Construction sites advancement monitoring by indoor mobile mapping systems or by TLS: the Gioa22 skyscraper case study

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Key words: slam, indoor mapping, advancement monitoring, toll structures

SUMMARY

The demands for automatic digital monitoring of the progress of the works in construction sites are constantly increasing. The answer to this need is usually provided through a workflow that involves scanning processes with laser scanner and / or photogrammetric surveys of the state of the art followed by the comparison between the state of advancement and the BIM model. The costs of the acquisition processes using static laser scanning technologies are however very high and therefore not applicable for a frequent monitoring of the state of advancement of the works. This study intends to verify whether it is possible to apply fast surveying techniques with 3D dynamic indoor mapping instrumentation based on SLAM technology, for the solution of this problem and if the accuracy of these instruments can fit the accuracies asked by the progress monitoring detection processes.

RIASSUNTO

Le richieste di monitoraggio digitale automatico dello stato di avanzamento dei lavori nel settore delle costruzioni sono in continuo aumento. La risposta a tale esigenza viene solitamente fornita attraverso un workflow che prevede la scansione con tecnologie laser scanner e/o fotogrammetriche dello stato di fatto a cui fa seguito il confronto tra lo stato di fatto e il modello BIM di progetto. I costi dei processi di acquisizione tramite tecnologie di scansione statica tramite laser scanner risultano però assai elevati e dunque non applicabili per un monitoraggio frequente dello stato di fatto. Il presente studio intende verificare se è possibile applicare tecniche di rilevamento speditivo con strumentazione di rilevamento dinamico 3D con approccio SLAM per la soluzione di tale problematica, ovvero se le accuratezze di rilevamento tramite queste tecnologie innovative sono sufficienti per l’esecuzione di tale attività di monitoraggio.

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1. CONSTRUCTION SITES PROGRESS MONITORING

The BIM approach (AGC, 2015; CRC Construction Innovation, 2007; Gu, N., and London, K., 2010) applied to construction has become indispensable for all civil engineering and construction sites of a certain importance. The BIM approach (Eastman, C. Et alii, 2008; Wong, AKD et alii, 2009; Fischer M., Kunz J., 2006) obviously does not consist in a simple design in three-dimensional digital mode but consists in an integrated philosophy that goes from the design, to the organization of the different construction phases up to the activities to support the management phases of the building over time. Within the management operations of the construction site phases, it is crucial to be able to manage the updating of the work progress phases, in the most reliable, rapid and automatic possible way (Kim, C. Et alii, 2013). There is a growing need to be able to automatically update the work status by monitoring platforms, which are based on updating the attributes associated with the individual elements of the BIM model, in order to be able to update the work progress status and therefore proceed with the management work, including in the digital process the administrative aspects of the construction site. It is necessary to be able to acquire a digital documentation of the progress status, in order to ensure the transparency and verifiability of the history of the construction project. There are several technologies that have been tested to acquire the data on the field and several workflows and processes have being tested to manage the acquisition of information in the field and to feed the managing DB. Going in the details, tripod based laser scanner technologies (Jacobs, G., 2008) seem particularly suitable for this purpose (Bosché, F ,. 2009) and the millimeter accuracy of the static laser scans are for use usable not only to study the progress of the works but also for an accurate monitoring of the metric characteristics of the built structures and to run a sophisticated “as built” vs “as designed” analysis. The full costs of this approach, caused by the timing of field survey and processing of the raw data and of the subsequent implementation phase of the monitoring processes (i.e. the comparison between the detected point cloud and the BIM model), do not allow to apply this approach is widespread and temporally dense activities. The innovative on the field automatic pre-alignment procedure installed in the latest laser scanner instruments, introduced by the most innovative tripod based laser scanner sensors (Wang, X. and Wu, X., 2019) have been of little use. The state of the art three-dimensional dynamic surveying technologies (Otero, R, et alii, 2020) through tools that integrate inertial systems, multibeam LiDAR sensors with a sophisticated management of the data detected through software based on SLAM algorithms, seem to allow a substantial and drastic reduction of the timing of acquisition in the field and of data processing, making the approach through these iMMS (indoor Mobile Mapping System) technologies compatible in terms of costs and timing with the need for monitoring the progress of the construction sites. However, the centimeter level accuracy of these mobile methodologies do not seem able to guarantee the monitoring of the geometric congruence of the building with the BIM project. In the this work we will therefore verify, in a real success story, if the approach of the IMMS systems, and in particular the accuracy and applied methodologies of practical on the field use, can allow to acquire three-dimensional models of 3D point clouds of a sufficient quality to allow to successfully run the progress monitoring analysis of construction sites.

2. SURVEYING TOOLS: HERON® MS Twin and Leica® RTC360

In order to verify the possibility of using a dynamic three-dimensional survey approach with SLAM approach (Weingarten, J, and Siegwart, R., 2005) to monitor the progress of the works on a construction site and in the order to compare the static and mobile approach, it was decided to use on the same test site, both the LiDAR mobile and the static laser scanner approach. As SLAM based instrument the HERON® MS Twin sensor has been selected (figure 1); equipped with a pair of VLP 16 Velodyne sensors (figure 1) and an IMU sensor, capable of providing 3D point cloud models, with reflectance, characterized by detection accuracies of the order of ± 3 cm, equal to the nominal accuracy of the multibeam LiDAR sensors used.

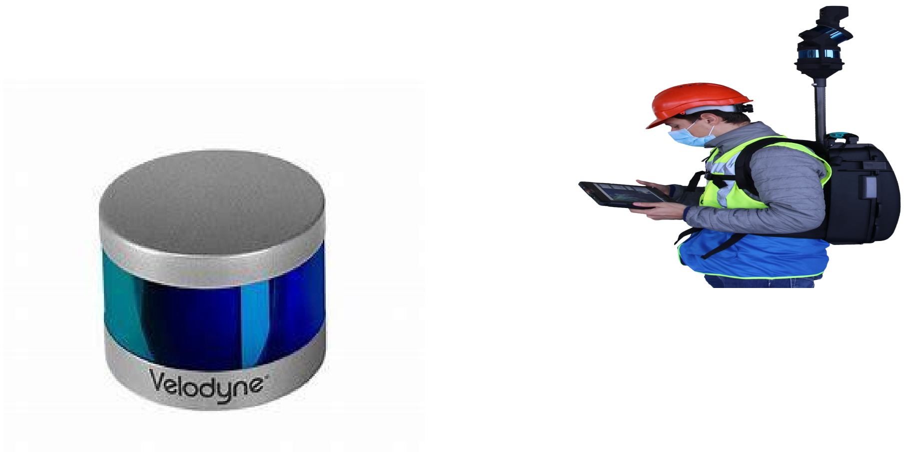


Figure 1: the sensor Velodyne® VLP16 (left side) and the HERON® MS Twin mobile mapping system (right side)

The multibeam 16 sensors of the Velodyne® VLP16 type are characterized by a range of up to 100 meters and a distance measurement accuracy of the order of ± 3 cm. Therefore, even if equipped with a sophisticated algorithm, the mobile instrumentation that implements them is characterized by a global accuracy in the generation of the 3D point cloud of the same order. These accuracies can only be improved by using data smoothing algorithms that can reduce the noise of the data, but can cause a decrease in the geometry quality detected in particular at the edges of the mapped structures. In this work we don't go in the detailed description of the instruments characteristics as for the small areas in which the instrument have been used (a few tens of meters on a multilevel structure), the accuracy of the point cloud obtained from similar systems that use the same type of sensor (VLP16 Puck Velodyne®) are sufficiently similar. The real differences between these different typologies of indoor mobile mapping systems are highlighted in their usability and in the management of acquisitions of large construction sites or those sites where particularly complex structures are present. This analysis is not the main subject of this work. For the laser scanner static acquisitions, a Leica® RTC360 sensor have been used, characterized by particular software features that allow a enough robust and fast scans pre-alignment of the field (figure 2), with a range measurement accuracy, declared by the manufacturer, of 1.9 mm at 10 meters (which is the average distance operated in the case described below).

Figure 2: The Leica RTC360 sensor with the tablet user interface with the automatic pre alignment process running, during the "Gioia 22" field test

For the Leica static laser scanner too, it is not considered appropriate to go into detail on the metric characteristics of the sensor, which are those typical of a mid-to-high-end sensor of construction site laser scanner sensors.

3. “GIOIA 22” TEST SITE

The site where the procedures have been testes, is a tool structures of 25 levels, located in the center of Milan (Nort Italy) (figure 3). The scanning activities have been applied at the 22nd and 22rd levels of the structure and along the stairs of the strucure, even if only for the tollest levels the construction progress workflow analyss have been applied (figure 4). The project of the buiding have been realized and managed in a IFC format, and only the structural model have been analysed. The mep and architectural information have been frozen.

Figure 3: The Gioia 22 building as appears in the center of Milan (Italy) (Courtesy of Coima)

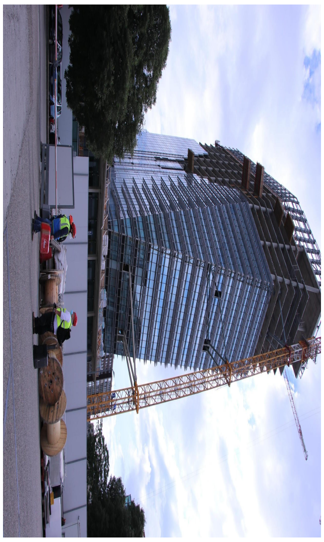
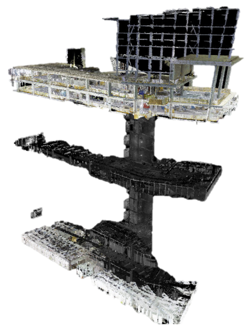


Figure 4 and 5: The structure as it appears during the test and the point cloud result of the 3D mobile mapping with HERON®

If we consider the mobile mapping surveying, no more then 20 minutes have been required. In fact the scanning time is equal to the walking time along the structure. To connect the acquired point cloud to the project-BIM reference system, the automatic self-localization feature present in the instrument have been used. The IFC BIM model of the 22nd and 23rd floors have been processed in a provided software, so to produce a reference frame that can be loaded on the HERON® mobile instrument and used by the instrument itself to automatically recognize its position, at the starting phase of the scanning procedure, inside the building. The post processing procedure asked for about 3 hours and a 3 cm resolution point cloud model, in the same reference

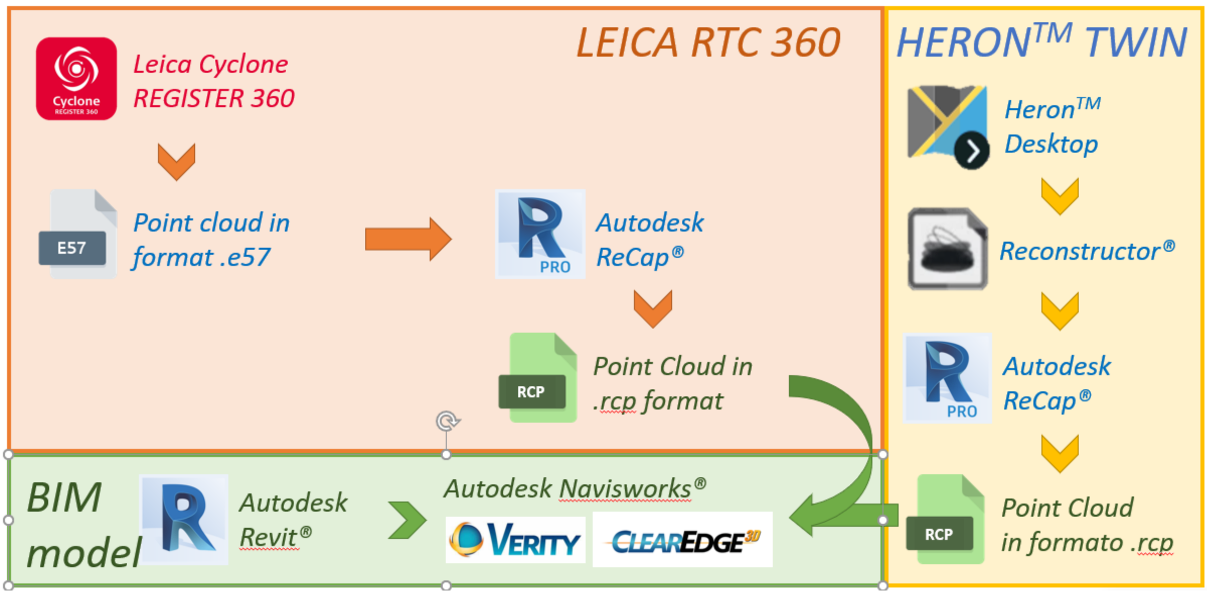


system of the BIM model, have been obtained. The scanning process by the Leica RTC360 static laser scanner have been asking more the two hours and the post processing phase have been asking more then two days. The elaboration time have to be considered as indicative due to the lack of experience of the operator that have been using the Leica post processing software. At the end of the process a 4 mm resolution point cloud have been obtained from the static scan procedure.

Figure 6: The mapping activity with HERON and Leica RTC360

4. THE DATA PROCESSING WORKFLOW

The data elaboration process has been required a big effort, due to the need of the huge number of software applications needed to complete the full data processing workflow briefly



described in Table 1. To manage the scans acquired by the Leica RTC360, the raw data with pre-alignment information have to be moved in the Leica® Cyclon REGISTER 360, for an accurate alignment calculation and for data filtering and editing. The high resolution point cloud model have to be exported in the standard E57 standard format and moved to Autodesk Recap® to be transformed in the .rcp format. For the mobile instrumet HERON, the Raw data acquired on the field have to be processed with a post processing SLAM based software, where the instrument trajectory and the full 3 cm resolution point cloud model is generated. This point cloud has to be moved in the associated point cloud post processing software, called Reconstructor®, where the point cloud is filtered, edited and exported in E57 and later moved in Autodesk Recap®. The Leica generated point cloud was still not in the BIM model reference system; the HERON generated point cloud, thanks to the automatic self generation tool, was already in the BIM r.s. . The two point clouds have been at this point moved in the Autodesk Navisworks® enviroment, where the Clearedge3D® Verity® software tool, to manage the progress monitoring analysis, runs. Due to some data format incopability, the ifc BIM model have been moved to Naviswork only after a import/export process by Autodesk® Revit®. After this time consuming process, it was possible to run the progress monitoring process in Verity.

Table 1: The software packages use for the data processing workflow

The static scanner point clouds have been aligned to the BIM model, using the coordinates of known target positioned in the structure (figure 7).

Figure 7: The alignment between BIM model and point cloud, and the target

5. THE DATA PROCESSING FOR PROGRESS MONITORING

The two point clouds models (From Mobile and Static approac) have been processed in the Verity® Clearedge3D® enviroment, obtaining interesting results. The Verity process run an automatic comparison between the BIM model and the as built, providing different code results that can be:

- Pass, color green, when the point cloud fits the corrisponding element of the BIM model inside the given tolerance. The element has been built !
- Out of tolerance, color jellow, when the element is recognized, but it seems out of the given tolerance. The as built vs as designed analsis faled.
- Uncertain, color orange, when there are not enough corrisponding data to sa anything
- Occluded, color purple, when for the given geometry the element was occluded during the scanning so the software cannot say if the element as been built or not
- Not found, color red, when the object has not been found, that meand that the element is not already has been built
- No Data or not enough data, when for different reasons nothing can be said about the heighleighted element

Picture 8 show the graphic result of the final delivery of the analysis software.

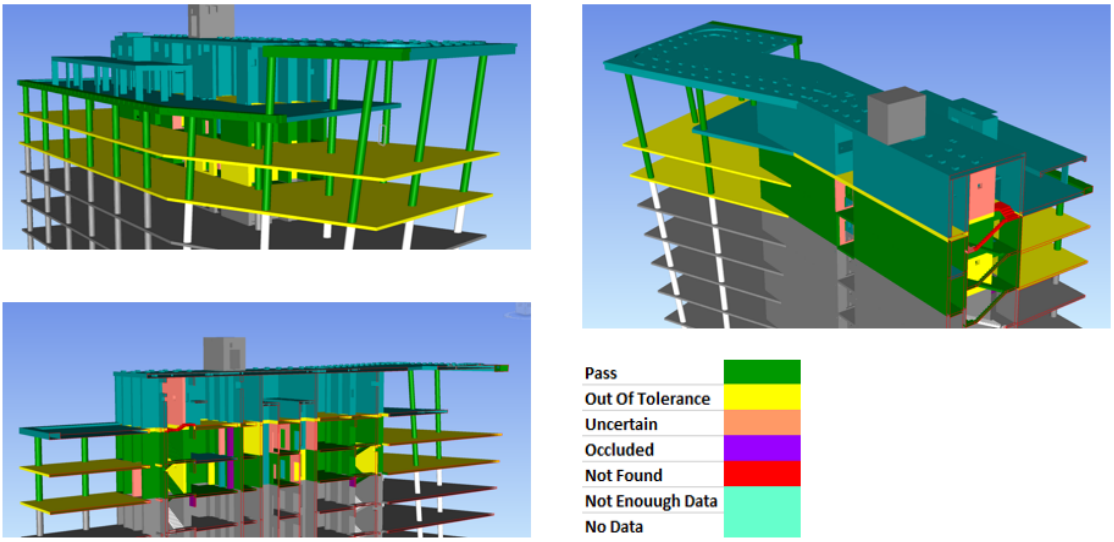


Figure 8: The graphic results of the progress monitoring analysis

Various tests have been carried out, using different Tolerance values applied to the two point clouds obtain with the mobile and static approach. The results presented in Figure 9, 10 and 11 clearly show how with the mobile approach and the static approch the results are quite similar and in some cases the recognition level of the mobile approach also better. This results show how using a mobile mapping fast approach, it is possible to obtain similar results of the static approach,

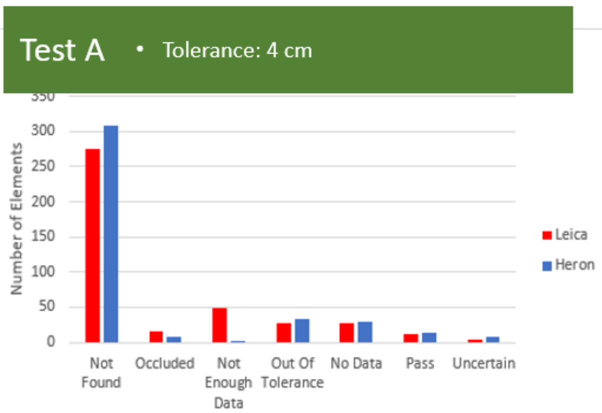


Figure 9: Differences using the two approaches. Level of tolerance 4 cm

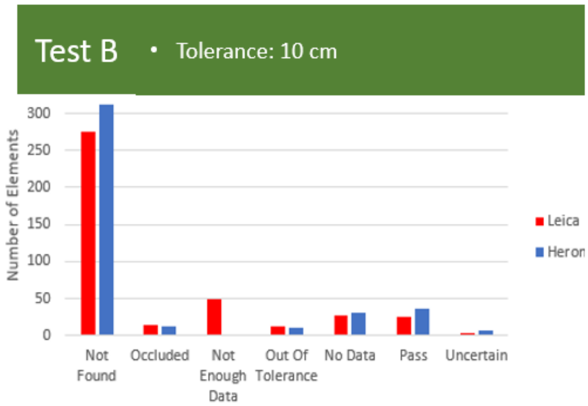


Figure 10: Differences using the two approaches. Level of tolerance 10 cm

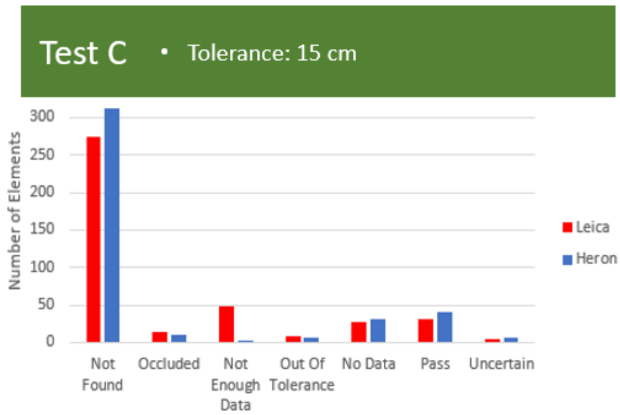


Figure 11: Differences using the two approaches. Level of tolerance 15 cm

with a high reduction of costs. In this way a daily or weekly surveying becomes substainable and the approach can really be applied in real construction sites.

6. CONCLUSIONS

The SLAM based indoor mapping technologies are becoming more and more familiar to the 3D surveying world. The experience here described demostrates that using this fast and realiable approach to acquire the as built status of a construction site, it is possible to run at substainable costs a progress monitoring analysis. Some developments are to be made to make easier the data processing procedures that still require too many efforts and different software tools to achive the final result.

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BIOGRAPHICAL NOTES

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