Interreg
EUROPEAN UNION

Sudoe

Sudoe Stop CO_2

European Regional Development Fund

TECHNICAL REPORT ON THE SPECIFIC DEMANDS FOR LASER-SCANNING OPERATION CONSIDERING THE BIM-LOD

Low-carbon economy
Cooperation depends on you
www.interreg-sudoe.eu

INDEX

SUMMARY

French

Le projet SUDOE STOP CO_2 vise à trouver des stratégies pour promouvoir l'efficacité énergétique dans les bâtiments des centres de transport (gares routières et ferroviaires) et ainsi réduire leur facture énergétique et leur impact environnemental.

Ce rapport porte sur les principales conclusions obtenues tout au long de la détermination des exigences technologiques pour l'application du BIM-LOD choisi pour les principaux éléments des modèles des gares routières. Ainsi, afin de mieux définir les exigences technologiques, des études approfondies ont été menées sur les exigences et les capacités globales du balayage laser, en recherchant quels paramètres amélioraient la capacité du nuage de points acquis à servir de référence lors du processus de modulation. Ce travail a abouti à la création d'une méthode de travail pour obtenir rapidement et précisément des données géométriques, permettant son utilisation pour la simulation de bâtiments. La méthode proposée a été appliquée avec succès pour l'acquisition et le traitement des données géométriques d'une gare routière.

Portuguese

O projeto SUDOE STOP CO2 pretende abordar as estratégias de promoção de eficiência energética nas estações de transportes e consequentemente reduzir a fatura energética e o impacto ambiental destas infraestruturas. Este relatório destaca as principais conclusões obtidas ao longo da determinação dos requisitos tecnológicos para a aplicação do BIM-LOD escolhido para os principais elementos dos modelos das estações de autocarros.

Como tal, a fim de definir os requisitos tecnológicos, realizaram-se estudos sobre os requisitos e as capacidades gerais do "laser scanning". pesquisando-se quais os parâmetros que melhoram a capacidade da nuvem de pontos a ser usada como referência no processo de modelação. Este trabalho culminou na criação de um processo de trabalho para uma aquisição rápida e precisa de dados geométricos, permitindo o seu uso para simulação do edifício. O processo proposto foi aplicado com sucesso na aquisição e tratamento dos dados geométricos de uma estação de autocarros.

Spanish

El proyecto SUDOE STOP CO2 pretende abordar estrategias para la mejora de la eficiencia energética en las estaciones de transporte y, de este modo, reducir la factura energética y el impacto ambiental de estas infraestructuras.

El presente informe destaca las principales conclusiones obtenidas durante el proceso de determinación de los requisitos tecnológicos para la aplicación del BIM-LOD elegido para los principales elementos de los modelos de las estaciones de autobuses.

Así, con objeto de definir los requisitos tecnológicos citados, se han llevado a cabo estudios sobre las capacidades y condiciones generales del "laser scanning", identificando aquellos parámetros que mejorar la capacidad de la nube de puntos para ser usada como referencia en el procese de modelización. Este proceso culminó con la creación de un método de trabajo para una obtención rápida y precisa de datos geométricos, permitiendo su uso en la simulación de los edificios. El proceso propuesto ha sido aplicado con éxito en la obtención y tratamiento de los datos geométricos de una estación de autobuses.

English

SUDOE STOP CO2 project aims to address strategies to promote the energy efficiency of transport stations and, consequently, reduce the energy costs and the environment impact of these facilities. This report highlights the main conclusions acquired throughout the determination of the technological requirements for the application of the chosen BIM-LOD for the main elements of the bus stations models. As such, in order to better define the technological requirements, extensive studies were conducted on the laser scanning overall requirements and capabilities, researching which parameters improve the ability of the acquired point cloud to serve as a drawing reference during the modulation process. This work culminated in the creation of an assessment workflow for an expeditious and accurate acquisition of geometric data, allowing its use for building simulation. The proposed workflow was successfully applied in the acquisition and treatment of the geometric data from a bus station.

1 INTRODUCTION

The SUDOE STOP CO2 project intends to improve the planning and energy management policies applied in transport station facilities. The refurbishment of existing facilities can benefit from techniques that are able to produce accurate and detailed information concerning them. The laser scanning technology can supply the means to acquire the geometric information required by a BIM model. In order to better define the technological requirements, extensive studies were conducted on the laser scanning overall requirements and capabilities, researching which parameters improve the ability of the acquired point cloud to serve as a drawing reference during the modelling process. The technological requirements depend on the BIM-LOD selection. This resulted in the creation of the following assessment workflow: initial laser scanning tests → laser scanning survey → point cloud software → BIM authoring software → technological requirements.

2 PRINCIPLES AND TOOLS

A laser scanner device emits a laser beam while rotating 360º around the vertical axis. Simultaneously, the mirrored surface from which the laser departs also rotates constantly with respect to an axis perpendicular to the previous one. This allows to cover the entire area around the device.

The emitted laser will reach varied surfaces. Whenever this happens the laser returns to the device with a given energy, which being strong enough is detected by a sensor. The equipment provides the distances to visible surfaces from where the sensor is located. These same measurements for each point have precisions of the order of centimeters or even millimeters, depending on several factors. Among these factors are the sensor in question, the laser ranges and the surface on which it is incident.

In addition to this, other information is measured in order to obtain tri-dimensional points. An example of this is the measurement of the angle of rotation in the horizontal plane of the equipment itself, in relation to the point in question, as well as the measurement of the angle of rotation in the vertical plane of the mirrored surface.

This information is subsequently converted into a set of points with a given reference (x, y, z), which are called point clouds. These points may even contain RGB information, which gives color to each point when scanning is accompanied by photographic procedures.

In this project, a Leica Scan Station P20 (Figure 1) was used for the field work. The Leica Cyclone 9.1 and Autodesk Revit were used in the treatment of the acquired point clouds and in the development of the BIM model.

Figure 1 – Laser scanner Leica Scan Station P20

3 LASER SCANNING TESTS

3.1 Laboratory tests – Presentation

As previously mentioned, the determination of the BIM-LOD for the created models is highly subjective to both its use (energy-analysis) and the information they are created from (point-clouds). As such, this topic addresses the determination of the laser scanning parameters and its influence over the laser scanner operations and the model LOD. To this end, a study to better understand the variables that dictate the final state of the point cloud was implemented. Several laboratory tests were performed, focusing on the laser scanner parameters, performance and limitations. These tests consisted on the acquisition of several point clouds, all taken in the same exact location, under similar conditions, but under different pre-established scanning parameters, which are described in the Table 1.

Table 1 –Scan Station parameters

Parameter	Description
Resolution	Dictates the distance (in millimeters) between captured points, both vertically and horizontally, for a radius of 10 meters measured from the laser scanner position. The larger the distance, the lower the accuracy and the number of points captured.
Quality	Relates to the precision with which a given point is acquired. Greater quality translates a lengthier scan rotation time, meaning the points are steadily acquired.
White Balance	Allows the acquisition of white tones and the overall photograph color correction. It displays four presets: Sunny; Cloudy; Cold Light; and Warm Light. The first two are used when predominantly subject to natural light, while the last two are used for artificial light.
Image Resolution	Defines the number of pixels, both vertically and horizontally, for the acquired photographs. Higher resolution translates into an higher overall image quality, with fewer blur, but also greatly increases the scan duration and file size.
High Dynamic Range (HDR)	Used to acquire, in higher detail, zones with much/few light. Photographs are taken with different shutter speeds, obtaining different levels of brightness based on the amount of light that got through the lens. The photographs are then combined resulting into a final photograph with on both the highlight and shadowy zones.

The first exploratory tests were conducted in a small test chamber presented in Figure 2. The test chamber isolated conditions, coupled with the details provided by the ground frame and the sample containers, created the perfect conditions to undertake the 38 laboratory tests displayed in Table 2.

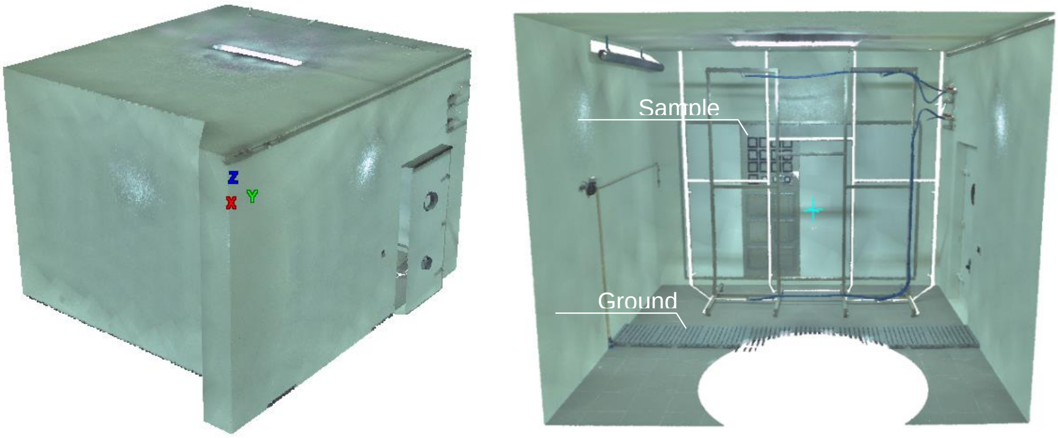


Figure 2 – Exterior and interior views of the test chamber, as seen in the acquired point clouds

Table 2 –Scan Station wide range parameters tests

Test	Scan Resolution	Scan Quality	White Balance	Image Resolution	HDR	File Size	Estimated Time
1	50.0mm@10m	1		960x960	No	150 MB	6 min 26 s
2	50.0mm@10m	2		960x960	No	154 MB	6 min 26 s
3	50.0mm@10m	3		1920x1920	No	572 MB	7 min 50 s
4	25.0mm@10m	1		960x960	No	168 MB	6 min 39 s
5	25.0mm@10m	2		960x960	No	171 MB	6 min 39 s
6	25.0mm@10m	3		960x960	No	168 MB	7 min 4 s
7	25.0mm@10m	4		1920x1920	No	591 MB	9 min 5 s
8	25.0mm@10m	4		1920x1920	Yes	605 MB	12 min 2 s
9*	25.0mm@10m	4		1920x1920	Yes	321 MB	12 min 2 s
10	12.5mm@10m	1		960x960	No	251 MB	7 min 4 s
11	12.5mm@10m	2		960x960	No	228 MB	7 min 55 s
12	12.5mm@10m	3	Cold Light	960x960	No	231 MB	9 min 36 s
13	12.5mm@10m	4		960x960	No	231 MB	12 min 58 s
14	12.5mm@10m	4		960x960	Yes	256 MB	15 min 27 s
15*	12.5mm@10m	4		960x960	Yes	172 MB	15 min 27 s
16	6.3mm@10m	1		960x960	No	464 MB	8 min 1 s
17	6.3mm@10m	2		960x960	No	465 MB	9 min 36 s
18	6.3mm@10m	3		960x960	No	466 MB	12 min 58 s
19	6.3mm@10m	4		960x960	No	467 MB	19 min 43 s
20	3.1mm@10m	1		640x640	No	1,3 GB	9 min 25 s
21	3.1mm@10m	1		960x960	No	1,4 GB	9 min 36 s
22	3.1mm@10m	1		1920x1920	No	1,8 GB	10 min 46 s
23	3.1mm@10m	2		960x960	No	1,4 GB	12 min 58 s

24	3.1mm@10m	3	960x960	No	1,4 GB	19 min 42 s
25	3.1mm@10m	4	640x640	No	1,3 GB	33 min 0 s
26	3.1mm@10m	4	960x960	No	1,4 GB	33 min 11 s
27	3.1mm@10m	4	1920x1920	No	1,8 GB	34 min 22 s
28	1.6mm@10m	1	960x960	No	5,1 GB	19 min 45 s
29	1.6mm@10m	2	960x960	No	5,1 GB	33 min 16 s
30	1.6mm@10m	3	960x960	No	5,1 GB	1 h 0 min 19 s
31	0.8mm@10m	1	640x640	No	19,9 GB	1 h 0 min 8 s
32	0.8mm@10m	1	960x960	No	20,0 GB	1h 0 min 18 s
33	0.8mm@10m	1	1920x1920	No	20,4 GB	1 h 1 min 29 s
34*	0.8mm@10m	1	1920x1920	Yes	20,4 GB	1 h 4 min 26 s
35	0.8mm@10m	2	640x640	No	19,9 GB	1 h 54 min 12 s
36	0.8mm@10m	2	960x960	No	20,0 GB	1h 54 min 23 s
37	0.8mm@10m	2	1920x1920	No	20,4 GB	1 h 55 min 33 s
38*	0.8mm@10m	2	1920x1920	Yes	20,4 GB	1 h 58 min 30 s

*Scans taken with minimal light on the room

3.2 Laboratory tests – Parameters influence over laser scanning operations

As it may be verified in Table 2, various parameters highly influence the laser scanning operations in terms of scan time and resulting file size. In the presented case study (Section 4), both these parameters were noted as highly impactful when surveying a building. As such, a brief analysis of the impact of the parameters on these subjects is presented.

From the above tests, it could be concluded that a growing scan resolution and image resolution implied a growing estimated time and data file size. It is also possible to conclude that although the scan quality does increase the estimated scan time substantially, the same is not always true for the file size. Furthermore, it can also be concluded that using HDR increases the scan time substantially but the increment on file size depends on the lighting of the scanned area. Moreover, it can be determined that although both scan and image resolution influence the file size and the scan estimated time, the former has a greater influence over these variables than the latter. In fact, throughout the tests, the changes in image resolution lead to small changes both in file size (around 400 MB) and estimated time (around 1 minute). However, the opposite can be perceived in what regards scan resolution, where its changes can be easily felt in the last few tests, displaying significant increments in file size (around 15 GB) and estimated time (around 40 minutes). In Figure 3, it is possible to address the exponential growth of the above-mentioned changes, using the average of the results acquired from the parameter tests seen in Table 2.

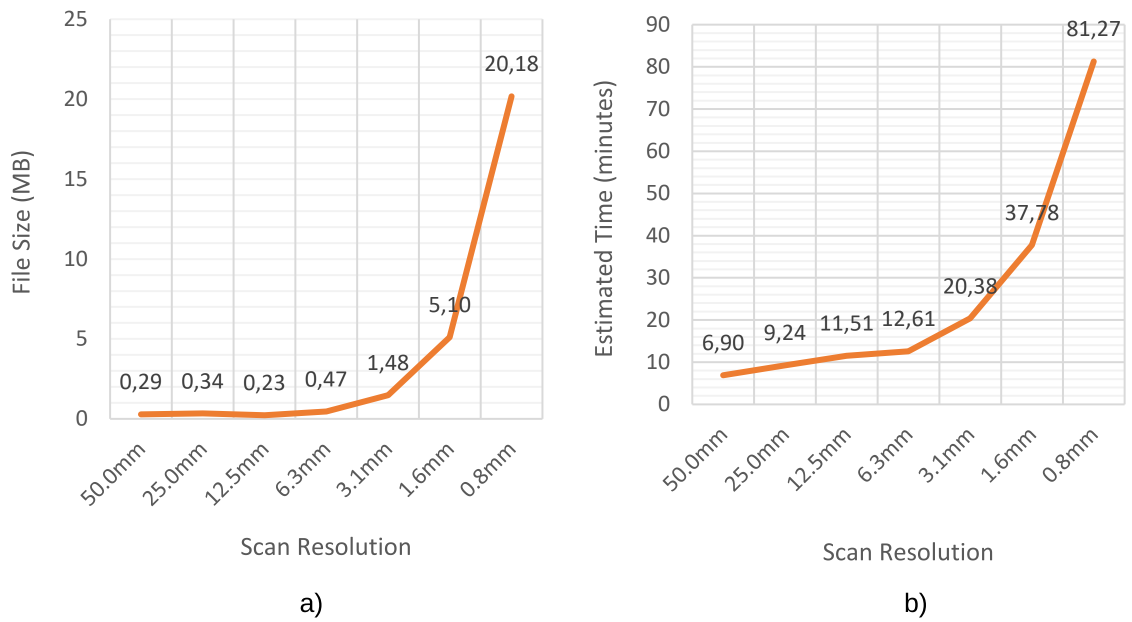


Figure 3: a) Average file size for the respective scan resolution at 10 meters, b) Average estimated time for the respective scan resolution at 10 meters

In Figure 3, the graphics clearly demonstrate the exacerbated file size and estimated time a scan may display when using a higher resolution. In fact, these results clearly emphasize the importance of this study, since the acquisition of a proper range for the laser scanning parameters undoubtedly benefits the user in both time and hardware capabilities.

As such, from these analyses it may be concluded that:

- Higher scan quality substantially increases the scanning time;
- Higher scan quality affects the final file size, but no correlation can be seen;
- Using HDR substantially increases the scanning time;
- Using HDR slightly affects the final file size depending on the room lighting;
- Image resolution substantially increases both the scan duration and the final file size;
- Scan resolution may extensively increase both the scan duration and the final file size.

3.3 Laboratory tests – Parameters influence on the final model LOD

After documenting the parameters influence on the laser scanner operation, the next step is to study their influence on the achievement of the selected LOD. To do this, the first step is to know which parameters actually influence the achievement of the selected LOD, which, in the case of the laser scanner, is the same as identifying which parameters restrict the modulation process on the BIM authoring software. In fact, since the point cloud objective is to be used as a drawing reference in the modulation process, this section requires the identification of which parameters alter the point cloud precision and ability to portrait the geometric form of a building.

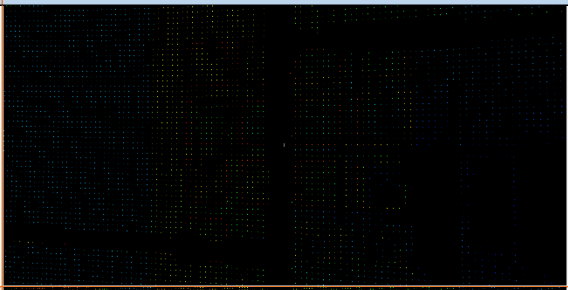
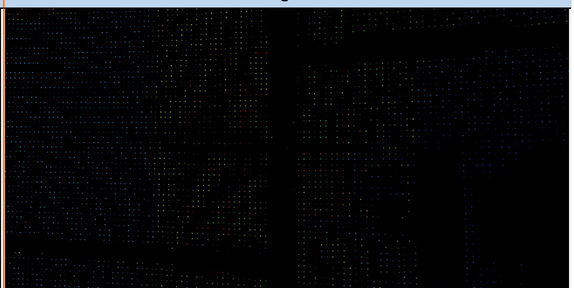
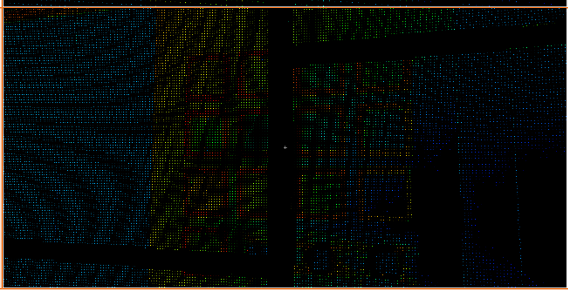
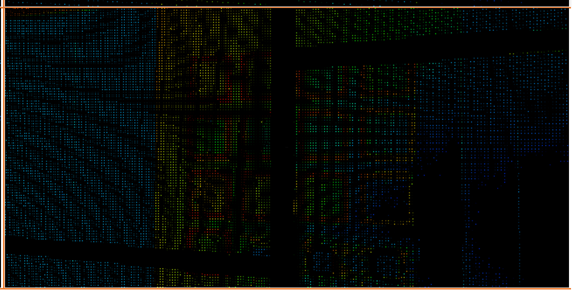
From the start, it is almost possible to exclude white balance, image resolution and HDR as impactful parameters in this topic. This comes from the fact that these parameters focus mostly on the esthetic value of the point cloud. In fact, from the multiple tests that were conducted, it was concluded that only in very specific cases the changes in these parameters allowed for a better modulation process. These cases mostly regarded situations in which the color of the point cloud might give extra information, such as discerning small-distant details such as ventilation grilles.

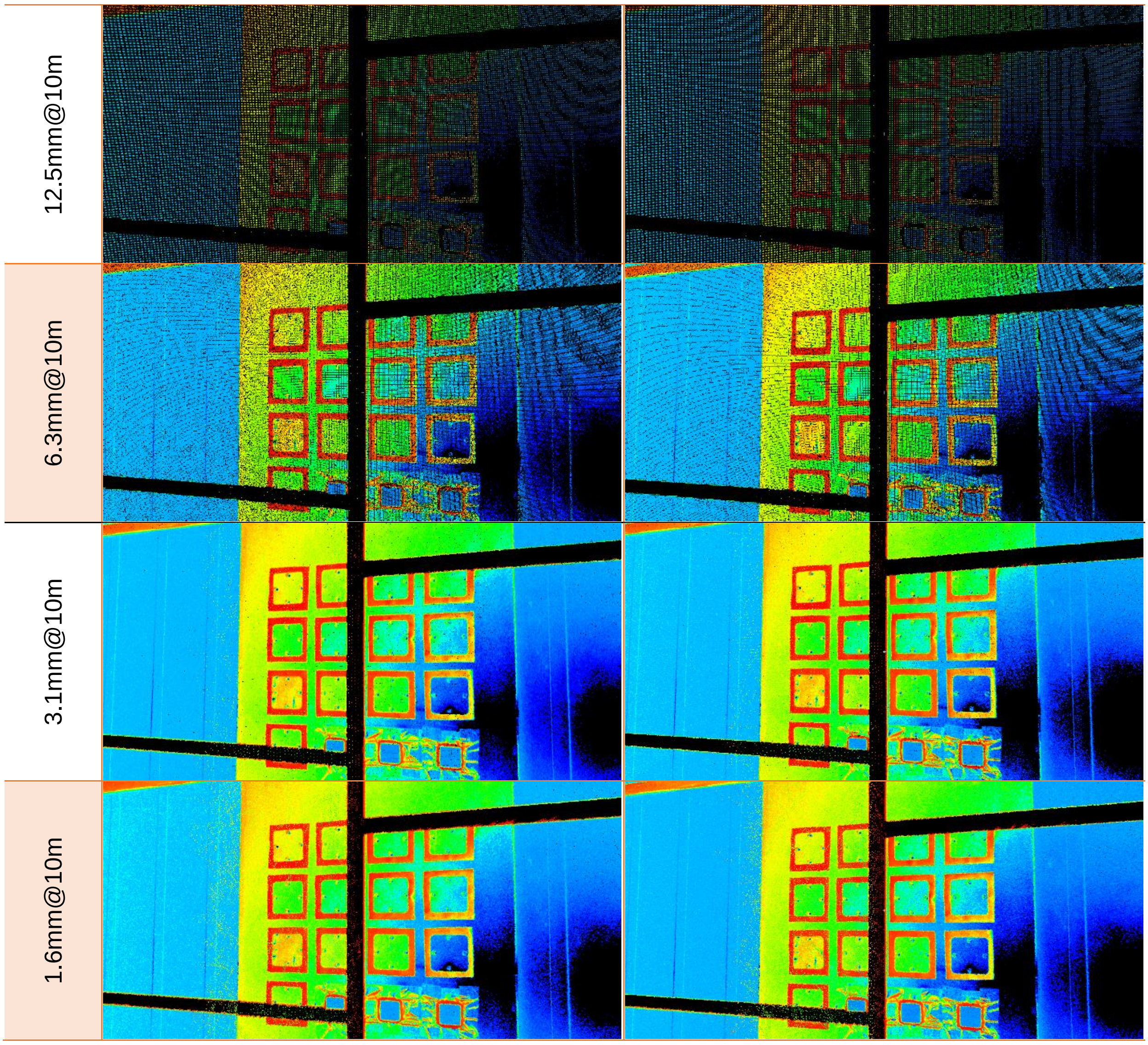
In what regards scan resolution and quality, since both directly relate with the point cloud's points position, the scans acquired from Table 2 tests were used as a tool to determine the impact of these parameters on the geometrical form of the point cloud. As such, Table 3 presents 12 scans representative of their respective scan resolution and quality, taken at an average distance of 5 meters. By observing theses scans, it is possible to conclude that a modification in quality does not result in noticeable differences regarding the point cloud ability to serve as a drawing reference in the modulation process. In fact, this same comparison was done using the quality parameters on different walls of the test chamber, with multiple point of view, and the same conclusion was met. However, in what concerns the scan resolution, by analyzing Table 3, it is possible to conclude that it is a major factor on the final point cloud ability to properly convey the building geometric form. It is clear that using a scan resolution of 25.0mm@10m delivers less geometrical information than a 1.6mm@10m resolution. However, it is also clear that using scan resolutions above the 3.1mm@10m, at a 5 meter range, results in insignificant detail gains (thus the 0.8mm@10m scan not being represented).

As such, from these analyses it may be concluded that:

- White balance, image resolution and HDR does not affect the quality of the point cloud's geometrical information. However, in specific occasions, the visualization of the colors of the real building on the point cloud may help discern certain details:
- Scan quality does not visibly affect the quality of the point cloud's geometrical information;
- Image Scan resolution has a major impact on the final geometric information conveyed by the point cloud.

Table 3 – Representative scans acquired from the Table 2 tests

Scan Resolut.	Quality	
	Q1	Q3
50.0mm@10m		
25.0mm@10m		



4 LASER SCANNING SURVEY

Equipped with the information acquired in Section 3, the following step in this study was the application of this knowledge in a real world survey. The selected case study was the “Campo 24 de Agosto” bus station in Porto, Portugal.

Two phases were stipulated in order to properly survey the station: planning and surveying. As the names imply, in first phase an overall planning of the survey was prepared, while in the second the actual survey was accomplished. In planning, early visits to the site were conducted with the following purposes:

- Meetings with the site administration for survey approval;
- Acquire the site plans and check its correspondence with the as-built site;
- Conducting an initial photographic survey;
- Determine the type of materials applied in the site and their influence on the scan;
- Study possible scan obstructions;
- Determine the required scanning stations and study their initial settings and location;
- Acquire the average scan duration;

- Plan station interconnectivity;
- Determine lighting conditions.

This phase allows for a more realistic view of the as-built site, enabling a better survey of the site in the following phase. It should be stated, that after this study, this phase was determined as the most important part of the research since multiple hours and information could be gained, if preformed correctly.

It was determined that a total of 54 scan stations would be used in the survey. These scan stations would be mostly comprised of 3,1 and 6,3mm@10m resolution scans, since an above-average quality was required for the end point cloud. In addition, a scan quality of 3 was selected for all the scans given the multiple glass surfaces in the site. Furthermore, it was also decided that the exterior environment of the station would also be surveyed, using 9 of the above 54 stations to do so. As such, the planning phase culminated with the creation of Table 4 and Figure 4.

Table 4 – Surveying scans

Scans	Resolution	Quality	White Balance	HDR	Scan Time
1 - 3	6.3	3	cold light	Yes	15m27s
4 - 7	6.3	3	cold light	No	12m58s
8	6.3	3	warm light	No	12m58s
9	12.5	3	cold light	No	9m36s
10	6.3	3	cold light	No	12m58s
11 - 12	12.5	3	cold light	Yes	12m5s
13	6.3	3	cold light	No	12m58s
14	12.5	3	cold light	No	9m36s
15	25	3	cold light	No	7m4s
16 - 18	12.5	3	cold light	No	9m36s
19 - 22	3.1	3	cold light	Yes	22m11s
23 - 24	3.1	3	cold light	No	19m42s
25 - 26	6.3	3	cold light	No	12m58s
27 - 28	3.1	3	cold light	No	19m42s
29	6.3	3	cold light	No	12m58s
30 - 31	12.5	3	cold light	No	9m36s
32 - 33	6.3	3	cold light	No	12m58s
34	6.3	3	sunny	No	12m58s
35 - 42	3.1	3	sunny	No	19m42s
43	6.3	3	sunny	No	12m58s
44	6.3	3	warm light	No	12m58s
45 - 46	12.5	3	cold light	No	9m36s
47 - 48	3.1	3	cold light	No	19m42s
49	6.3	3	cold light	No	12m58s
50 - 52	12.5	3	sunny	No	9m36s
53 - 54	6.3	3	cold light	No	12m58s
				Total	10h24m00s

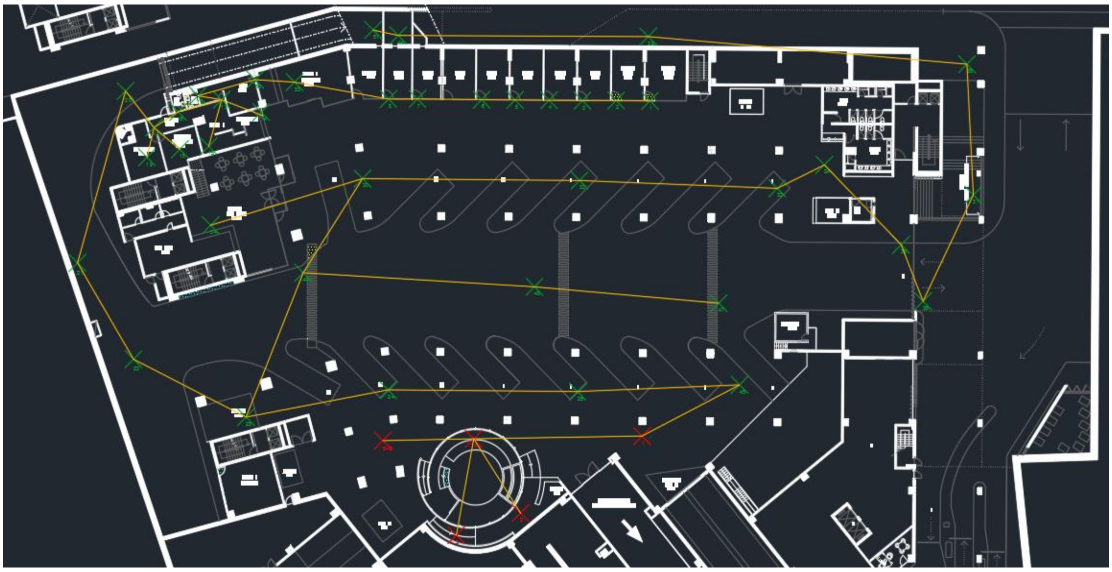


Figure 4 – Plan of the scanning stations used in the case study

The selected scan parameters and interconnections between stations (for the point cloud unification process) were all confirmed to be properly determined in the point cloud analysis (Section 5), resulting in the acquisition of 54 scans that required registration and cleaning work.

For reference, in Figure 5 it is possible to address a registered (unified) version of the acquired point cloud (exterior included), without any cleaning. However, it should be emphasized that Figure 5 is just for demonstrating the raw state of the point cloud, since the point cloud should not be registered without undertaking a proper cleaning procedure first (as seen in Section 5).

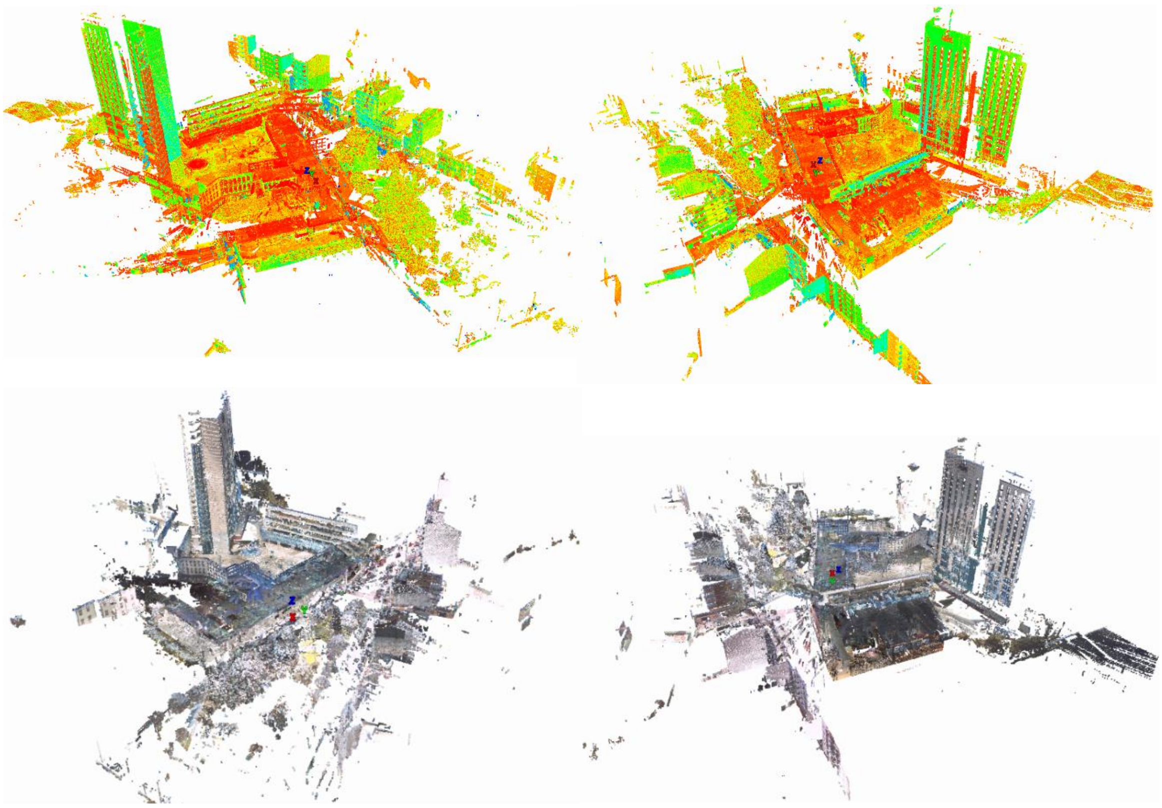


Figure 5 – Exterior and interior views of the case study, as seen in the acquired point clouds.

5 POINT CLOUD SOFTWARE

Most of the work in this topic revolved around the requirements for the proper registration (process of unifying the various scans through the identification of at least three concurrent points between scans) and cleaning (process of deleting unwanted data from the scans) of the acquired point clouds.

It should be stated that through experimentation of various methodologies, the one that resulted in clearer and recognizable point clouds was the one which started with a first individual scan station cleaning, followed by the registration process and, finally, another overall point cloud cleaning. The first cleaning is intended to eliminate most of the noise from the point clouds, removing persons, cars among others. The second is targeted at illumination changes, previously missed noise and point cloud delimitation.

5.1 First Cleaning process

Throughout this study, it was possible to conclude that a better cleaning process would result in faster modulation time in the authoring software. The reasons are twofold:

- Less point cloud “noise” results in smaller file sizes and less required computer power. This is important since large point clouds may create lag while in the BIM authoring software;
- The less “noise”, the easiest it is to accurately modulate a building, especially in what regards its interior surfaces.

As such, a well cleaned point cloud is necessary when addressing larger building such as bus stations. To accomplish this, and as previously stated, two cleaning stages were created. In this first stage, noise is eliminated from each point cloud individually, resulting not only in an easier registration process but also in a better final product. In Figure 6, it is possible to see an example of the first cleaning process using these tools, while in Figure 7 it is possible to recognize the increased difficulty intrinsic to the modulation process of a non-cleaned point clouds when compared to a cleaned one.

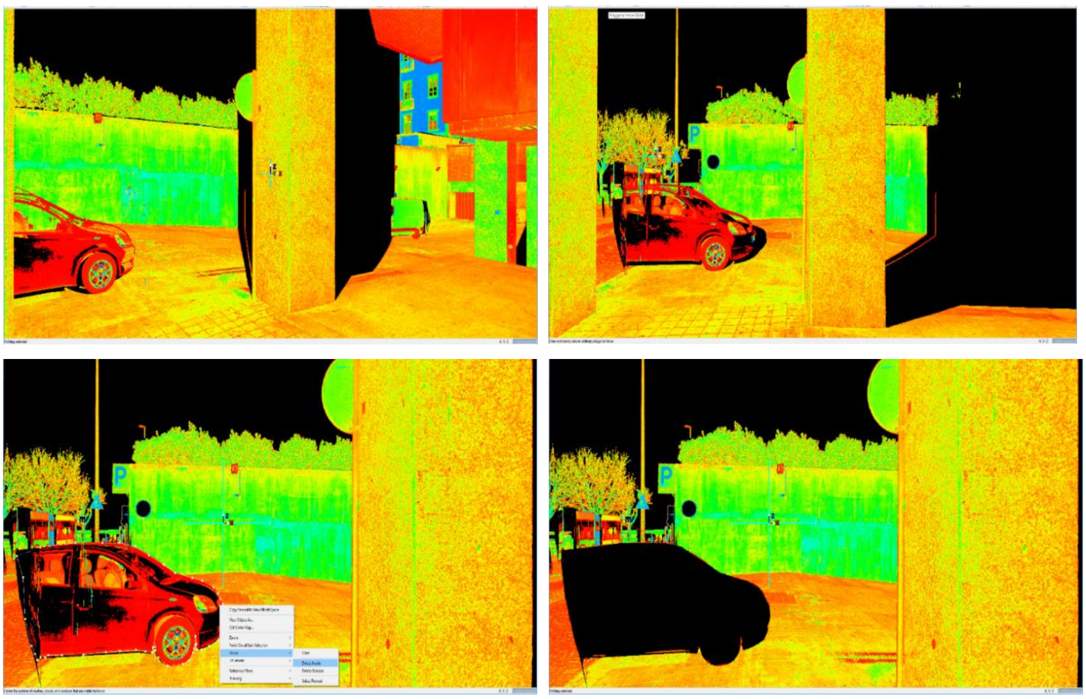
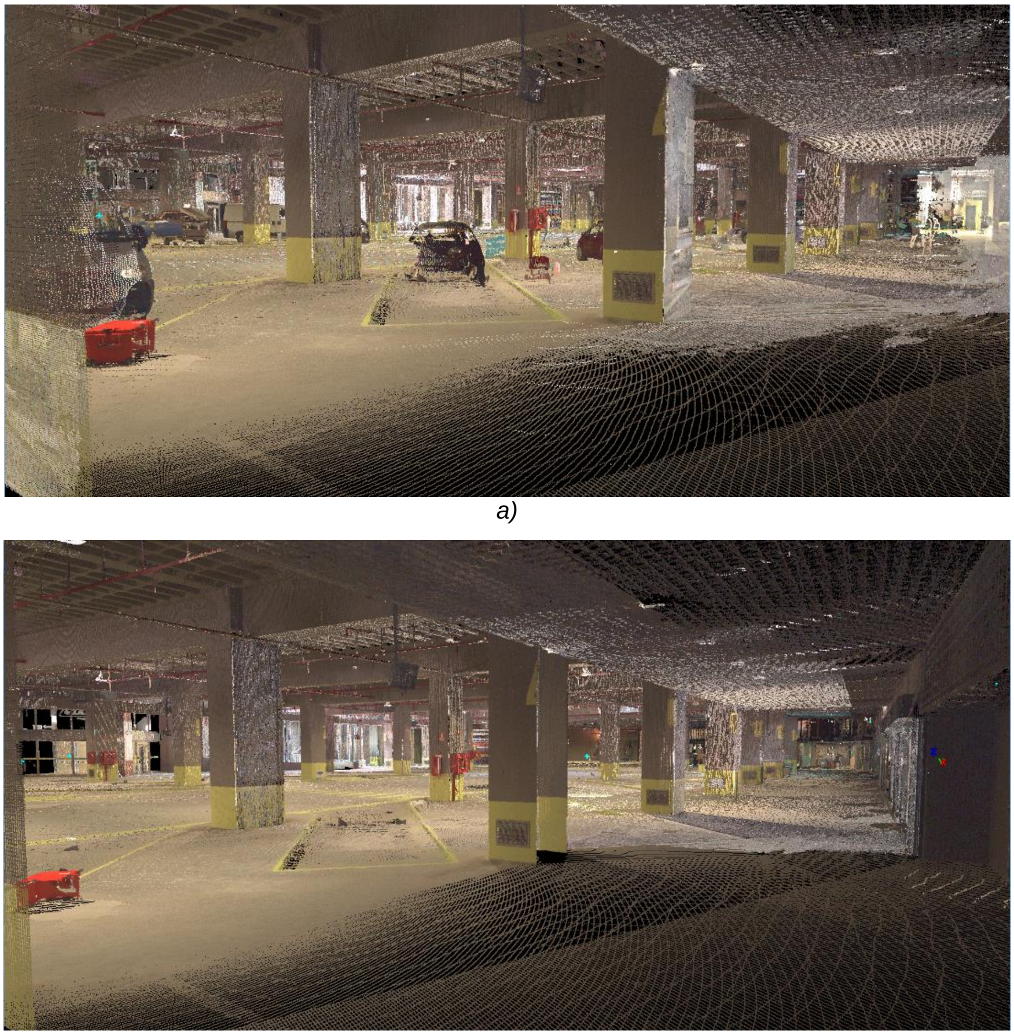


Figure 6 – First cleaning process, elimination of unwanted data from the point clouds

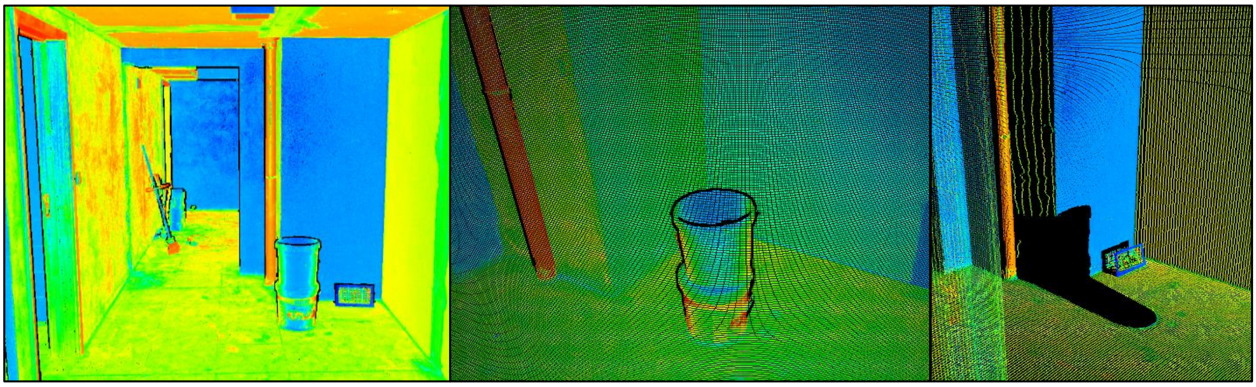


a)

b)

Figure 7 – Point cloud: a) before the first cleaning process, b) after the first cleaning process

Finally, the importance of doing this process before the registration should be emphasized. In fact, when eliminating any portion of the point cloud, the applied software may also delete the points behind the eliminated object in a “laser-beam” fashion. As an example, consider Figure 8 where the registration process is complete. Figure 8a) and Figure 8b) represent scan stations that acquired still not-cleaned portions of the final point cloud. If the two buckets in Figure 8b) were to be eliminated using the shown point of view, the resulting point cloud from Figure 8a) perspective would be Figure 8c). This is highly inconvenient since information is easily lost. It is possible to choose each laser scanning station individually after the point cloud is registered (process used in the second cleaning process shown is Section 5.3. Nevertheless, it is a lengthier process and it also results in decreased accuracy for the final point cloud, since it is harder for the software to encounter concurrent points between scans.



a) b) c)

Figure 8 – Elimination noise and its impact on the point cloud

5.2 Registration process

In regards to the registration process, it was found that using a manual registration instead of the semi-automated registration, resulted in registrations far more precise, with accuracy levels around 0.001 mm. This value is far lower than the 0.4 mm accuracy acquired from the semi-automated registration. Furthermore, it was also determined that the use of more than three concurrent points did not increase the final registration accuracy. However, the definition of three non collinear points, separated throughout varied 3D planes, would result in improved accuracy. Such conclusions were important since the resulting registration will be used as a base for the creation of the BIM model, which will be directly influenced by the registration accuracy.

5.3 Second Cleaning process

After registering the point cloud, the second cleaning process was performed. Although the impact of this process is less significant than the previous one, its importance to the point cloud clarity is also vital. Figure 9 illustrates this by displaying a photograph-like portion of the point cloud, made possible by focusing and eliminating the following four aspects:

1. Small portions of noise that were not found in the first cleaning;
2. Portions of the point cloud acquired through glass or reflected from mirrors and water puddles;
3. Surfaces with different tonalities;
4. Unnecessary point cloud limits.

The first two aspects are quite straightforward. Any noise or inaccurate points that were not found and eliminated in the first cleaning may be eliminated in this second process. In fact, although it is harder to delete these points in the second cleaning, it was found that after the point cloud is unified, it is easier to detect any portions of the point cloud originated from reflection or acquired through glass.

The third process relates to the acquisition of point clouds under different lighting conditions. In this particular case, since the survey was performed throughout multiple days during both the morning and afternoon, there were different natural (sun exposure) and artificial (electric lighting) lighting conditions. This results in surfaces displaying an unnatural mixture of textures and tones that hinder the user ability to clearly analyze the point cloud. This particular aspect may be better seen in Figure 10 cleaning process.

The fourth and last aspect of this second cleaning process relates to the clear definition of the point cloud's limits. This eliminates unnecessary data on the edge of the point cloud and helps the user focus on its core section. Figure 11 illustrates this aspect for the interior and exterior of the station.

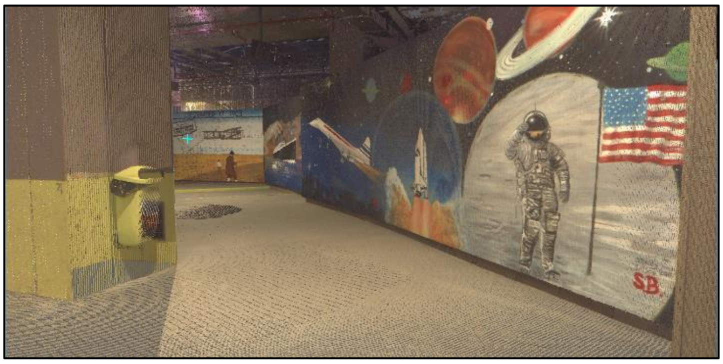
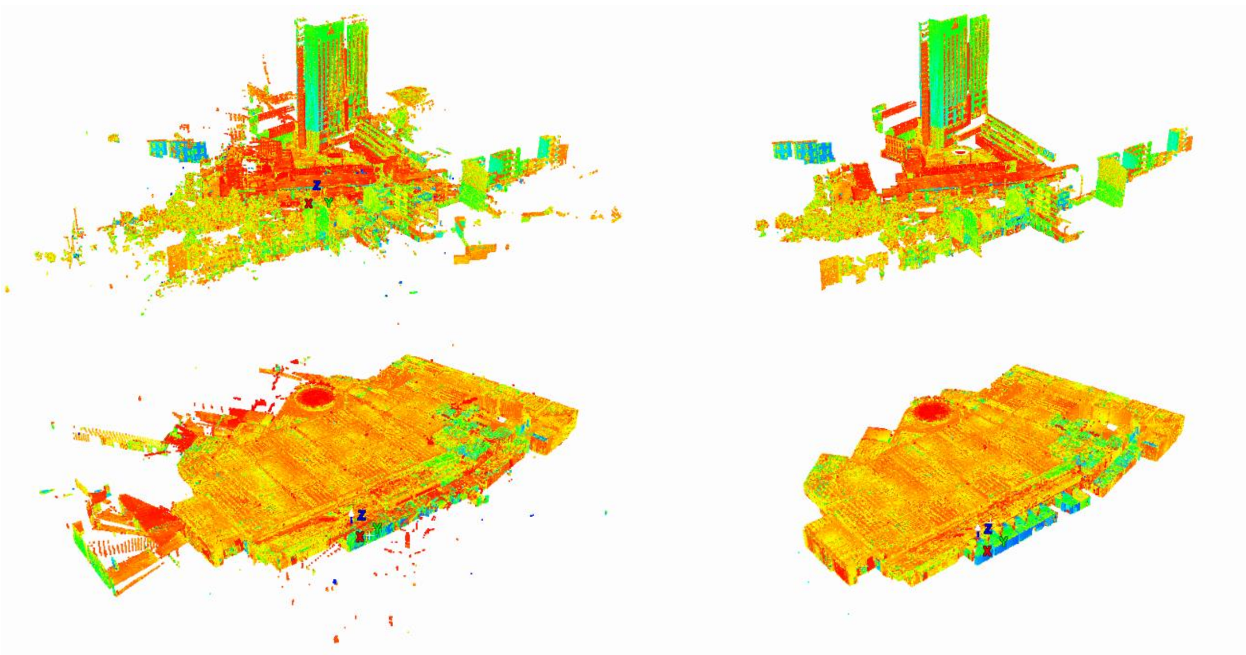


Figure 9 – Portion of the final point cloud.

a) *b)*

Figure 10 – Point cloud before (a) and after (b) the different surface tonalities are eliminated

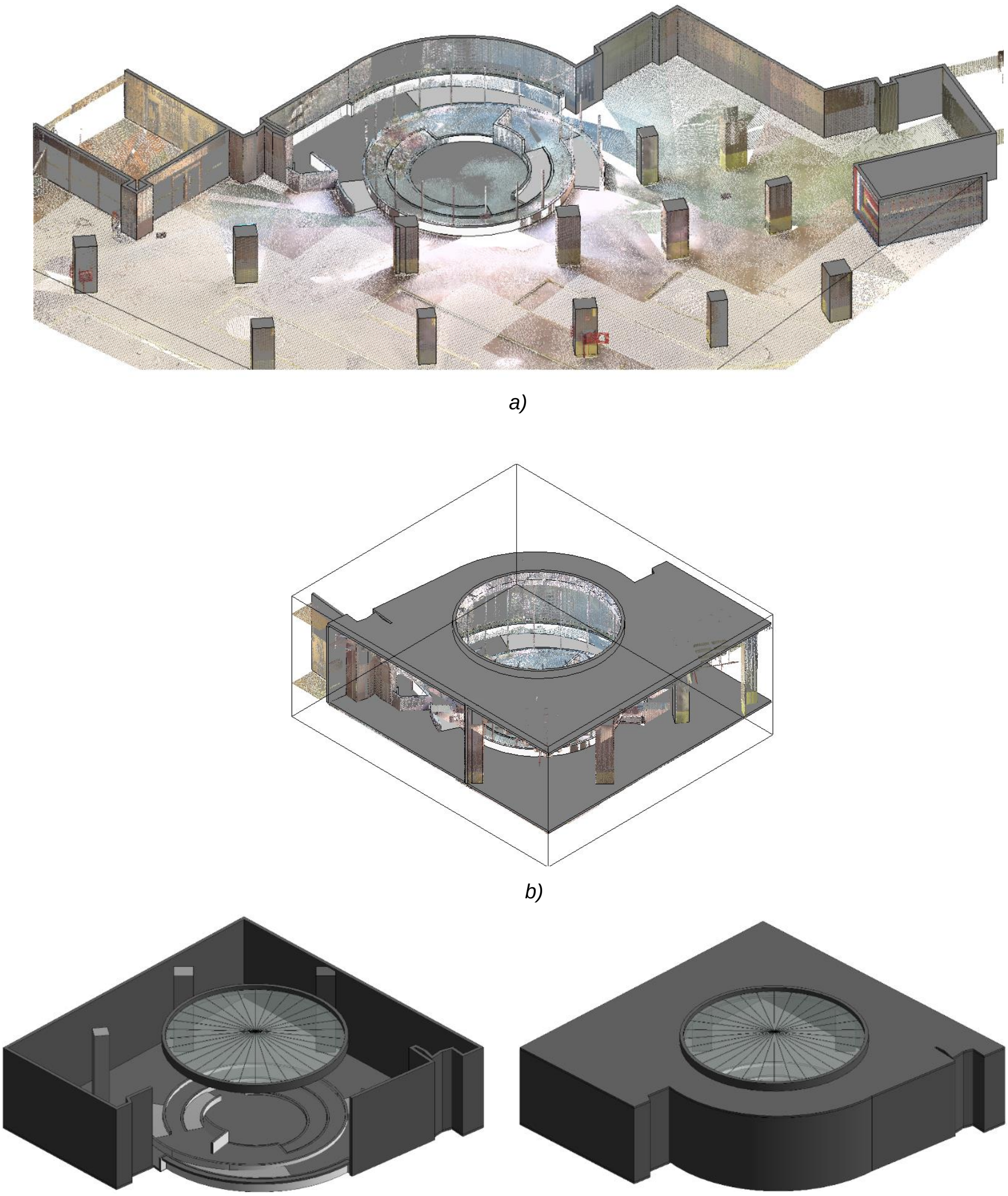


a) *b)*

Figure 11 – Point cloud before (a) and after (b) the point cloud limits definition

6 BIM AUTHORING SOFTWARE

With the end of data analysis, and in order to validate the point cloud usage as a geometric data source for the creation of BIM models, the acquired point cloud was imported into Revit. Figure 12 displays the process of creating the model from the point cloud. However, as it may be seen in Figure 12b) to Figure 12d), only a highly detailed portion of the point cloud was chosen to be imported into the simulation software. This portion consists on a small, open waiting area inside the bus station, covered by a circular skylight, with multiple steps and ramps to access its centre.



a)

b)

c) *d)*

Figure 12 – Process of creating the BIM model from the point cloud in Revit

7 TECHNOLOGICAL REQUIREMENTS

With the end of the data analysis phase the case study was completed. By analyzing the acquired and treated point clouds, it was possible to conclude that they were suitable to be used as a source of geometric information for energy simulation. In fact, in what relates to three energy simulations, namely single-zone, multizone and CFD, it was determined that the acquired point clouds were captured with excessive detail, including more information than the required by these methods.

This was initially expected since an above-average resolution (the most important parameter in regards to conveying geometric information, as concluded in the laboratory tests) was used throughout the survey, displaying a theoretical average scan resolution of 7,2mm@10m. However, in practice, this value was aggravated by the sheer amount of columns and enclosed spaces that dictated an increment in scan stations, which translated into a smaller resolution overall. In fact, when calculating the scan resolution using the farthest distance between each scan station and their respective acquired surfaces, it was concluded that the merged point cloud would display an average resolution far below 5,3mm@10m. This value does not account for the exterior scan stations since it would greatly influence the resulting average.

8 CONCLUSIONS

Although current methodologies for building geometry acquisition allow for the successful energy-retrofit of a building, their cost efficiency and lengthy duration jeopardizes the achievement of the energy simulation goals mentioned in this report.

By applying laser-scanning techniques to this problem, this work proposed a workflow for an expeditious and accurate acquisition of as-is geometric data, allowing its use for building simulation. The proposed workflow was successfully applied in the acquisition and treatment of the geometric data from a bus station.