As-built drawing generation of LFM building ITB using terrestrial laser scanner

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Abstract. The LFM ITB building, which was built in 1939, needs to be renovated in some or all parts of the building without removing the existing characteristics and philosophical values. Therefore, renovations must refer to the building's as-built drawing documents. As-built drawings can be made using Terrestrial Laser Scanner technology. TLS technology will be the main component in making the three-dimensional model of the LFM Building which will later become a reference in making as-built drawings. The purpose of this study is making 3 dimension model and as-built drawing of LFM building from TLS data.

In this research, Building LFM modeling uses data from measurements using TLS. Data is processed through a registration process to unify all data. The average value of registration errors is 0.006 meters. The noise removal process removes unused data. The modeling process is carried out to produce a solid model that represents the shape of the LFM Building in the field. The results of the three-dimensional model will be used as a reference in making as-built drawings that include floor plans, visualizations, and building pieces. The results of the registration are then validated by using a distometer for vertical distance and measuring tape for horizontal distance. Vertical distance validation has the largest value of 0.012 meters and horizontal distance has the largest value of 0.011 meters.

1. Introduction

1.1. Research Background

Bandung Institute of Technology (ITB) is a State University (PTN) which was established on July 3, 1920 as TH te Bandoeng and officially changed its name as ITB on March 2, 1959. As a state university, ITB always carries out the development of facilities needed for the academic community to advance. One of the facilities in question is the construction and renewal of the lecture buildings. The lecture buildings at ITB have their own philosophical and distinctive values in the form of construction, exterior and interior, building use and, location. LFM Lecture Building (Room 9009) is one of the buildings that have this characteristic. The LFM building was built in 1939 and began to be used on August 1940. This building, which can accommodate ± 140 people, was built to anticipate the increasing number of new students. The location of this building is to the north of East Hall. This building is also used as a student cinema by ITB Student Film League [1].

The LFM Building (Room 9009) did not experience changes in form or structure for approximately 79 years. Considering this, the Infrastructure (Sarpras) department of ITB, wanted to renovate the LFM Building to improve and add more facilities so that the academic activities could be carried out more optimally. As-built Drawing is needed as a reference to restore a building. As-built Drawing is a technical drawing of the work report processed from the initial plan drawing and adjusted to the condition of the finished building. It can be useful as a guideline for building management such as operation, maintenance, and as a basis in carrying out renovations or changes in the future. Unfortunately, the LFM ITB Building does not have an As-built drawing.
because it was built a long time ago. However, with the latest technology, As-built Drawing can be made digitally from a three-dimensional (3D) model of a building.

One of the technologies that can be used in making a three-dimensional (3D) model of a building is the Terrestrial Laser Scanner (TLS). TLS is a tool that uses the technique of scanning the surface of an object with laser technology and recording a large number of points, namely point clouds that coordinate three dimensions (positions x, y, and z). TLS is capable of recording large numbers of points with high accuracy and a relatively short time [2]. The points produced by TLS represent the surface shape of the object to be modeled with a point density that can be adjusted as needed.

TLS technology will be applied for building construction. The LFM Building 3D model will be able to be formed in both point clouds and solid shapes using TLS. Then, various perspectives of As-Built Drawing will be made using the solid form of the 3D model of the building. The 3D model in solid form is used as a reference because it can represent the size that matches the building's original condition. As-Built Drawing that will be created is expected to be able to be used well by the ITB Facilities and Infrastructure Department for better management of the LFM Building without losing its historical value and characteristics.

1.2. Research Aims
The objectives to be achieved from this research are:
1. Making a three-dimensional model of the Bandung Institute of Technology's LFM Building using TLS Data.
2. Making and analyzing the As-built Drawing of the LFM Building in the Bandung Institute of Technology from TLS Data.

1.3. Data And Methods
The main data used in this study are point clouds generated by TLS. The workflow of this research includes data acquisitions, registration, georeferencing, filtering, 3D modelling, dan as-built generation.

2. As-Built Drawing
As-built drawing is one of the essential parts of every construction project. As-built drawings are final drawings that show the dimensions, geometry, and location of all project elements precisely as it is following the implementation in the field where the construction is carried out after the construction project has adopted all changes (specifications and drawings). As-built drawings act as building operational guidelines and are based on shop drawings that have been revised following the changes that occurred during construction. The making of as-built drawing is carried out after the construction work has been completed completely. Making this image requires a significant amount of time. So if the image creation is considered in the development part, the progress will be difficult to reach the end, which causes the work to delay. As-built drawings are made by the contractor with the approval of the work owner who has been checked by the work supervisor consultant.

Making as-built drawings in the implementation of construction projects must go through several stages. This image was made by the contractor by sending a drafter who will pass the quality control check process by the engineering manager. Then, this picture was submitted to the supervisor consultant to check its suitability with the finished building. If appropriate, the consultant will approve the drawing by providing a signature and stamp. The contractor then prints as-built drawings on paper that have been approved in the work contract and will be approved by the contractor, construction management, consultant, and work owner. In the final stage, the consultant provides as-built drawings along with the handover of the building key.

Measuring the dimensions of the final condition of the objects built is done when the construction process is complete. The dimensions that need to be measured are related to the details of construction that are the same
as the dimensions measured in the measurement of the initial dimensions in the shop drawing. Measurements were made using a laser or conventional meter measuring device. The results of the final measurements will be used to verify the value of the initial dimensions with the final dimension values, which are then used in making as-built drawings.

As-built drawings are made to be able to explain the parts that have changed during the development process. Examples of as-built drawings can be seen in Figure 2.1. Another purpose of this image is as a report or archive as well as being a guide in the future in building management. Management in question can be in the form of operations, maintenance, or as a reference in carrying out renovations. To be easily understood from time to time, as-built drawings generally contain the following things:

1. A description of the modifications made
2. The date is written on the corner of the drawing sheet
3. Use the same scale for different sheets
4. Coloring, if necessary, as a sign for addition, deletion, or important changes to an object.

3. Terrestrial Laser Scanner (TLS)

Terrestrial Laser Scanner (TLS) is a technique of measuring points in a pattern directly on a three-dimensional scale using laser light from objects found on the surface of the earth. The results obtained in the form of dots in large numbers, also known as point clouds, that have three-dimensional coordinates of the tool stand. Point clouds can then be used as an analysis of objects and materials for making three-dimensional models. Although it looks sophisticated, TLS cannot still acquire colors that match the original colors. The color produced by TLS is the reflection intensity of the object shot by the laser [3].

TLS has a lot of advantages compared to other surveying instruments such as tachymetry, photogrammetry, dan GPS [2]. Some of them are:

1. Capture three-dimensional coordinate points in large numbers and details in a short time.
2. Data acquisition can be done in a place where there is no light.
3. Complete and comprehensive scanning.
4. The resulting data can be used until the future.
5. It can cut costs and finish work much faster.
6. It can be used in areas or objects that are difficult to reach by traditional instruments.

Terrestrial Laser Scanner is a technology that uses laser (Light Amplification by Stimulated Emission of Radiation) techniques. A laser is an instrument that can emit and amplify visible light waves. Lasers emit light at a certain distance depending on the frequency and wavelength. This beam is then emitted to measure the scanned object. The principle of TLS measurement is divided into two types, namely measurements carried out based on pulses (pulse-based) and based on phase difference (phase difference based). Pulse-based measurement (pulse-based) is a measurement using the travel time of pulses carried by a laser from being emitted by a device until it is received by the device. Based on the travel time experienced by pulses, there are two times, namely when leaving and when returning, the distance can be obtained using the following equation.

\[ D = \frac{c \cdot t}{2} \]

with,
- \( D \) = Distance from the instrument to target
- \( c \) = Light velocity in air
- \( t \) = Signal travel time
The speed of light/wave propagation is known by its fixed value. The advantage of pulse-based measurement is that the concentration of laser emitted energy is high so that the accuracy of even long distance measurements will produce good data.

In Laser Scanning, the number of points measured using pulse or phase difference as basis can reach thousands of points in a single scan so that a set of points is called point clouds which represent a condition in an object in the real world. This can happen if the tool used is equipped with a prism that functions as a diverter of light waves. Light waves emitted through one source then hit a prism, the prism will bend the light waves in all directions caused by the movement of the rotating prism. In measurements using TLS, there are four types of mirrors used, each of which has its characteristics and uses, as follows.

1. Oscillating Mirror is a type of mirror that produces a winding/zig-zag pattern at the points being scanned. This is due to the movement of the mirror which changes in the middle of the phase and at the end of the phase in the form of acceleration and deceleration which causes the point distance to be different.
2. Rotating Polygon, this type of mirror is a type that produces dots with a regular and evenly pattern that has the same distance between points along the transverse and longitudinal paths.
3. Palmer Scan is a type of mirror that deflects light waves on the rotation axis with the mirror surface not forming a 90° angle.
4. Fiber Scanner is a type of mirror that will produce regular points but the distance between points on the transverse and longitudinal paths is not the same. This type is the most stable type of mirror because the mirror is embedded in the instrument which causes the mirror to experience no movement. Besides, this mirror contains glass fiber which can transmit light waves into an arrangement.

Illustrations of mirror types found in TLS can be seen in Figure 1.

![Figure 1. Mirror type on TLS (Vosselman & Maas, 2010)](image)

Positioning on Terrestrial Laser Scanner devices is the same as positioning on other mapping survey tools. The initial data needed is angle and distance which are then processed into coordinate

Based on the geometry scheme above, there will be an equation that can be formed to formulate the initial data into coordinate data. The equation formed is in the form of distance (ρ), horizontal direction (θ), and zenith angle (α) as follows.

\[
\rho_{ij} = \sqrt{x_{ij}^2 + y_{ij}^2 + z_{ij}^2}
\]
\[
\theta_{ij} = \arctan \left( \frac{y_{ij}}{x_{ij}} \right)
\]
\[
\alpha_{ij} = \arctan \left( \frac{z_{ij}}{\sqrt{x_{ij}^2 + y_{ij}^2}} \right)
\]

where \((x, y, z)\) is the point \(i\) coordinate in tool \(j\) which has a relation to the object’s space coordinates through the following transformation.
\[
\begin{pmatrix}
X_{ij} \\
Y_{ij} \\
Z_{ij}
\end{pmatrix} = M_{sj}^o \begin{pmatrix}
X_i \\
Y_i \\
Z_i
\end{pmatrix} - \begin{pmatrix}
X_{cj} \\
Y_{cj} \\
Z_{cj}
\end{pmatrix}
\]

And \((X_{cj}, Y_{cj}, Z_{cj})\) are object space coordinates that refer to the position of the \(j\) and \(M\) devices are the rotation matrices of the object space \((o)\) to the sensor frame \((s_j)\) which are parameterized in three consecutive angles.

\[
M_{sj}^o = R_3(\kappa_{sj}^o)R_2(\phi_{sj}^o)R_1(\omega_{sj}^o)
\]

Where \((X_{cj}, Y_{cj}, Z_{cj})\) and \(\omega, \kappa, \phi\) are obtained from the device’s external orientation.

In all measurements in the mapping survey with any method, errors are things that cannot be avoided. Errors can affect the quality of observation data, including TLS measurement data. The errors of each TLS will vary depending on the company that produces the tool. However, errors in the tool can be divided into four factors, namely instrument errors, errors in the nature and shape of objects, errors by the environment, and methodological errors (Cosarca, 2009).

Instrument error is an error caused by the instrument or the instrument itself. This error can be either a random error or a systematic error. Random error is an error that is attached to the results of the measurement itself and can only be reduced by using corrections when processing data. Systematic error is an error originating from a laser scanner component. These components are laser rangefinders, beam deflection units, and angle measurement systems. The laser rangefinder is the main component used to calculate the distance of a point. An error will occur when the tool works beyond its capacity. The beam deflection unit is a mirror that serves to direct the laser to the intended point. This error is zero error (mirror is not at point 0) and scale error (converter device does not work correctly). This error can be avoided by conducting a calibration of equipment that is carried out regularly and making tools that are following the procedure.

Another error in the instrument is the angle measurement system, which includes errors in the vertical, collimation, and horizontal axes because they are not properly installed. Errors occur when the mirror rotation axis is not perpendicular to the gravity line at the tool standpoint. This error can be reduced by making the tool perpendicular and stable when scanning is done [2].

Errors in the nature and shape of the object are caused by the characteristics of the scanned object which will affect the reflectance of the laser emitted by the device. Reflectance is the ratio between the intensity of the wave emitted with the intensity reflected. Reduced wave intensity reflected can be caused by the following factors.

1. The color of the surface of the object
2. The angles of transmitting light waves
3. Surface temperature
4. Surface moisture
5. Texture or level of surface roughness
6. Laser wavelength
7. Physical properties of objects such as electrical permittivity, magnetic permeability, and conductivity.

The greater the reflectance value, the better the quality and accuracy of the data produced. The multipath effect can appear to be a cause of an error when the wave transmitting angle is large enough. This effect will cause the accuracy of the information on the position of the measured point to be less good [2].

3.1. LFM ITB Building (Room 9009)
The LFM or Room 9009 building is a building in which existence cannot be separated from the establishment of the Bandung Institute of Technology (ITB). The history of ITB began in the early 20th century over the rulers of the colonial era. The beginning of the campus was established intended to fulfill technical personnel,
which became difficult due to the disruption of relations between the Netherlands and its colonies in the archipelago caused by the first world war. Bandung’s De Technische Hoogeschool or what is now called the Bandung Institute of Technology was established on July 3, 1920, with a faculty from Faculteit van Technische Wetenschap which only had one department de afdeeling der Weg en Waterbouw. The campus complex, now called ITB, was designed by Henri Maclaine Pont, a Dutch architect. The first complex of ITB buildings has harmonization between one building and another, which can be seen from the similarity of the shape of the building. This has become a historical value and distinctive characteristic of architecture at that time.

The LFM Building is designed with the same style and shape of the roof as the ITB Hall building, located to the north of the East Hall of ITB building. The College of Film Student College Building was built from 1919 to 1921. The building was connected by a stone column hallway exposed and included in the building which was built in the first phase of the ITB campus complex. This building is used as a lecture hall that can be seen from the arrangement of space and seating that resembles a theater. In addition to being used as a lecture hall, the LFM Building is also used as an ITB campus cinema building, a film screening place at the right price for students. This campus cinema is managed by a student activity unit of the Student Film League (LFM) ITB [1]. Illustrations of the LFM ITB Building can be seen in Figure 2.

### 3.2. Data Acquisition

Planning is essential in mapping activities. Planning can reduce the possibility of errors when taking data in the field and can shorten the time of data collection. Planning is carried out by the needs of the work and executor. In this study, the planning was carried out in the form of a reconnaissance survey to identify the condition of the LFM ITB Building and the objects around it. The conditions in question are the shape and design of the building. Objects that are around the building are parks, roads, and other buildings. Another plan is to determine the points that will become the tool stand. The accuracy or density level between points used is equal to 6.3mm so that the details of objects in the building are formed more clearly. The determination of standing points of the tool is required to be able to reach all objects from the building to be mapped. The distribution of points where the tool stands can be seen in Figure 3.
3.3. Data Processing

Data scanning results of the LFM ITB Building are still in the form of point clouds that overlap with each other. To be a three-dimensional model, the scanning data needs to go through several stages, namely registration, noise removal, filtering, three-dimensional modeling. As-built drawings will be created after a three-dimensional model has been formed. This will shorten the time of making as-built itself. Data processing uses several types of software that have their respective functions and objectives. The use of a lot of software is due to the absence of software that can cover all the required processing. The first data processing process is extracting data from the device to the computer by copying data from the SD card on the device to the computer. The data that has been copied later through the process of changing the format of the data from .clr to .e57. Conversion is carried out on all scan data totaling 25 pieces. Conversion is done so that data can enter the registration phase.

3.3.1. Registration

Registration is an important step in processing data in this study. Registration is a combination of scanning data in the form of point clouds from one point where the tool stands with the point where the other tool stands so that a scanned object is formed. Registration can be done by various methods according to processing requirements and data collection methods. In general, registration is divided into three methods, namely Iterative Closest Point (ICP) registration, target to target registration, and cloud to cloud registration.

The registration used in this research is a registration with the cloud to cloud method. This registration method combines data point clouds at each point where the tool stands by using the geometry of the objects at each point. Registration is very necessary because data retrieval does not use a target as a tie point so that the scan data overlap is shown in Figure 4.

![Figure 4. Point clouds from two scanning points that still have noise and are not registered.](image)

(a) Filtering

Filtering is the process of screening the results of scanning data in the form of point clouds. The filtering is in the form of deleting and cleaning data from point clouds objects that are not needed in the next stage. This stage can be a consideration in making decisions in registration. Elimination of noise must be carried out carefully so that the object that becomes the reference for binding is not deleted. The process of removing noise is done is the elimination of objects that are around the building such as trees, roads, other buildings, parks, and people so that all that remains is the object of the LFM Building ITB. Visualization of the scan data that still has noise at one point can be seen in Figure 5.
3D modeling or three-dimensional modeling is an activity carried out to create a model or digital replica that represents the actual object in three-dimensional space. A three-dimensional model is created using dots in three-dimensional space which are then connected with various geometric shapes. Some points that have been connected will produce a full three-dimensional shape resembling the actual object.

This study does not use the georeferencing method so that the orientation of the model will be adjusted to the local orientation, both coordinates, and north. The determination of the north direction of the model is adjusted to the part of the object facing north on the actual situation. Determining local and north coordinates by making space around the object to be used as a flat check x, y, z object. Select 3 points in the space created then set from points and fill in the points based on local coordinates and rotation so that the object has the appropriate north-orientation.

There are two techniques used in making three-dimensional models in this study, namely by using the create object feature, insert shape and patch insert. Insert shape technique is a model making technique where the shape that will be the shape of the model adjusts to the shape of the point clouds. The size of the shape of the model will be adjusted to the size of the shape made of point clouds. This technique is used when the object to be modeled tends not to have many details, objects have relatively the same shape, and objects have spatial dimensions.

Patch insert technique is a model making technique where the form of the inserted model adjusts the points, forming a field, which has been chosen. The size of the patch shape will be adjusted to the shape of the point clouds with the tip of the object as a reference. This technique is used when the object to be modeled has complex details and when objects are only two-dimensional. However, this technique can form three-dimensional shapes that are used to make complex three-dimensional objects. Patches that have followed the shape of the object will then be expanded using the extrude menu. This menu will convert two-dimensional objects into three dimensions. An example of using this technique is when making a roof object because the object is two-dimensional and the roof frame object because it has quite complex details.

The shape and size of the model made by the two techniques above must follow the point cloud shape size because this shape has a size that matches the actual conditions. Forms made with insert shape and patch insert techniques must coincide with the point clouds. In carrying out collisions between solid models and point clouds, the size can be adjusted by measuring the distance of objects formed from point clouds first. The measured size will be the size of the solid model by entering the size value in the properties of the model. The illustration of making a model using the patch insert technique can be seen in Figure 6 and making a model with both insert shape techniques can be seen in Figure 7.
(c) As-built Drawing Making

In this study, As-built drawings were made from a three-dimensional model of all parts of the building that had been made. The three-dimensional model is the reference for making as-built drawings must contain the parts and objects needed. As-built drawings that are made will only cover a few parts. The built-in is not entirely based on shop drawings or details from the LFM Building. This is due to the absence of this two documentation. The built-in As-built does not identify the material and specifications of the materials that make up the object but only identifies the structure of the building and its size. This limitation of manufacture is based on the scope of mapping using TLS.

In making as-built drawings using TLS, the main thing to consider is building a data structure. The LFM building which is the object of this research does not only contain structure but has been equipped with lecture support facilities. This facility can be an obstacle in retrieving data structures because the structure is blocked by other objects which are supporting facilities, such as chairs, tables, curtains, and blackboards. In the condition of a building that has many objects such as the LFM building, planning a stand placement point is very important. The standpoint of the tool must be in a place that can record the structure, both partially and completely. The point distribution must be able to accommodate all parts of the building. If data retrieval is difficult to do from the front of the object, scanning is done from two or many sides that can record the object as a whole. The thickness of the wall and other objects can be obtained by scanning from the opposite side. Details of each object in the building should be acquired so that the building of as-built for building rehabilitation does not change the philosophical and value of the building. For the purposes of rehabilitation/restoration of buildings, as-built drawings that can be made using TLS in this study include plans, pieces, and visualization of buildings.

As-built drawings are made from three-dimensional models that represent all parts of the building. To get the data, scanning using TLS must include the interior of the building (interior), the exterior of the building (exterior), and the corridor of the building. Scanning at each point must have the same object as the registration requirement. The method used in this study uses a free scan which means that the scan does not require a reflector as a binder between points. TLS established still must meet the level requirements. Noise caused by people passing around the measurement area must be reduced so that the object can be fully recorded.

In making digital, the worksheet will display the three-dimensional form of the LFM ITB Building. From three-dimensional shapes, data is converted into two-dimensional shapes with different stages according to the
¬-built parts that will be displayed. The visualization / outward appearance of the building is made by rotating and specifying a three-dimensional model in accordance with the required display, such as the north, south, east, west, or isometric. These results are then loaded on one page with an approved layout. The floor plan has a special stage because the floor plan will show the main shape of the building seen from the top of the building. To display the inside of the building in question, a three-dimensional model will be cut until the inside and the corridor are seen together. Then, the point of view on the worksheet is changed to appear in the building. In the floor plan, the building structure is given dimensional values in meters. The building cut was made to show the vertical shape of the building. The cut shown is a piece showing the vertical structure of the building from the south, east and west. The dimensions of the structure size are added in meters.

(d) Data Validation
Mapping using TLS (Terrestrial Laser Scanner) is a modern mapping method that is fairly sophisticated. The greatness of this method is certainly a hope for many parties that this method will be more effective and efficient than conventional methods such as distance measurement with measuring tape, meter or distometer. TLS can be superior if the quality of data produced by TLS will be better than other conventional methods. The quality of the data tested is in the form of horizontal and vertical distance values from several objects that are part of the ITB LFM Building. Objects measured horizontally are building walls, podiums in front of the class, stands, and pillars in the corridor. The object measured is its vertical distance, which is the height of the podium in front of the class, the distance between the uppermost stands and the class ceiling, between the podium and the ceiling, and the distance between the class floor and the class ceiling structure. The quality of the data is tested by comparing the data on the size of the TLS results with the data of the results of the distometer or measuring tape. Data validation is carried out, namely as-built drawing size data derived from geometry and registered point cloud size data. Validation of point cloud size data appears due to poor as-built size data so that it is necessary to confirm the location of the error whether it is in a three-dimensional model or the point clouds of the registration result.

4. RESULT AND ANALYSIS

4.1. RESULT

(e) Result of registration and filtering
Registration using the cloud to cloud method takes a long time because the data generated at each point must be tied one by one. This binding is done sequentially according to the points that have the same geometry of the object. Registration from three points on the interior with this method can be seen in Figure 8.

Figure 8. Results of registration of three interior points

The use of the global registration feature can provide an RMS error value for a registration process. The value of the RMS Error registration result is 0.002 - 0.006 meters. The RMS value of the resulting error is very small for the size of the building as big as the LFM ITB Building. However, this value cannot be a reference to the
truth of the registration results from the free scan data because it is proven that there are still shifting in some parts that can be seen in Figure 9. To anticipate shifting, registration is done again without using the global registration feature.

![Figure 9. Shifting on the building wall](image)

Filtering is done to sort out point clouds that are used in the modelling process and which are not used. Noise removal is done manually by deleting parts that are not included in the plan for registration. The number of point clouds before and after the removal of noise can be seen in Table 1.

| Number of point clouds | Exterior  | Interior  | corridor | Total         |
|------------------------|-----------|-----------|----------|---------------|
| Before Filtering       | 207,482,286| 205,414,156| 240,321,386| 653,217,828  |
| After Filtering        | 8,932,128  | 205,134,481| 180,709,368| 394,775,977  |

Data that has been processed in the registration and filtering process can be referred to as a three-dimensional point cloud model provided that no part of the object experiences an error in the form of an object's shift or mismatch from one point to another. The results of the registration and filtering process can be seen in Figure 10.

![Figure 10. Result of point clouds model from registration and filtering.](image)

(f) Result of 3D Modelling

Three-dimensional modeling in this study uses Cyclone software with the technique of making objects squeezed to the point clouds of the object. The model of this technique will certainly have a size that matches the point cloud model which also represents the actual size. Objects that cannot be scanned at the time of measurement can still be modeled by following the object model that has similarities or by making object models with reference photos. The photo will be a reference for the shape of the model, for the size will be adjusted according to the scanned point clouds.
Three-dimensional modeling was carried out from the modeling of the main structure of the LFM ITB Building such as floors, walls, and roofs. The next modeling stage is the main building objects such as vents, windows, and doors with a simple form. The final stage of modeling is the giving and addition of model details according to actual conditions. The results of three-dimensional modeling can be seen in Figure 11.

![Figure 11. Result of 3D Modelling](image)

Three-dimensional modeling results for interior parts of the building can be seen in Figure 12.

![Figure 12. The three-dimensional modeling of the interior parts: the direction towards the front of the room (a) and the direction towards the back of the room (b).](image)

Three-dimensional modeling must represent the shape of the object in the actual conditions in the field. In this study, the resulting model has been attempted to approach the actual shape. The actual model and conditions have several differences such as the absence of vines on the model, the absence of curtains on the model, incomplete furniture in the room, and the lack of some detailed objects on the model. The three-dimensional modeling results above are then given details and materials that are similar to the actual conditions. A comparison of models with actual conditions can be seen in Figure 13.

![Figure 13. Comparison of models with actual conditions](image)
Figure 13. Comparison of the results of the three-dimensional model with the actual conditions: southeast of the building (a), northeast of the building (b), west of the building (c), south of the building (d), front view of the room (e), and back view the room (f) (continued).

(g) Result of As-built Drawing

As-built drawing or commonly called the final image of construction activity is made based on the results of the three-dimensional model of the LFM Building ITB. The results of the three-dimensional model can be a reference for making as-built drawings because these results already represent the shape and size of the actual conditions in the field. The final image will be made into several themes, namely the theme of the outside appearance of the LFM Building ITB, the theme of the building plan, and the theme of the building pieces. The outside appearance of the building will be displayed in four directions where all four directions can represent the overall appearance of the building. The scale of the as-built drawing is adjusted to the information to be conveyed and the aesthetics of the display.

The three themes taken for making as-built drawings in this study are based on the capabilities and scope of TLS technology in conducting three-dimensional mapping, namely mapping the shape of objects and their size. As-built that was made prioritized the structure of the LFM ITB Building which was the object of this research. The structure contained in the as-built research is the overall structure of the building including interiors, corridors, and exterior, pillars, exterior roofs, and window structures. The results of the as-built drawing that displays the pieces can be seen in Figure 14.
Figure 14. Result of as-built drawing, section: long 01 (a), cross 02 (b), dan cross 03 (c).

The results of as-built drawings that show the visualization of outside buildings can be seen in Figure 15.

Figure 15. The results of the as-built drawing visualization of the outer building: isometric (a), top view (b), south (c), west (d), and east (e).

Figure 15. The results of the as-built drawing visualization of the outer building: isometric (a), top view (b), south (c), west (d), and east (e) (continued).

The results of as-built drawings that show building plans can be seen in Figure 16.
5. Analysis

(h) Stages of making as-built drawing using TLS data

Data retrieval is done by using the free scan method, which means that the scan does not use the target as a point cloud binder generated at each point where the tool stands. This method has its advantages over other methods which are also under the situation and conditions of the LFM ITB Building and short measurement time. The situation and condition in question are that the LFM ITB Building has a symmetrical structure, both horizontally and vertically, and the forms that are components of the building have many similarities. Both of these things make it easier for researchers to carry out the registration stage. Besides, the time provided for scanning the building was limited because the building was used for lecture activities and around the building which became a pedestrian lane. The interval or density used is 6.3 mm.

The interval will affect the number of point clouds recorded, the smaller the core, the more point clouds will be. The 6.3 mm interval is chosen so that the building details can be taken completely. The details are intended such as the shape of a stone wall, roof support wood, door shape, roof shape, and column grooves and ventilation. The roof support wood in question can be seen in figure 3.17. However, not all objects are recorded as point clouds, if further reviewed the door, roof truss and glass are not recorded. This is because the objects have a small reflectivity so that the laser emitted from the device is not reflected.

Registration is the most important part of this research. This is because the results of registration will be the main reference in making a three-dimensional model that includes geometry, detail, size, and conformity to actual conditions. Good registration results will produce a three-dimensional model and good as-built drawing. The method used in data collection and registration will affect each other. Registration uses the cloud to cloud method because the data retrieval method used is a free scan. This registration method requires very extra precision and perseverance because the point clouds form a large number of objects so that the determination of the point cloud to be bound must be exact and the same between the scanning points.

Registration is divided into three parts which are adjusted to the division in data retrieval. The registration process is carried out for the exterior, interior and corridor sections together. Registration starts manually by tying the point cloud of the same object at each scanning point, the example of the object bound is the wall of the box space in the western part of the interior. After the object is bound, the data from manual registration is then registered globally by using the global registration feature. Global registration is an automatic registration based on the Maptek software algorithm and can produce good quality results. Global registration will provide
an RMS value such as with a range of 0.002 - 0.006 meters. However, the use of features in this study gave poor results. This is indicated by the wall experiencing a shift. The shift due to global registration is because many objects have similar forms so that the software algorithm's ambiguity increases. The algorithm will incorrectly tie one point cloud to another which causes the same object not to coincide with each other. To justify the results of global registration, manual registration is again done by translating and rotating the data. Manual registration is done in binding to each part and also to the merging of three parts into one whole building. The quality of the registration results in the form of three-dimensional point cloud models is checked using the Autodesk Recap software. This software is used because it has advantages in displaying point clouds in detail but lightly run by a computer.

Constraints that exist in the registration process, namely the time needed is quite long because there are 25 points and use the cloud to cloud registration. This registration method requires precision and perseverance. Besides, computer capacity is inadequate, causing frequent crashes during the registration process. The factor that causes a crash is the data used has a very large capacity that reaching 1GB because the density used is 6.3mm.

Filtering is done before and after the registration process. Elimination of noise must consider which object will be used as a binder for some scan data from different points. The object can be in the area that is the research area or outside the research area. The object chosen for binding must be in two or more scanned data and have a clear or unique form. Removal of noise carried out before the registration process takes the form of deleting point clouds that do not enter the research area on each scan data. This is intended to facilitate the identification of objects that will be bound and lighten the workload of the computer in registering. Elimination of noise before the registration process must be done carefully and careful consideration so that the object that becomes the tie is not removed. Removal of noise after the registration process is carried out to clean the model point clouds of objects that can interfere with the actual shape of the building construction, for example, plants propagating on the pillars can make the size and shape of the pillars ambiguous.

Filtering is done before and after the registration process. Elimination of noise must consider which object will be used as a binder for some scan data from different points. The object can be in the area that is the research area or outside the research area. The object chosen for binding must be in two or more scanned data and have a clear or unique form. Removal of noise carried out before the registration process takes the form of deleting point clouds that do not enter the research area on each scan data. This is intended to facilitate the identification of objects that will be bound and lighten the workload of the computer in registering. Elimination of noise before the registration process must be done carefully and careful consideration so that the object that becomes the tie is not removed. Removal of noise after the registration process is carried out to clean the model point clouds of objects that can interfere with the actual shape of the building construction, for example, plants propagating on the pillars can make the size and shape of the pillars ambiguous.

Forming a model must be done after all data point clouds are fully registered and do not contain any errors. This is because modeling is done by inserting objects that will follow the shape and size of the model point clouds. The modeling carried out in this study does not entirely refer to the model point clouds because some data cannot be retrieved. This empty data has an impact on imperfect/hollow point clouds. Data that cannot be taken is in the form of roof truss and the eastern part of the building because there is no access to scan the part. Other data that cannot be taken is glass and black objects because it has a very low reflectivity value.

Forming a model for empty data uses several other alternative methods. For the eastern part of the building, form modeling is made the same as the western part of the building according to the actual situation. Modeling for the glass section uses the features provided by the software by making the glass frame a measure of the size of the glass. Roof truss modeling is not made due to limited access to know the actual shape. Modeling black objects is done by using objects around them as a reference for the shape of the black object or by making a model with photos as a reference. Making models with photos is not recommended because this technique does not have a size that matches the actual conditions.

As-built Drawing in this study was made into three themes, namely the outward appearance of the LFM ITB Building, building plans, and building pieces. Outside view of the building will display information in the form of visualization from the outside of the building. This visualization only aims to show the appearance of the building. The building plan will show information in the form of space access, space orientation, degree of openness of space, dimensions of space, and zoning of space. Space access will explain the location of the door as access in and out of the building. Space orientation explains the direction orientation of the building which is the front side of the building facing north and facing directly on the road. The degree of openness will explain the location of doors and windows. The space dimension will contain information about the size of the object in the building. Space zoning will explain the zone of the class as a semi-private zone and dark space as a private zone because access is limited. The building pieces will display information in the form of visualization of the shape of the building, dimensions of the building, and system of building structures. The
dimensions of the building in this theme will provide information in the form of height from pieces of the building. The pieces will provide information on the inner roof truss and structure of the LFM ITB Building.

In making as-built drawings, TLS technology used in this study, Topcon GLS-2000, cannot cover all aspects of existing as-built. Aspects that cannot be covered are the inside of the roof of the building, the type of material and the specifications of the material used to build an object. The limitations of this technology are also seen in scanning on objects that have low reflectivity, namely black and glass objects. Glass cannot be scanned because the nature of the glass continues the light so that the absence of reflected light returns to the device. Black objects have the property of absorbing light so that the light fired by the tool does not reflect. In this study, TLS can include several objects, namely corridors, pillars, outer roofs, window structures, walls and thickness, interiors, and building structures. The structure that can be taken in this study is the building structure that is shown vertically through a section and horizontally through plans.

Making as-built drawings from Terrestrial Laser Scanner data has advantages compared to other conventional methods, such as the Electronic Total Station and a combination of a distometer and measuring tape. The advantages of making as-built drawing using TLS compared to ETS lies in the reference for making the model and data acquisition process, as follows.

1. The number of points that can be recorded is more in the same duration.
2. Data acquisition is done automatically so that it can reduce blunder errors.
3. Data acquisition covers a wider area in one measurement.
4. The details of the resulting model will be better because there are more reference points for making models.
5. The scanning points will form a clearer object.
6. Shorter time.

Making as-built drawings using a combination of distometer and measuring tape is a data acquisition technique commonly used in the field of architecture. Distometer is used to measure vertical distance and measuring tape to measure horizontal distance. However, this acquisition technique is a conventional technique compared to using TLS. The advantages of making as-built drawings use TLS compared to the combination of a distometer and measuring tape as follows.

1. The products produced are not only two-dimensional maps but also three-dimensional models.
2. The acquisition of size data on objects that are difficult to reach, such as roof support, the top of the room, and the roof of a building does not require more effort because it can be measured digitally through the object formed.
3. The size of all objects can be acquired more effectively and efficiently.
4. Parts in the structure of an object can be acquired such as ventilation.
5. The analysis that can be done is more diverse because the product is a three-dimensional model.
6. Visualization of the as-built drawing product better reflects the actual conditions.

(i) Data Validation

The first validation is to find out the quality of as-built drawing / three-dimensional models. This size data validation comes from the as-built floor plan. Dimension size compared is the size stated in the plan. Measurements in the field using a measuring tape. The difference from as-built size with field size shows the quality of as-built which can be seen in Table 2 and Table 3.
Table 2. Data comparison between pillar distance in as-built (floor plan) with distance in the field.

| No | Type | Name | Distance in ASB (m) | Distance in the field (m) | Difference (m) |
|----|------|------|---------------------|--------------------------|----------------|
| 1  | 1    |      | 0.83                | 0.85                     | 0.02           |
| 2  | 2    |      | 2.993               | 3                        | 0.003          |
| 3  | 3    |      | 0.853               | 0.87                     | 0.017          |
| 4  | 4    |      | 1.126               | 1.13                     | 0.004          |
| 5  | 5    |      | 3.221               | 3.2                      | 0.021          |
| 6  | 6    |      | 3.213               | 3.2                      | 0.013          |
| 7  | 7    |      | 3.193               | 3.21                    | 0.017          |
| 8  | 8    |      | 3.213               | 3.21                     | 0.003          |
| 9  | 9    |      | 3.252               | 3.25                     | 0.002          |
| 10 | 10   |      | 2.153               | 2.18                     | 0.027          |
| 11 | 11   |      | 2.219               | 2.35                     | 0.131          |
| 12 | 12   |      | 2.01                | 2.05                     | 0.04           |
| 13 | 13   |      | 2.015               | 2.05                     | 0.031          |
| 14 | 14   |      | 2.402               | 2.4                      | 0.002          |
| 15 | 15   |      | 2.199               | 2.2                      | 0.001          |
| 16 | 16   |      | 2.525               | 2.5                      | 0.025          |
| 17 | 17   |      | 2.55                | 2.55                     | 0              |
| 18 | 18   |      | 2.206               | 2.3                      | 0.094          |
| 19 | 19   |      | 2.204               | 2.27                     | 0.066          |
| 20 | 20   |      | 1.179               | 3.2                      | 0.021          |
| 21 | 21   |      | 3.197               | 3.25                     | 0.051          |
| 22 | 22   |      | 3.126               | 3.35                     | 0.025          |
| 23 | 23   |      | 3.174               | 3.18                     | 0.006          |
| 24 | 24   |      | 3.197               | 3.2                      | 0.003          |
| 25 | 25   |      | 1.25                | 1.38                     | 0.13           |
| 26 | 26   |      | 0.723               | 0.72                     | 0.003          |
| 27 | 27   |      | 2.841               | 2.98                     | 0.039          |
| 28 | 28   |      | 0.99                | 0.95                     | 0.04           |
| 29 | 29   |      | 3.188               | 3.25                     | 0.062          |
| 30 | 30   |      | 1.031               | 1.02                     | 0.011          |
| 31 | 31   |      | 1.086               | 1.01                     | 0.076          |
| 32 | 32   |      | 3.17                | 3.23                     | 0.06           |
| 33 | 33   |      | 3.188               | 3.2                      | 0.012          |
Table 3. Data comparison between the distance of objects in as-built (floor plan) with distance in the field.

| No | Type            | Name                      | Distance in ASB (m) | Distance in ASB (m) | Difference (m) |
|----|-----------------|---------------------------|--------------------|--------------------|---------------|
| 34 | Room dimension  | North wall                | 19.536             | 19.55              | 0.014         |
| 35 | East wall       |                           | 13.784             | 13.79              | 0.006         |
| 36 | South wall      |                           | 19.557             | 19.504             | -0.053        |
| 37 | West wall       |                           | 13.62              | 13.83              | 0.21          |
| 38 | East wall 1     |                           | 1.325              | 1.27               | -0.055        |
| 39 | East wall 2     |                           | 2.989              | 3.1                | 0.111         |
| 40 | East wall 3     |                           | 1.718              | 1.65               | -0.068        |
| 41 | East wall 4     |                           | 1.716              | 1.81               | 0.094         |
| 42 | East wall 5     |                           | 4.783              | 4.78               | -0.003        |
| 43 | East wall 6     |                           | 1.254              | 1.26               | 0.006         |
| 44 | West wall 1     |                           | 6.049              | 5.988              | -0.061        |
| 45 | West wall 2     |                           | 1.717              | 1.8                | 0.083         |
| 46 | West wall 3     |                           | 5.854              | 5.902              | 0.048         |
| 47 | Classroom width |                           | 13.178             | 13.159             | -0.019        |
| 48 | Podium length-stand |              | 8.669              | 8.641              | -0.028        |
| 49 | stand 1         |                           | 0.8                | 0.8                | 0             |
| 50 | stand 2         |                           | 0.8                | 0.8                | 0             |
| 51 | stand 3         |                           | 0.8                | 0.8                | 0             |
| 52 | stand 4         |                           | 0.8                | 0.795              | -0.005        |
| 53 | stand 5         |                           | 0.814              | 0.795              | -0.019        |
| 54 | stand 6         |                           | 0.8                | 0.8                | 0             |
| 55 | stand 7         |                           | 0.8                | 0.8                | 0             |
| 56 | stand 8         |                           | 0.8                | 0.8                | 0             |
| 57 | Room dimension  | Classroom width-darkroom (south) | 4.555          | 4.69               | 0.135         |
| 58 | Classroom width | darkroom (north)          | 4.426              | 4.69               | 0.264         |
| 59 | Darkroom length (south) |              | 4.256              | 4.49               | 0.234         |
| 60 | Darkroom width (east) |              | 4.052              | 4.04               | -0.012        |
| 61 | Front room width 1 |              | 2.007              | 2.075              | 0.068         |
| 62 | Front room width 2 |              | 2.34               | 2.38               | 0.04          |
| 63 | Front room width 3 |              | 4.348              | 4.91               | 0.562         |
| 64 | Front room width 4 |              | 2.512              | 2.46               | -0.052        |
| 65 | Front room width 5 |              | 1.419              | 1.402              | -0.017        |

Data distance comparison in as-built with distance in the field has a value that is tolerable and also not. Tolerance means that the difference in data size is still below 3 cm. This value is considered good because 3 cm is the maximum value of error when measuring with a measuring tape because of the placement of zero points and endpoints that are not right in the middle (for pillars) and in the corner of the object (for walls) and thickness caused by sticking stone ornaments on pillars and walls. While values that exceed the tolerance limit, the difference in value is marked in red. The quality of the as-built size in this study is 60%. This value which is out of tolerance of 40% is an error that can be caused due to negligence in making a model or in registering. Therefore, the next validation is to validate the size of the size cloud points on the field to find out where the error is.

The next size data validation aims to determine the quality of point clouds. The validation is done by comparing point cloud size data that is registered with measurement data in the field. Field size data acquisition activities by measuring distance using a measuring tape for horizontal distance and a distometer for vertical distance. The size of the object taken is an object that has a different value that is beyond tolerance in the validation of the data size as-built with the size in the field. Data on a comparison of the size of vertical distance and horizontal distance in Table 4. Objects taken for validation are objects that are easy to know whose size is marked by the edge of an easily identifiable object. This has the purpose of reducing errors in taking edge objects.
Table 4. Comparison data between the size of distance in point clouds and in the field.

| Type         | Name                        | Distance in point clouds model (m) | Distance in the field (m) | Difference (m) |
|--------------|-----------------------------|------------------------------------|---------------------------|----------------|
| Horizontal   | North wall                  | 19.509                             | 19.51                     | 0.001          |
|              | East wall                   | 13.784                             | 13.79                     | 0.006          |
|              | South wall                  | 19.51                              | 19.504                    | 0.006          |
|              | West wall                   | 13.83                              | 13.819                    | 0.011          |
|              | Podium length               | 8.339                              | 8.35                      | 0.011          |
|              | Stands length               | 11.278                             | 11.27                     | 0.008          |
|              | South wall of the dark room | 4.493                              | 4.49                      | 0.003          |
|              | Bouvenlich length           | 0.349                              | 0.341                     | 0.008          |
|              | Pillar                      | 0.39                               | 0.4                       | 0.01           |
|              | East wall 2                 | 3.09                               | 3.1                       | 0.01           |
|              | East wall 4                 | 1.818                              | 1.81                      | 0.008          |
|              | West wall 2                 | 1.859                              | 1.8                       | 0.059          |
|              | Front classroom width 1     | 2.09                               | 2.075                     | 0.015          |
|              | Classroom width-darkroom (South) | 4.6                         | 4.69                      | 0.09           |
|              | Classroom width-darkroom (North) | 4.658                       | 4.69                      | 0.032          |
| Vertical     | Upper stand - ceiling       | 3.94                               | 3.942                     | 0.002          |
|              | Podium - ceiling            | 5.417                              | 5.411                     | 0.006          |
|              | Floor-ceiling               | 8.368                              | 8.356                     | 0.012          |
|              | Podium height               | 0.301                              | 0.3                       | 0.001          |

The difference between the point cloud size and the size in the field is the quality of the point clouds formed after going through the registration stage. The average horizontal distance difference is 0.018 meters and the vertical distance is 0.005 meters. This can be caused by several incorrect factors originating from measuring tape, distometer, and TLS. Errors originating from the distometer and TLS occur because the device is not properly calibrated which causes the laser beam to emit from the device until it is received back not perpendicular to the cross-section of the tool. In horizontal distance measurement, the measuring tape has a non-straight error and the measuring tape is upright when measuring objects. The resulting value is a fairly good value and entered into tolerance.

Judging from the second quality of data validation above, the quality of the size of point clouds is better than the quality of data sizes on as-built / three-dimensional models. This shows that errors occur in making three-dimensional models. This error arises because the making of the model continues to experience changes and adjustments along with the addition of objects for aesthetics in the visualization of three-dimensional models in image and video.

6. Conclusion

The conclusions from all stages of the research on Analysis of Making As-Built Drawing from Terrestrial Laser Scanner data with a case study of the LFM Building of the Bandung Institute of Technology are as follows:

1) Terrestrial Laser Scanner will produce data in the form of point clouds from the LFM Building ITB. Point clouds data still overlap irregularly because each point in the clouds does not have the same orientation. Data points are registered using a global registration method, which results in a registration RMS value
of 0.002 - 0.006 meters. The results of global registration must be re-checked whether all parts have been properly registered or not. Parts that still have errors are then manually registered. Point cloud data that has been properly registered can be referred to as a three-dimensional point cloud model. The three-dimensional point clouds model then becomes a reference for making actual three-dimensional models by making objects that match the shape of the point clouds. There is a part of the building that cannot be modeled because the part is difficult to be accessed by the TLS instrument. The three-dimensional model produced has several size differences with the actual size. This is because there are objects that are not appropriately recorded, causing vacancies in point clouds. This condition is resolved by manual adjustment using the surrounding shape and personal interpretation of the researcher.

2) Mapping using Terrestrial Laser Scanner produces data in the form of point clouds that can be used for making as-built drawing documentation. Making as-built drawing documentation must go through several processes, namely registration, noise removal, and 3D modeling. 3D models that can be used to make as-built drawing documentation are three-dimensional models that have been perfectly registered and do not contain errors. This is important so that the shape and size of the model can represent the shape and size of the building in its actual condition. As-built drawings made in this study using TLS can only cover several parts of the building structure, considering that in the LFM Building there are parts that cannot be accessed by TLS Topcon GLS-2000. Another analysis that the technology cannot do is the determination of materials and specifications of building materials. As-built drawings can be made in the form of floor plans, pieces, and visualizations of the LFM Building ITB. As-built is well illustrated but still has a 40% error in size caused by incorrect three-dimensional modeling. In order to reduce these errors, the three-dimensional model is only used as the basis for as-built depiction while point clouds should replace the dimensions that are beyond tolerance.

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