DOI: 10.15593/2409-5125/2019.04.05
UDC 528.9:624.1:721.01

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ANALYSIS, MODELING AND FOLLOWING OF STRUCTURAL DEFORMATIONS THROUGH LASER SCANNER AND ITS BIM IMPLEMENTATION

The basis of this project is to implement the use of laser scanner to analyze structural deformation in construction and its subsequent modeling to complete the 3D model of a building. The advantages of a measurement are analyzed with high accuracy, non-invasive and whose results can be implemented in BIM, evaluating the deformation of structure in real time and being able to incorporate the existing geometry, detecting interferences between architectural or MEP installation elements and the model.

In opposition to the operational complexity of the evaluation of load testing on structures and their impact on the management of the project, this method does not interfere with the work due to the fact they are executed in a few minutes and can be repeated at different times without any impact.

The laser scanner has been used with estimated error based on a working distance of less than 0,20 mm and a reinforced concrete structure under construction; specifically, we study the deformation of a cantilever of 3.50 m, scanning at different moments of its loading, measuring the deformations.

Point clouds have been compared and analyzed by CloudCompare©, and imported into Revit to model the structure. The workflow and process standardization are detailed for general application.

Keywords: laser scanner, structural, Cloud point, deformation, building construction, building information modeling (BIM).

Introduction. The 3D Laser Scanner technology allows to generate point clouds in three dimensions with a very high millimeter precision. The information obtained has an infinity of applications, being the most significant

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Кос-Гайон Лопез Ф., Льюэсма К.А., Льясер Х.К., Анкела Хулиан А.Б., Фуронес А.М., Хинер Гарсия М.И. Анализ, моделирование и отслеживание деформации конструкций с помощью лазерного сканера и его использование при информационном моделировании зданий // Вестник Пермского национального исследовательского политехнического университета. Прикладная экология. Урбанистика. – 2019. – № 4 (35). – С. 45–54. DOI: 10.15593/2409-5125/2019.04.05

Cos-Gayon López F., Lluesma C.A., Llácer J.C., Anquela Julián A.B., Furones Á.M., Giner García M.I. Analysis, modeling and following of structural deformations through laser scanner and its bim implementation. PNRPU. Applied ecology. Urban development. 2019. No. 4 (35). Pp. 45-54. DOI: 10.15593/2409-5125/2019.04.05

in the construction the possibility of creating BIM models that reflect the real state of the work, with the possibility of generating plans, etc.

But recently, on the occasion of great earthquakes, this technique has begun to be used to monitor almost instantaneous structural damage in buildings, being a vital tool to guarantee the safety of rescue teams. It also helps to make decisions about the structural viability after the seismic episode.

This research aims to go a little further; use this method of data collection to monitor the behavior of a structure during loading, and do it in real time. This supposes an important advance for the cases of structural or constructive complexity, being able to make decisions in an anticipated way**.**

Objective. The objective of this communication is to present the use of the data collection by laser scanner, its treatment in specific applications and their BIM integration to carry out a study of deformations of a structure and its quickly and non-invasive follow-up.

Like in almost every discipline integrated in BIM, it is more important how is done than what is done; in other words, the processes and workflows necessary to successfully complete the transition from data collection to decision making.

Methodology. A project in execution has been selected for the research object of this communication, with a structural design that incorporates 3.50 m long cantilever beams. We will proceed to perform an initial scan of the structure and the repetition of the process by adding a point load on the cantilever to check the deformation and then compare the two point clouds generated by the scanner.

The scanner that has been used for this project is the Focus 3D X130. Gets the 3D coordinates of each point within its scope within a radius of 130 m, being able to perform scans in just two minutes, which is essential to show the operational ease of the procedure.

With the point cloud generated by the scanner, we can obtain 3D coordinates with pinpoint accuracy and, subsequently, to generate surfaces and 3D models for BIM [1]. With a second scan after several months we proceed to compare the two point clouds to obtain the deformations of the cantilever.

For this purpose we will combine the 3D Laser Scanner technology with a deformation control software. The three-dimensional coordinates will be used to geometrically compare the two scans using CloudCompare©, a deviation analysis software.

Finally, we will use point clouds to make a BIM model using the Autodesk© Revit™. In addition, this tool will give us the opportunity to experience immersive virtual reality technology for a visualization of the project through Smartphone and HMD device (Head-Mounted Display).

State of the art. The laser scanner technology has many applications. In terms of construction, the most remarkable thing is that it can be used to track works (being able to offer visualization in immersive virtual reality), locate facilities, make work certifications, perform a quick modeling in BIM, calculate volumes, etc. ...It is also extremely useful in the field of architecture and restoration for obtaining plans, cataloging heritage, checking the current status and control of deformations (Fig. 1).

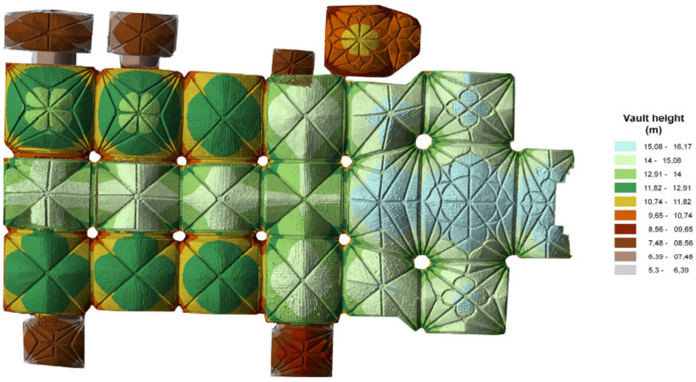


Fig. 1. Control of deformations. Faro, Spain (2012)

Рис. 1. Контроль деформаций. Фаро, Испания (2012)

Nother sector in which this technology is widely used is engineering. From the construction of roads, bridges and tunnels up to quality testing in parts of all types of industries and reverse engineering [2].

It is also being used in the development of video games because of its ability to capture environments, pieces and characters. It is even used in the simulators of the most prestigious racing teams in the world, since they need the recreation of the circuit to be as close as possible to reality [3].

Laser scanning technology has been intensively developed in recent years because not only is able to geometrically obtain the state of a building, but to analyze variations in its state, and this is a determining factor in this research [4].

These tools have been previously used for structural monitoring in case of earthquakes, providing a large amount of information, with much detail, so it is able to obtain the 3D coordinates with great precision, being able to study the fissures and measure the deformations [5–7].

In addition, Olsen describes how the laser scanner is used for the detection of damage and the volume variation analysis of a structure [8].

A deformation study can also be performed comparing the point cloud generated by a laser scanner with a theoretical model of finite-element (FEM) [9].

Continuing with this approach, different study methods have been combined; as an example, which combines the laser scanner with photogrammetry at close range, a georadar and FEM to document the structural condition of bridges [10].

In any case, the structural monitoring has been carried out in parallel by other methods other than laser scanner technology. One of the used ones has been the implementation of a motion capture system for the measurement of deformations of the structure of a building [11]. Another of them has been using strain gauges [12], resulting in a more precise technology than laser scanner, but being limited in terms of scope of action [13–15]. The laser scanner has much more range and gets more information in less time.

Development of the research work. To perform a full 3D scan of a structure, you should study the route and the links of the different parking lots that we will need. The scanner captures the information so we will have to think and organize the parking lots well so that there is no hidden part and, therefore, be done with the minimum possible number to reduce the time of scanning and processing, thus facilitating the management of the point cloud in the computer.

One of the solutions for joining scans is to use spherical reference objects. These objects act as position references when they are visibly arranged in two consecutive scans.

A factor to take into account is the gap that exists when joining two consecutive scans. This gap is minimal (tenths of millimeters) but if we are going to link 31 scans, as is the case, the gap is multiplied by 30. For this reason, a consecutive link has been avoided, creating multiple paths, thus minimizing those gaps (Fig. 2).

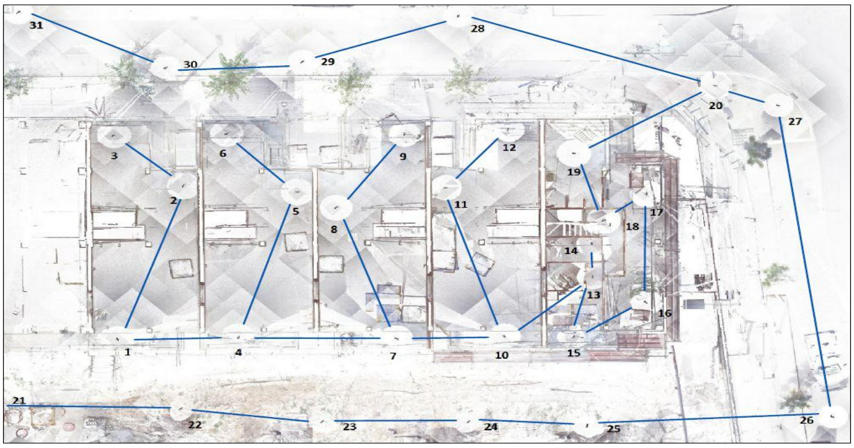


Fig. 2. Laser scanner mapping of parking spaces

Рис. 2. Картография парковочных мест с помощью лазерного сканера

Once the field work is done, the data processing begins. For this, we have used Scene™, the software provided by Faro©.

We must take care of the scattered points (which appear because the point of the laser is not infinitely fine, but it has a thickness and when it finds a change of plane (a corner, for example) the point remains divided. A line of points is projected from one end of the corner.

We will also use the pre-processing function to locate the spheres. If we check the "Detect artificial references" box, it will recognize us all the spherical objects.

Finally, with the point cloud created, we can make sections with a "clipping box", orthophotos, virtual tours, etc. To do this, we must create a "clipping box" parallel to a plane, which we define by three points. In this way, we create a box with which we can do several things: orthophotos, sections and export elements.

To carry out the deformation study, it has been decided to scan the inverted non-passable gravel roof once it has been executed. By subjecting the structure to a small load, we have to avoid possible errors. As the study is performed only on the cantilever of the beam, we will locate a scan of each state. In this way we will avoid the small margin of error of overlap and only we have left the error of the scanner, which is 2 mm every 25 m. This means that if an object is at a distance of 25 m, the margin of error of the scanner is 2 mm. With this data we can establish that, measured the distance between the scanner and the cantilever (2.22 m), the maximum error will be 0.18 mm in our study of deformation of the cantilever.

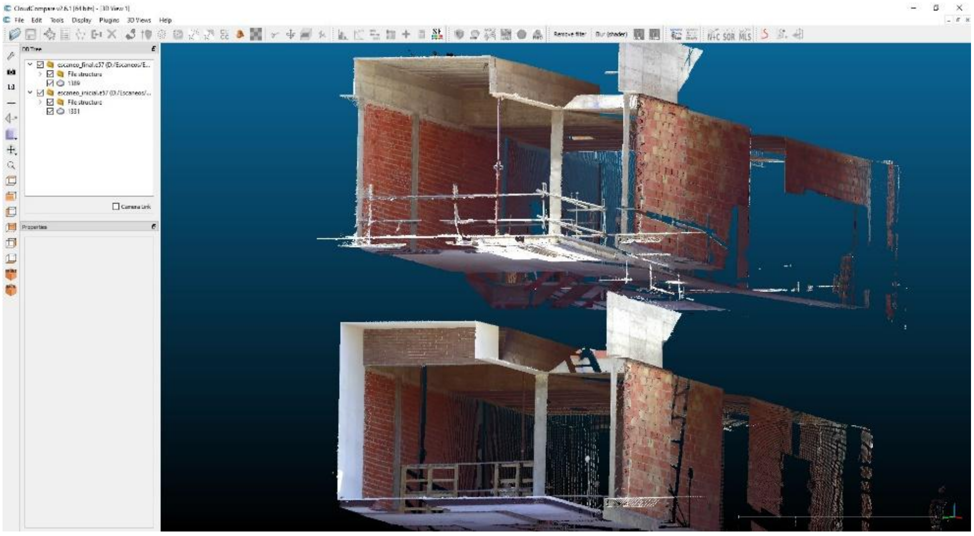
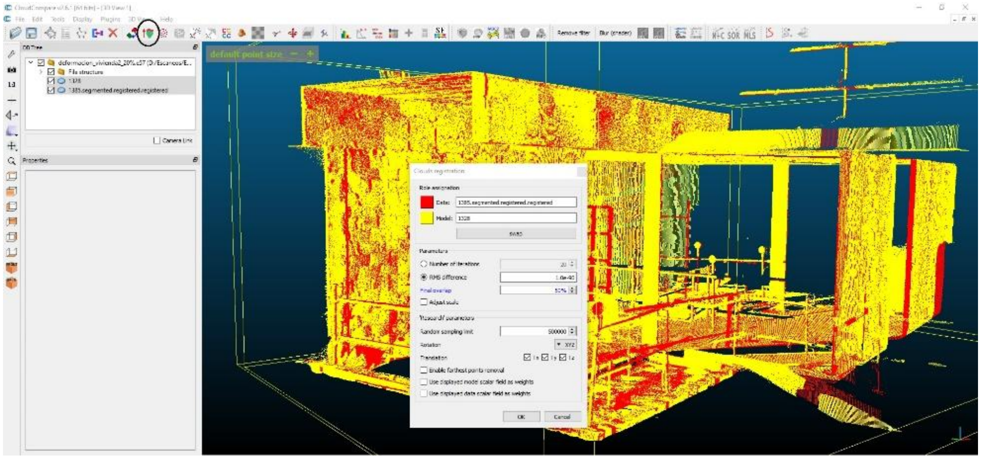


Fig. 3. CloudCompare

Рис. 3. Программное обеспечение CloudCompare

From Scene™ the cantilever scans have been exported in ".e57" format and have been imported into CloudCompare©. We insert the two scans and place them so that they are approximately in the same position. This is necessary to facilitate the alignment of the two clouds. This alignment is done with the command "Register previously aligned clouds", the icon can be seen highlighted in the illustration (Fig. 4).



Cloud registration

Role assignation

🟥 Data: 1385.segmented.registered.registered

🟨 Model: 1328

○ Number of iterations 20

● RMS difference 1.0e-40

Final overlap 50%

☐ Adjust scale

Random sampling limit 500000

Rotation XYZ

Translation ☑ Tx ☑ Ty ☑ Tz

☐ Enable farthest points removal

☐ Use displayed model scalar field as weights

☐ Use displayed data scalar field as weights

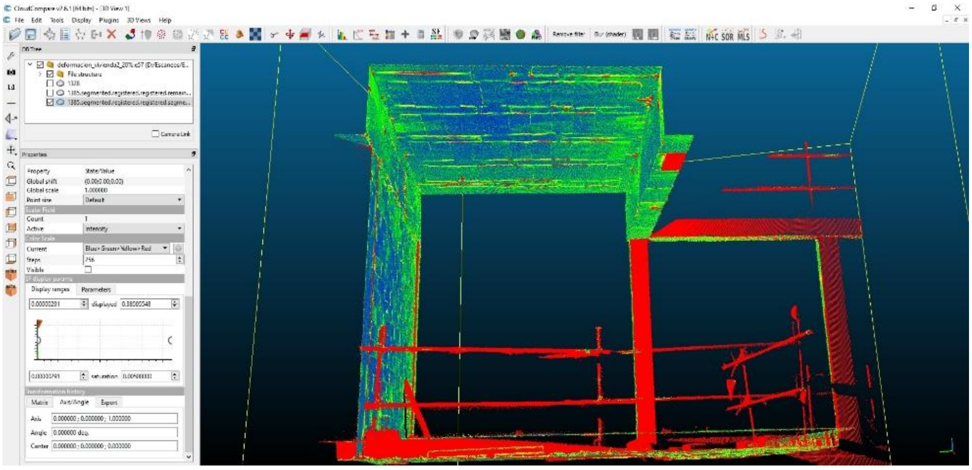
Fig. 4. Alignment scans in CloudCompare©

Рис. 4. Сканирование выравнивания в программе CloudCompare©

We use, as mentioned, the analysis of deviations with the program Cloud Compare©, free software. Once we have the two clouds perfectly aligned we proceed to the comparison. Select the "Compute cloud/cloud distance" or "Calculate distance cloud/cloud" command. Again we select in "Reference" our initial scan and accept. We choose the "Octree level" box and leave it in 9, by default. We select "Compute" and wait for the process to finish.

We already have the analysis of deviations. The analysis can be visualized with a color scale that has been saved in the final scan. We must deactivate the initial scan to see only the end. We can modify the maximum saturation so that it shows an unacceptable number in red previously fixed. There are large areas in red, as there have been changes due to the progress of the work (enclosures and slopes of terraces). The overhang has a coating of 1 cm thick and the scanner a margin of error of 0.18 mm. The color scale has been modified to start marking in red from 1.5 cm, which would mean a deviation of 5 mm in the area of the coating. It can be seen how intermediate areas and red zones begin to appear on the beam and on the roof. This may be due to several reasons. The first is that there is variation in the thickness of the plaster because both in the initial zone of this and in the final red zones are appreciated and it is very difficult that there has been deformation so close to the pillar. Another reason would be that the alignment of the two scans has not been entirely perfect. And the last one would be that there really was a deformation of up to 5 mm.

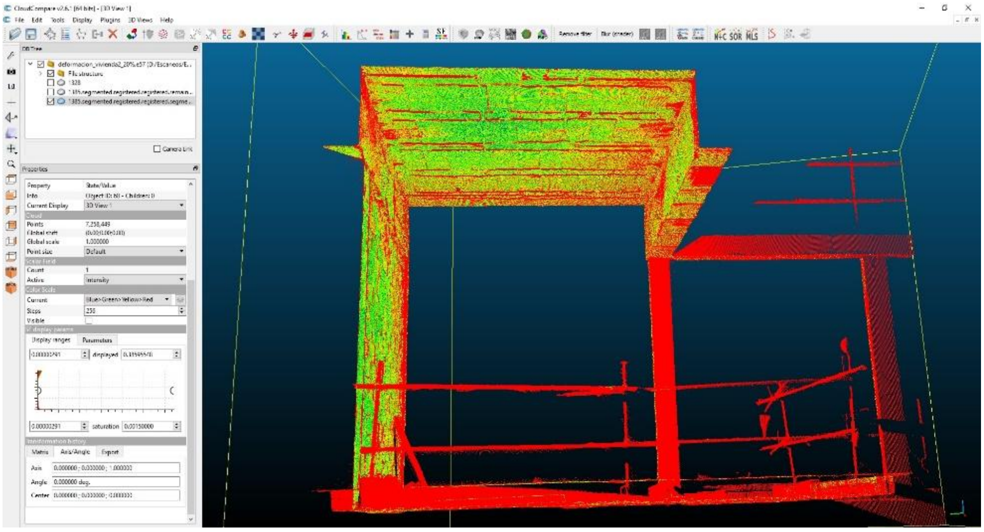
To verify if really there has been a deformation we will proceed to do the same process but with two different scans, those of the adjacent house.



Property: State/Value
Global shift: (0.00;0.00;0.00)
Global scale: 1.000000
Point size: Default
Count: 1
Active: intensity
Current: Blue> Green> Yellow> Red
Steps: 256
Visible: ☐
0.00000291 displayed 0.38500548
0.00000291 saturation 0.00500000
Axis: 0.000000 ; 0.000000 ; 1.000000
Angle: 0.000000 deg.
Center: 0.000000 ; 0.000000 ; 0.000000

Fig. 5. Second house results

Рис. 5. Результаты по второму дому



Property: State/Value
Info: Object ID: 60 - Children: 0
Current Display: 3D View 1
Points: 7,258,449
Global shift: (0.00;0.00;0.00)
Global scale: 1.000000
Point size: Default
Count: 1
Active: intensity
Current: Blue>Green>Yellow>Red
Steps: 256
Visible: ☐
0.00000291 displayed 0.38599540
0.00000291 saturation 0.00150000
Axis: 0.000000 ; 0.000000 ; 1.000000
Angle: 0.000000 deg.
Center: 0.000000 ; 0.000000 ; 0.000000

Fig. 6. Results at 1.5 mm

Рис. 6. Результаты на 1,5 мм

We can see the results of this house in fig. 5. In this scale of colors a distance of 5 mm has been set in red and we see how there are no areas that are so deviated. Adjusting this value we can observe that red zones with a value of 1.5 mm begin to appear (Fig. 6) so we can say that the deformation is despicable.

All this information must be consolidated to keep an editable and accessible record. To do this, we opted for the export of point clouds to Autodesk© Revit™, and the subsequent modeling, following the workflow described by Cos-Gayón et al. (2016) [16], and including information with the data from the analyzes performed.

Conclusions. In the first place, the hypothesis of this research is confirmed, that it is possible to track in real time the behavior of the structure of a building under a load, with high precision, in an operative and economic way, something fundamental so that any system can be implemented in the real economy.

With regard to its scope, it is possible to establish the limitation of the equipment's accuracy, in this case and distance, of ±0.18 mm, so deformations below this amount would not be detected.

Finally, all this data and analysis is integrated into a BIM model, which will provide valuable information about the structural behavior at an early age, which will be completed with interventions that may require, where appropriate, the structure of the building.

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Получено 18.08.2019

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АНАЛИЗ, МОДЕЛИРОВАНИЕ И ОТСЛЕЖИВАНИЕ ДЕФОРМАЦИИ КОНСТРУКЦИЙ С ПОМОЩЬЮ ЛАЗЕРНОГО СКАНЕРА И ЕГО ИСПОЛЬЗОВАНИЕ ПРИ ИНФОРМАЦИОННОМ МОДЕЛИРОВАНИИ ЗДАНИЙ

Основой этого проекта является применение лазерного сканера для анализа структурных деформаций при строительстве и его последующего моделирования при составлении 3D-модели здания. Преимуществами таких измерений являются высокая точность анализа, неинвазивность и получение результатов, которые могут быть использованы в информационном моделировании зданий (BIM), с оценкой деформации структуры в режиме реального времени и с возможностью включения в себя существующей геометрии, с выявлением взаимодействия между архитектурными или монтажными элементами инженерных сетей и моделью.

В отличие от эксплуатационной сложности оценки нагрузочных испытаний конструкций и их влияния на управление проектом, предлагаемый метод не препятствует работе, поскольку измерения выполняются в течение нескольких минут и могут повторяться в разное время без какого-либо воздействия на объект оценки.

Лазерный сканер использовался с расчетной погрешностью, базирующейся на рабочем расстоянии менее 0,20 мм для железобетонной конструкции в стадии строительства; в частности, мы изучали деформацию кронштейна длиной 3,50 м, сканируя разные моменты его нагружения и измеряя деформации.

Был проведен анализ и сравнение облаков точек с использованием программы CloudCompare©; результаты переданы в программный комплекс Revit для моделирования конструкции. Рабочий процесс и стандартные требования к процессу подробно описаны для общего применения.

Ключевые слова: лазерный сканер, облако точек, деформация, строительные конструкции, информационное моделирование зданий.

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