides a study for the RCP and LGS files, there are other types of point cloud files that needs to be studied. Also, this paper only presents an analysis of the architectural and structural elements on a residential building, more future research is required for other types of elements and other type of facilities.

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