TESTING A LASER SCANNER IN COMPARISON WITH A SPECIFIC TOTAL STATION IN LAND SURVEYS.

Dimosthenis Stathas, George Pantazis, Evangelia Lambrou
Department of Topography, Laboratory of General Geodesy
School of Rural and Surveying Engineering
National Technical University of Athens
Email : stathas@survey.ntua.gr, gpanta@central.ntua.gr, litsal@central.ntua.gr

Abstract: The wide use of laser scanners in many applications for the documentation of several surfaces raises the need to test them in large area surveys.
The aim of this paper is the detection, restriction and explanation of the differences appeared in the final product that is produced by either a modern specific reflectorless total station, with scanning possibilities, or a laser scanner. These differences are related to the accuracy, reliability and the quality information that these instruments provide when they are used for a surface scanning.
The instruments that were used for the experimental applications are: The total station Trimble 5605 DR$^+$ and the Calidus 3D laser scanner. The experiments were carried out on the following surfaces:

- A façade of a building and
- An almost vertical rocky declivity.

The differences that were defined in the final façade plans refer to the comparison of the geometric elements and the differences that were determined at the position of the contour lines on the declivity plans.
The above-mentioned disagreements in the geometric documentation are analyzed, discussed and justified. The use of both measuring systems and methodologies is criticized with criteria such as the precision, the quickness and the completion in accordance with the scale of the documentation.

1. INTRODUCTION

The appearance of laser scanners either helped surveyors to dilate their activities or in many cases facilitated their works. Laser scanners are very recently developed instruments that can scan an area producing 3d digital plans. These instruments can measure about 1000 to 10000 points per second as a cloud of points. Their measurement range varies from 1.5m to 100m and the coordinates of the points may be determined with an accuracy of ±6mm to ±45mm [10], which is satisfactory for the 1:100 scale. The accuracy, that is achieved, depends on parameters like the distance from the surveyed object, the scanning speed, the nature of the reflecting surface and the method of the laser ranging system used by each one.
As the laser scanners may yet not be considered as the ideal instruments for all the surveying applications, it is useful to refer to some of their disadvantages as:

- Their weight, which ranges from 10kgr to 30kgr and their high cost.
- Due to the fact that the diameter of the outgoing laser spot is in the range of 15 to 300mm for distances up to 50m, it is difficult to discern small objects.
- The consequence of the limitation of their field of view, especially in the vertical direction, is that their distance from the scanned surface should be long in the cases of height surfaces.

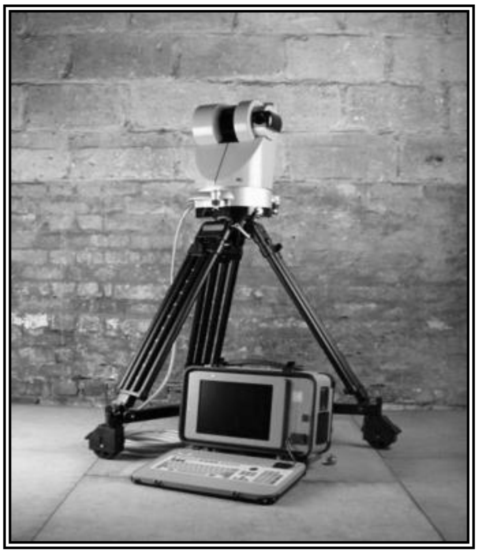
Finally, another problem is the interference of the ″unwanted″ data, recorded within the cloud of points [7], [1].
A great deal of applications has been carried out using the scanners for architectural, archeological or tunneling purposes [4], [5], [8], [9] and [13]. Other experiments have been carried out using them in combination with digital cameras [2], [11] with very good results. A proposal for measuring the route of Marathon race has also been presented [16].
The accuracy and the precision of laser scanners have been also investigated. The possible sources of errors that influence the angular and distance measurements of the scanners have been examined in detail [12] and [13]. Tests on distance accuracy, measured by scanners, have also been carried out [3], [6], and [13].
Nowadays, the almost simultaneous appearance of scanners and reflector less total stations, with scanning possibilities, gives the opportunity to use these instruments for several applications either in small areas, like buildings or tunnels, or in large areas, like steep and rocky terrestrial surfaces. It is also well known that the images obtained by the scanners provide quality details of the scanned object.
It is a matter for investigation to compare both the kinds of instruments regarding the final product that a 3D laser scanner provides in land surveys and the accuracy of the positioning. Thus, an experimental application was designed and performed in real site conditions for the investigation of the information and the reliability that a laser scanner plan provides in comparison with a reflector less total station.
The aim of this paper is to contribute to all the literature with the experience which was obtained using both instruments, the laser scanner Calidus 3D and the reflector less total station with scanning possibilities Trimble 5605DR$^+$.
The experiments concern short range scanning applied on a building and on a ground surface as follows:

1. Both instruments have measured a part of a building façade, which mainly consists of regular geometrical elements. The measurements by the total station were carried out by the conventional survey procedure.
2. Both instruments scanned a steep rocky vertical declivity surface.

The relative accuracy was checked by comparing the details of drawings in both cases regarding the specific known distances on the objects as well as the reliability and quality of information. The differences are discussed and analyzed in the following paragraphs.

2. INSTRUMENTATION

The precision of the Callidus (Picture 1) scanner is ±18 ″in the horizontal angles measurement and ±32 ″in the vertical angles. It measures distances of ±5mm and up to 32m, but its accuracy in the distance measurement is reduced as the range extends up to 40-80m, depending on the nature of the reflecting surface. It can measure about 1750 points/sec and also cover surfaces up to 360^o horizontal angle and 280^o vertical angle [17].
The total station TRIMBLE 5605 DR$^+$ (Picture 2) was used as a reference instrument. It measures distances up to 600m without the use of reflector. Its angular precision is ±5 ″and its distance precision ±5mm.
This instrument is analogous with the laser scanner as it has the possibility to sweep automatically a surface as long as a horizontal and a vertical sweeping step have been set.
A great number of points can be determined by a procedure corresponding to the laser scanner but in an absolutely geodetic manner.



Picture 1: The laser scanner Callidus

Picture 2: The total station TRIMBLE 5605 DR^+

The software ″Surface″ had been established in the total station configuration as a field application [15]. If a surface is going to be sweeped the user must define the surface limits by three points A1, A2 and A3 as illustrated in figure 1.

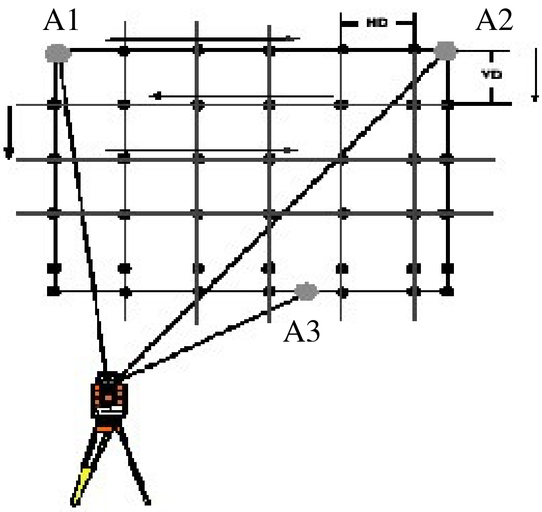


Figure 1: The definition of the scanning surface

Before the use of the total station TRIMBLE 5605 DR^+ in the following applications, a laboratory test was carried out. The instrument had been tested for its proper function and the provided precision of its results, according to the following procedure. The appropriate points on the ceiling of a laboratory hall were measured to determine the best fitting plane surface on the ceiling. The measured points cover an area of about $300m^2$ (10mx30m). The ″Surface″ software has been used. About 373 points were measured on the ceiling surface within 30 minutes. The sweeping step was set 1m in both directions.

The same experiment had also been carried out by using several instruments and methods and a laser scanner, as illustrated in table 1 [14]. The following mean plane equation had been used:

$$A \cdot x_i + B \cdot y_i + C = z_i \quad (1)$$

Whence A, B and C the parameters of the plane and

x_i, y_i and z_i the coordinates of each point i.

The table 1 illustrates the comparative elements of the approximation that had been calculated by each instrument measurements.

Method	A	σ_A	B	σ_B	C	σ_C (mm)	$\sigma_0^{\ 2}$
Leica TC1800	$9.338*10^{-4}$	$\pm 4.78*10^{-4}$	$6.685*10^{-5}$	$\pm 7.54*10^{-4}$	1.8326	±3.4	$1.793*10^{-4}$
Leica TCR303	$9.341*10^{-4}$	$\pm 4.72*10^{-4}$	$-2.547*10^{-5}$	$\pm 7.45*10^{-4}$	1.8295	±3.4	$1.755*10^{-4}$
Leica TCR303 (random)	$6.79*10^{-4}$	$\pm 5.59*10^{-4}$	$4.11*10^{-4}$	$\pm 5.59*10^{-4}$	1.8264	±2.3	$1.782*10^{-4}$
CYRAX Laser Scanner	$8.00*10^{-4}$	$\pm 4.46*10^{-4}$	$-3.00*10^{-4}$	$\pm 1.76*10^{-4}$	1.8170	±0.5	$7.569*10^{-4}$
TRIMBLE 5605 DR$^+$	***$4.991*10^{-4}$***	***$\pm 1.577*10^{-4}$***	***$8.432*10^{-4}$***	***$\pm 7.12*10^{-5}$***	***1.8280***	***±0.5***	***$7.946*10^{-4}$***

Table 1: The values of the plane parameters A, B and C and their standard errors [14]

As illustrated in the table 1, the calculated values of the best fitting plane parameters A, B and C via the total station Trimble 5605 DR$^+$ measurements, are compared with those which had been calculated by the other instruments or methods. It is also obvious that the coefficients A and B have very small values, therefore they are statistically zero. Thus, the ceiling surface is approximated by a horizontal plane. Consequently, the use of the Trimble 5605 DR$^+$ and the ″Surface″ software guarantees the accurate documentation of any surface.

3. THE DOCUMENTATION OF A BUILDING FAÇADE

At first, a geometric surface as a building façade was decided to survey. The façade was about 33m in length and 4m in height. It was surveyed by the conventional method, using the opportunity of the Trimble 5605 DR$^+$ to perform reflectorless measurements. Totally 107 points were measured which include all the geometric elements of the façade as doors, windows, stairs in one-hour time. Figure 2 illustrates the result of this documentation.

Afterwards, the same building façade was scanned by use of the laser scanner Callidus. The minimum sweeping step is chosen for the scanning as the surface contains details that must be surveyed. The horizontal sweeping step was set 1′.8 while the vertical was set 15′. The minimum and maximum distances between the position of the instrument and the façade were about 7.5m and 20m respectively. This means that in the middle of the façade the measured points have an interval from 4mm to 3.3cm while at the outer façade limits, the measured points have an interval from 1cm to 9cm. There were measured 1540754 points in 30 minutes. Figure 3 illustrates the result of the laser scanner documentation.

Concerning the survey quality between the two produced plans it is stated that in the laser scanner plan some elements are missing, since the distinctness of the produced images do not permit the drawing of these detailed elements on certain surface areas.

Moreover, same characteristic dimensions are measured at different positions on the façade.

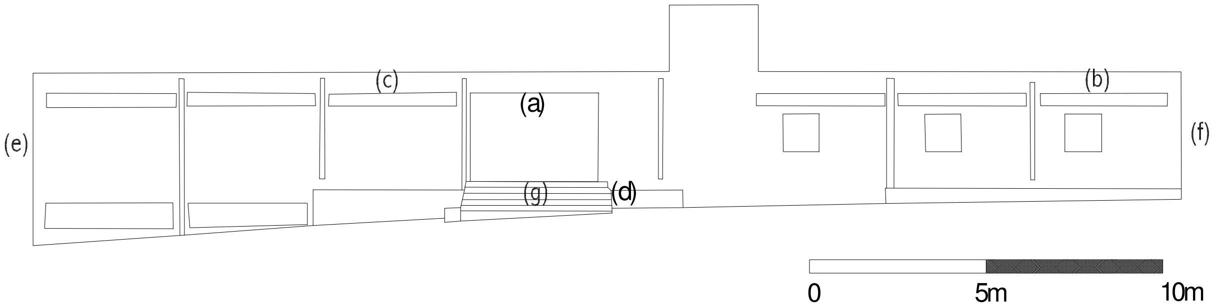


Figure 2: The façade of the building produced by using the Trimble 5605 DR^{+}

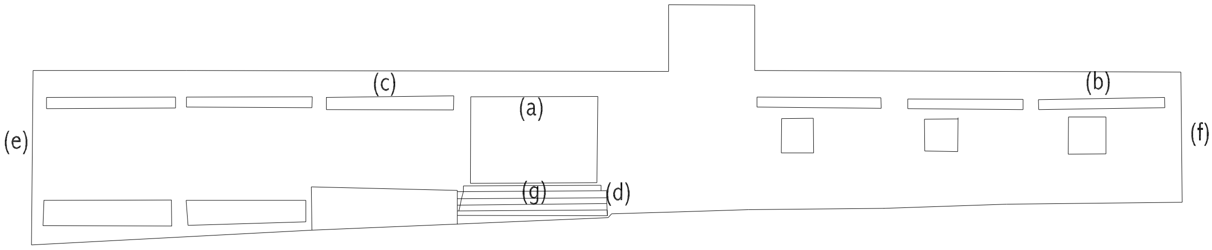


Figure 3: The façade of the building produced by using the 3D laser scanner Callidus.

The results appear in table 2. The differences vary from 6mm to 57mm. The elements, which were found at the right or the left boundaries of the surface, have bigger differences than those that were found in the middle area. As it is shown in table 2, the differences are negligible for 1: 100 printing scale, but are apparent for 1:50 scale and significant for 1:25 or 1:20 scales.

Geometrical element	**Element code**	**5605 DR^{+} (m) (reference distance)**	**Callidus (m)**	**ΔS (mm)**
Door openning	(a)	3.630 (±7mm)	3.596 (±10mm)	34
Window length	(b)	3.676 (±7mm)	3.647 (±10mm)	29
Middle Window length	(c)	3.609 (±7mm)	3.599 (±10mm)	10
Stair height	(d)	0.167 (±7mm)	0.161 (±10mm)	6
Building height at the left side	(e)	4.860 (±7mm)	4.904 (±10mm)	44
Building height at the right side	(f)	3.593 (±7mm)	3.650 (±10mm)	57
Stairs length	(g)	4.268 (±7mm)	4.244 (±10mm)	24

Table 2: Values of the differences Δs, of the characteristic façade elements.

As mentioned above, the distance measurement accuracy is ±5mm for both instruments. The scanner has a mean angular accuracy of ±25″ and the total station of ±5″. According to the covariance law, the coordinates of each point, which are calculated via the polar method measurements, have an accuracy of about ±5mm as the measured distances are of the order of 20m for both instruments. Thus, the error in the measured distance between two points on the total station plan is ± 7mm since on the laser scanner plan the error is of the order of ± 10mm as is increased by the image distinctness [6], [12] and [13]. Finally, the difference ΔS of the size of each element between the two plans as presented, in table 2 has an error of ± 12mm and for confidence level 95% (z=1.96) the acceptable error is ± 24mm. Some of these differences surpass the limit. This is an indication of wrong drawing or measurement.

4. THE DOCUMENTATION OF A VERTICAL DECLIVITY

The next experiment was carried out on the rough surface of a vertical declivity (Picture 3). The declivity was 60m in length and 15m in height. The selected surface was swept using the Trimble 5605 DR$^+$ via the ″surface″ software application. The limits of the declivity surface were defined by three points A1, A2 and A3, as presented in Picture 3. The sweeping step was selected 1.00m in both horizontal and vertical directions. In one hour and 30 minutes, 806 points were measured. The data processing was carried out using the TGO software, which produces the façade of the declivity that is presented in figure 4.

Picture 3: The vertical declivity

Using the 3D laser scanner Callidus, the same surface was scanned. The sweeping step was set 7′.5 horizontally and 15′ vertically as not extreme details were desired. The distance between the position of the laser scanner, during the measurements, and the vertical declivity surface varies from 8m to 21m, which means that the interval between two neighboring measured points on the declivity is 1.7cm horizontally and 13.2cm vertically at the closer declivity area and 4cm horizontally and 26.2cm vertically at the remote declivity area. There were measured 261942 points during one hour. The point cloud processing was carried out via the ″Real Work V4.0″ software. The produced plan of the declivity façade is also presented in figure 4.
In both cases, the contours interval was selected to be 0.5m. The two plans have some differences but at the bigger part of the area they have similarities. Both constitute a satisfied survey of the declivity façade.
The laser scanner is capable of measuring approximately 300 times more points and more details, proportionally to the used scanning step, in half of the time. The differences that are obvious at certain areas on the declivity plans, as the area in the circle (fig. 4), mainly depend on the density and the detail of the survey, as well as on the huge number of points that the scanner can measure. This enormous data acquisition is not always useful because it usually contains many ″unwanted″ data that must be removed and are almost obscure. Also, each instrument has different processing software, which approximates quite differently, the measurements.
In order to assess the size of the differences between the produced façade plans, three vertical sections were drawn.

The positions of the sections are illustrated in figure 4. Figure 5 shows the drawings of the three sections. The observed vertical discrepancies, of the homologous points in both plans, fluctuate from 0 to 1.5 m; as well as the horizontal position differences fluctuate from 0 to 0.6 m. It is also remarkable that larger discrepancies were found in the sections A – A and C – C (0m – 1.5m), which are placed at the declivity edges than in the section B – B (0m – 0.5m), which was situated in the middle of the area. This may be justified as less information was provided by the total station, which produced a coarse drawing, as well as at the distortion that the laser scanner models used to have at their edges.

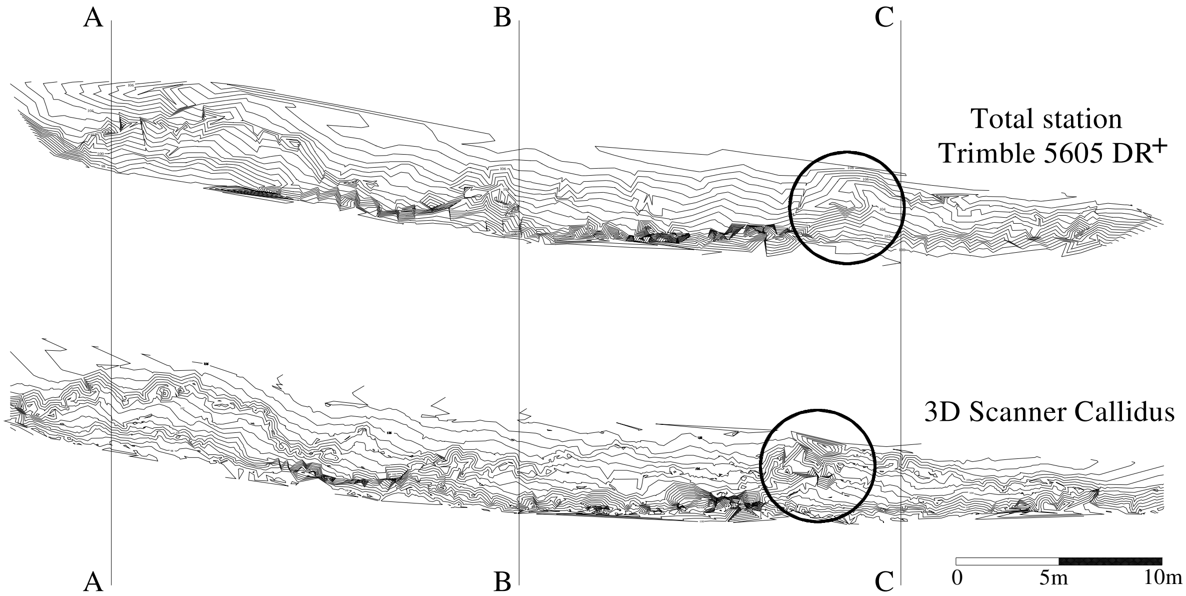


Figure 4: The façades of the vertical declivity.

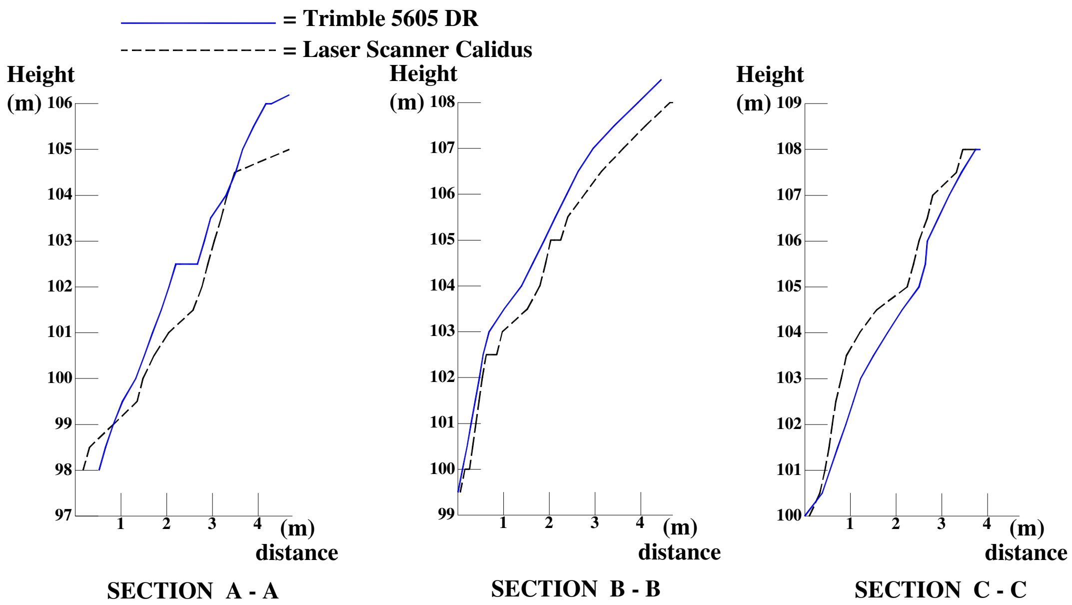


Figure 5: The vertical sections A- A, B-B and C-C.

5. DISCUSSION

The investigation of the above mentioned cases, demonstrate the following:

- Concerning the survey of the building façade, the conventional method, using the total station, provides satisfied accuracy but no quality information about the surveyed object. The differences that appear in comparison with the laser scanner sweeping, mainly at the surface edges, are justified as the distance of the laser scanner from the outer façade points is longer so the interval between the measured points is bigger as the sweeping step remains constant. Thus, at the façade edges the measured points are sparser. Moreover, the images that had been taken by the scanner have not adequate distinctness at the façade limits. In this way, the quality of the final drawing is not satisfied. Consequently, for better result, the scanner may be put at more positions closer to the desired object, sweeping from every position a limited part of it. The junction of these models has difficulties and reduces the precision of the result, as homologous points in each model must be accurately recognized. Additionally, a powerful computer was needed to support the scanner data processing. Finally, the completion of the plans would be useful at certain areas by the total station measurements.
- Concerning the survey of the declivity, the differences that appear between the two façade plans, at the contours position fluctuates from 0 to 1.5m. The differences are justified as the laser scanner measures a huge amount of points, which describe the declivity relief in detail. From the other side, the sweeping by the total station is sparse including same unwanted data, which are difficult to remove from the plan, as they are not recognizable. The same points are easy recognizable and can be taken away as the laser scanner gives the image of the swept area.

6. CONCLUSIONS

The succeeded goal of this paper is to pick out the applications that a 3D laser scanner or a modern digital total station is advantageous to use. The following remarks are underlined:

- The modern digital total stations have respective accuracy with the laser scanners for detail surveys for 1:100 and smaller scales, for distances of the order of 20m.
- The advantages of the use of a total station for a site survey are the quickness of the total process and the high and unique accuracy all over the surveying area.
- The sweeping opportunity that the total station arranges is a great advantage as well as its low cost in comparison with the 3D laser scanner.
- By using a total station to sweep a surface the points that were measured follow a grid according to the given sweeping step and some of them would be useless for the drawing as they are not characteristic ones. Thus, the latter can only be used to sweep shapeless surfaces as not quality information about the surveyed object has been given.
- The sort range of the laser scanners, the big weight, the high cost as well as the alteration of the measuring precision as far it measures are disadvantages. Consequently, the final product has lack of uniformity.
- The erase of the ″unwanted″ data from the 3D laser scanner points cloud is a very laborious and difficult task.

Consequently, one may distinguish the applications. If some quality information is needed as colors, materials, texture, the choice of the laser scanner gives an adequate but more complicate and expensive solution.

The laser scanner may give reliable results, if careful sort range and limited area scanning is applied. The previous presuppositions have high cost in time and money.

The conventional survey method by using modern digital total stations and the sweeping program remains still attractive, although the quality information is missing, as it is a cheaper, accurate and rigorous method at the site and the data processing.

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