Geoid
Journal of Geodesy and Geomatics

Geoid Vol. 20, No. 2, 2025, 71-79

P-ISSN: 1858-2281; E-ISSN: 2442-3998

Study of 3D Cadastral Mapping in the Teaching Factory Building of The Vocational School, Diponegoro University Using SLAM (Simultaneous Localization and Mapping) Method

Ardyan S P Pratama*, Yoga K Nugraha, Mitha A Rahmawaty
Applied Bachelor's Program in Spatial and Land Use Planning, Vocational School, Diponegoro University, Semarang, 50275, Indonesia
*Corresponding author: ardyansatriaputrap@lecturer.undip.ac.id

Received: 20 Januari 2025; Revised: 24 Juni 2025; Accepted: 02 September 2025; Published: 06 October 2025

Abstract: Cadastre is a land information system based on land parcels. The growth in the number of land parcels is influenced by the increasing conversion of land into residential areas, which in turn is driven by several factors, one of which is population growth. The demand for housing initially expanded horizontally; however, due to limited land availability, it has now shifted toward vertical development. Vertical housing types such as flats or apartments are emerging, which introduce complexity into the cadastral system due to the partitioning of internal spaces. Cadastre requires high-accuracy measurements; hence, the increase in measured areas leads to a higher workload. The SLAM (Simultaneous Localization and Mapping) method offers a breakthrough in fast and accurate measurements using laser-based technology, which can be implemented in cadastral mapping to update spatial data precisely and efficiently. This method combines the flexibility of handheld operation with high data precision by employing dense laser scanning. This study utilized the SLAM method, resulting in a polygon area processing of 0.3558 m², with an average center-point distance deviation of 0.0658 m, a polygon circularity ratio of -0.002, and a regression value of less than 10%. When this model is applied with a tolerance of up to 10% spatial error, it can achieve vertical measurements up to the 43rd floor, in accordance with the Directorate General of Taxation Circular and tested based on ISO 19113:2011 standards.

Keywords : Cadastre; Linear Regression; SLAM

How to cite: Pratama, Ardyan S P., Nugraha, Yoga K., & Rahmawaty, Mitha A. (2025). Study of 3D Cadastral Mapping in the Teaching Factory Building Of The Vocational School, Diponegoro University Using SLAM (Simultaneous Localization And Mapping) Method. *Geoid, 20*(2), 71-79.

Introduction

Cadastre is a land information system based on parcels and up-to-date data, containing records of interests in land (such as rights, boundaries, and responsibilities) (FIG, 2023). In terms of boundaries, this refers to the geographical aspects of a land parcel that must be measured to obtain accurate data. The development of 3D cadastre methods has been ongoing since the 1990s (Alkan et al., 2021). The demand for land parcels for housing is indirectly related to population growth (Ramadhani, 2021).

As the demand for housing continues to increase, vertical housing types such as apartments have also undergone significant development. The first apartments were built in the Special Capital Region of Jakarta, now known simply as Jakarta, and their construction required three-dimensional (3D) measurements to accurately determine location and position. Unlike conventional cadastral measurements that use only two vector components—X and Y (2D)—3D measurements require three vector components—X, Y, and Z—to represent the height dimension (Mappatombong et al., 2020).

This condition highlights the growing importance of more complex and accurate measurement methods, such as 3D cadastral surveying, in addressing the dynamic development of vertical residential areas. Cadastral surveying plays a crucial role in land management, and as the area to be measured expands, the workload also increases. This presents new challenges, particularly in measuring vertical structures such as apartment buildings. The demand for housing continues to rise over time, as reflected in the land development in Jakarta, which reached 853.43 hectares between 2014 and 2022 (Syahidan et al., 2023). As shown in the Figure 1, the demand for housing in Jakarta remains high, with projections from Bappeda Jakarta indicating it will remain above 250,000 units until 2035.

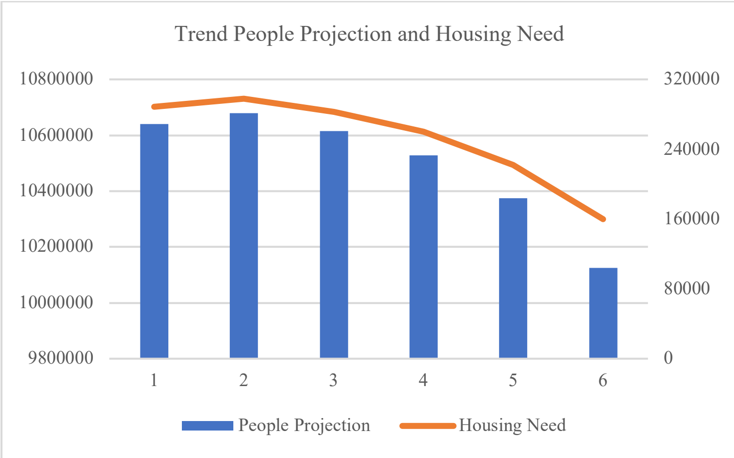


Figure 1. Graph Housing Need (Bapeda Jakarta, 2016)

Shifts in lifestyle and public preferences have also driven demand for various types of property, including landed houses and vertical housing (apartments), particularly in densely populated urban areas (Yustika, 2023). The trend of vertical housing in urban regions is driven by several key factors, including rising land prices due to high demand for strategically located land—especially in areas with high accessibility and complete facilities (Handayani et al., 2021) as well as limited land availability, which accelerates land price increases in urban areas (Nurhana et al., 2021) ,and the growing population mobility toward major cities in search of employment opportunities (Harahap, 2013). As a result, the need for affordable and quality housing has become a critical issue in future development planning (Sutaryono et al., 2021), encouraging developers to provide housing both horizontally and vertically, with vertical construction increasing each year.

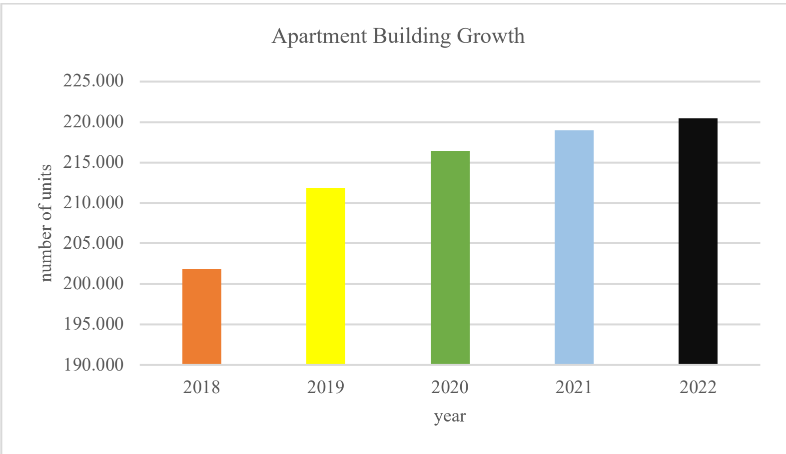


Figure 2. Apartment Growth Chart (Ahdiat, 2023)

Measurement technology has evolved from optical visible light methods using total stations and satellite imagery (Yagol et al., 2015) to laser-based technologies (Giannaka et al., 2014; Souza & Amorim, 2012), which accelerate measurement processes and improve mapping accuracy. Indoor mapping typically uses total stations, which are more practical as they can directly produce coordinate points and can be immediately linked to reference points.

Methodology

Cadastre is a system that contains detailed information about land status based on location, ownership, and associated rights. Technological advancements have led to the emergence of 3D cadastre, which allows measurements to be conducted not only in two dimensions (XY space) but also in the vertical dimension (Z space). This is crucial for providing a more realistic spatial representation, especially in urban environments with complex multi-story buildings or underground infrastructure. Implementing 3D cadastre requires precise elevation data, which can be generated using modern methods such as SLAM (Simultaneous Localization and Mapping). SLAM technology, which is based on LiDAR (Light Detection and Ranging), offers fast and accurate spatial measurements without requiring a GNSS (Global Navigation Satellite System) connection during operation. However, to ensure the data can be linked to real-world locations, global reference points are needed particularly in the context of integration with national or international coordinate systems.

The use of SLAM in 3D cadastre measurement represents a significant breakthrough, both for indoor surveys (Ress et al., 2024) and outdoor surveys (Nüchter et al., 2007). This technology is capable of producing three-dimensional representations of buildings that closely resemble their actual structures, allowing for accurate volume calculations and more precise land use analysis. The data obtained from SLAM surveys are then assessed for quality using the ISO 19113:2011 standard, which provides guidelines for evaluating the quality of spatial data. This evaluation includes three main aspects: positional accuracy, topological consistency, and data completeness.

Positional accuracy ensures that spatial data corresponds to its actual location, while topological consistency verifies the geometric relationships between objects in the dataset. Data completeness, on the other hand, ensures that all relevant elements within the survey area are fully represented. By applying this standard, 3D cadastral measurements not only provide better visualization but also guarantee the quality and reliability of the data produced, thereby supporting transparent and sustainable land management. Data quality assessment is conducted using ISO 19113:2011, which is used to measure spatial data quality across the following three aspects:

1. Polygon Area
   This test method uses a comparison of the area formed from the measurement results with data that is considered correct, where the closer to the correct data, the better the measurement(Roussillon et al., 2007).
   $$\Delta D = L_{test} - L_{ref} \quad (1)$$
   Where :
   ΔD = Difference in Area
   L_{uji} = SLAM measurement area
   L_{ref} = TS measurement area

2. Polygon Near Distance
   This method tests the accuracy of the center point of a polygon by calculating the difference in distance from its center point (Roussillon et al., 2007).
   $$Distance = \sqrt{(X_{test} - X_{ref})^2 + (Y_{test} - Y_{ref})^2} \quad (2)$$
   Where :
   X_{test} = X coordinate of SLAM measurement result
   X_{ref} = X coordinate of TS measurement result
   Y_{test} = Y coordinate of SLAM measurement result
   Y_{ref} = Y coordinate of TS measurement result

3. Polygon Circularity Ratio
   This method calculates boundary complexity based on perimeter and area calculations (Roussillon et al., 2007). Circularity Ratio indicates the compactness or smoothness of the edges of a polygon shape, which is important in geospatial analysis.
   $$Cr = \frac{4 \times \pi \times A}{P^2} \quad (3)$$
   Where :
   $Cr = Circularity\ Ratio$
   π = Phi Value
   A = Building area
   P = Building perimeter length

In addition, testing was also conducted based on Directorate General of Taxes Circular Letter No. SE-19/PJ.6/2003, which sets a threshold for error tolerance in the presentation of Geographic Information System (GIS) data. This circular is an important reference, especially in measuring land area, with a maximum permissible error tolerance of 10%. This test aims to ensure that data generated from both traditional methods and modern technologies such as SLAM (Simultaneous Localization and Mapping) meet the established accuracy standards.

In production, simple linear regression is also used for forecasting or predicting quality and quantity characteristics. This is usually referred to as simple linear regression (SLR) (Harsiti et al., 2022). The general equation for the simple linear regression method used in this study is:

$$Y = AX + B \tag{4}$$

The use of linear regression = used to model and predict the value of the dependent variable (Y) which is based on Directorate General of Taxes Circular Letter No. SE-19 / PJ.6 / 2003, which is a difference of 10%, based on one or more independent variables (X), namely the number of floors, using the best straight line approach through the data (Kahfi et al., 2023).

Results and Discussion

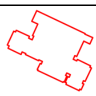
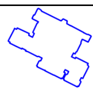
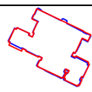
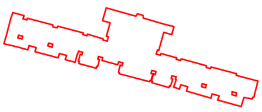
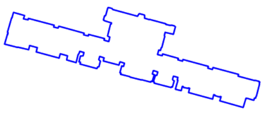
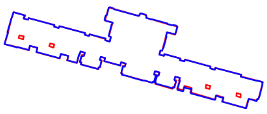
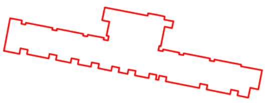
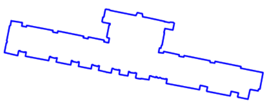
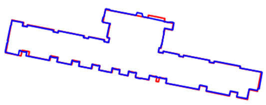
Data collection was carried out by direct survey using Portable LiDAR and Total Station instruments carried out per floor. LiDAR data collection followed a pattern of first scanning the perimeter of the building from the outside, followed by scanning from the first floor to the fifth floor, then returning to the starting point. Total station measurements were assisted with a tape measure, using the trilateration method to improve detail accuracy in hard-to-reach areas.

(a) SLAM (b) Total Station

Figure 3. The process of taking survey data using Lidar (a) and Total Station (b)

After data capture, data processing was performed using software to produce shape comparisons as shown in Table 1. SLAM measurement provides a more detailed picture as it scans the surface comprehensively, although it has limitations when the area is obstructed by other objects (e.g. a crowd of students in this study). However, this can be overcome by elevating the scanning area above human height to achieve optimal results.

Table 1. SLAM and TS Data Processing Results

Floor	Total Station	SLAM	MIX
1			
2			
3			

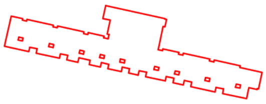
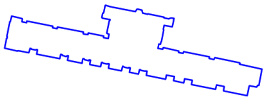
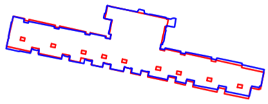
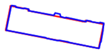
4			
5			

Table 1 shows that the measurement results using the SLAM and Total Station methods have very close values, with differences that are within the measurement tolerance limits. This shows that both methods can produce similar data which will be tested using 3 quality test parameters.

Polygon Area

Mobile LiDAR measurements can produce enough detail to create a cadastral map. This research focuses on 3D cadastres using the example of the Teaching Factory (TeFa Undip) building for shared spaces (hallways). The data comparison highlights the differences and can be used as a basis to consider SLAM as an alternative mapping tool. According to statistics, RMS data can be used to predict future trends (Carlsson, 2023). The processed results are shown in Table 2.

Table 2. The result of the polygon area test

Floor	TS (m^2)	SLAM (m^2)	Difference (m^2)
1	87.31	87.345	0.035
2	187.333	187.427	0.094
3	190.268	190.31	0.042
4	189.659	190.805	1.146
5	48.791	49.253	0.462

Table 2 presents the results of the comparison of area measurements using the Total Station (TS) and SLAM methods on five floors of the building. The difference between the two methods is relatively small, with the largest difference occurring on the 4th floor of 1.146 m^2. This shows that the SLAM method can produce data that is quite accurate and close to the results of conventional measurements. Polygon area processing produces an average for 5 floors of 0.3558 m^2 which is still below the 10% error rule of the Directorate General of Taxes Circular Letter No. SE-19/PJ.6/2003.

Polygon Near Distance

The results of the analysis using the Polygon Near Distance (PND) method show the difference in the difference in the center point of a plane shape which in this study for the first floor has better design quality than the fifth floor. This can be seen from the smaller PND value of the first floor, indicating the closeness of the location of the geometric center point of the SLAM measurement floor with the geometric center point of the higher TS measurement. In contrast, the fifth floor has a larger PND value, reflecting a higher degree of deviation from the shape of the TS measurements. The smaller value of the first floor confirms a design that is more in line with the TS measurement space and thus can be said to be similar to the real-world representation of the object shown in Table 3.

Table 3. The result of the Polygon Near Distance test

Floor	**TS**		**SLAM**		**Distance**
	X (m)	Y (m)	X (m)	Y (m)	m
1	4874.640	4597.590	4874.611	4597.593	0.029
2	4873.469	4568.923	4873.492	4568.916	0.024
3	4875.393	4536.293	4875.353	4536.298	0.040
4	4874.738	4506.097	4874.745	4506.210	0.113
5	4873.320	4481.933	4873.443	4481.939	0.123

Table 3 displays the results of the Polygon Near Distance test by comparing the coordinates of the plane center point (X and Y) between the Total Station (TS) and SLAM methods on five floors. The difference between the two methods is very small, ranging from 0.024 to 0.123 meters. These results show that the position of the center point of the SLAM method is close to the TS measurement results. With the average result of the five floors, the difference in the center point distance is 0.0658 m.

Polygon Circularity Ratio

The results of the analysis using Polygon Circularity Ratio (PCR) show that the first floor has a better level of design optimization than the fifth floor. This is indicated by the smaller PCR value of the first floor, indicating that the shape is closer to the original shape where the original shape can be represented with model data using TS, so the efficiency of modeling the space is higher. In contrast, the PCR value of the fifth floor is larger, reflecting a less optimal shape and a lower degree of similarity to the original shape. This improved first floor design allows for more efficient space measurement, supporting the mapping activities more optimally as shown in Table 4.

Table 4. The result of the Polygon Circularity Ratio test

Floor	TS		SLAM		ΔCR
	P (m)	A (m^2)	P(m)	A(m^2)	
1	57.316	87.310	57.542	87.345	-0.002
2	124.583	187.333	124.215	187.427	0.001
3	113.772	190.268	113.167	190.310	0.002
4	111.677	189.659	112.236	190.805	-0.001
5	35.360	48.791	35.883	49.253	-0.010

This table presents the comparison of perimeter (P) and area (A) between the Total Station (TS) and SLAM methods, as well as the difference in Circularity Ratio (ΔCR) on the five floors of the building. The ΔCR value shows the difference in the plane shape compactness ratio between the two methods, with a very small difference value, ranging from -0.010 to 0.002. This shows that the results of plane shape measurements using SLAM are very close to the results from TS and have a high level of geometric accuracy.

Regession Test

In accordance with Directorate General of Taxes Circular Letter No. SE-19/PJ.6/2003, the maximum area difference allowed for measurement purposes is 10% (Surat Edaran Direktorat Jenderal Pajak Nomor SE-19/PJ.6/2003, n.d.)This rule is an important reference in ensuring the accuracy of measurement data, especially in the application of modern technology such as SLAM (Simultaneous Localization and Mapping). In the research conducted, the measurement data using SLAM compared to the Total Station showed good results, thus meeting the tolerance criteria. It can be seen in the linear data distribution pattern shown in Figure 4.

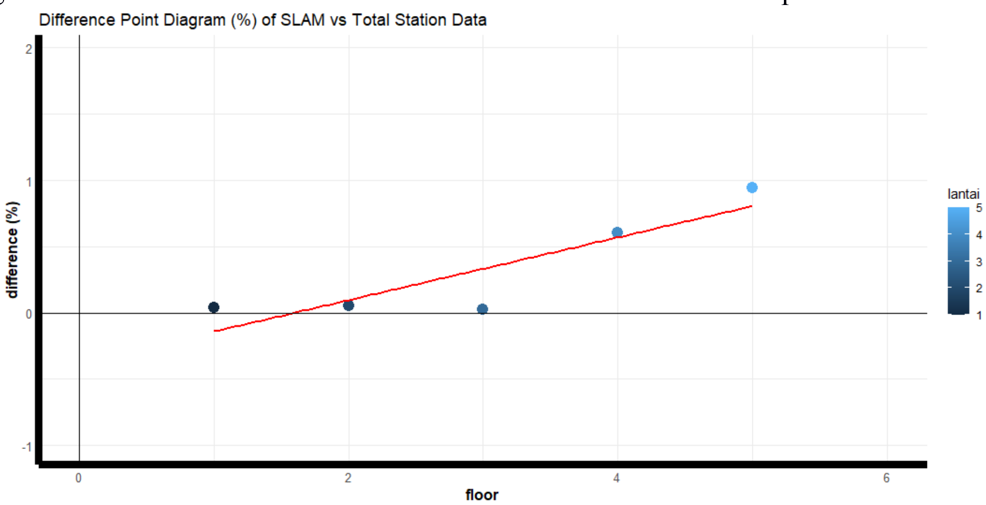


Figure 4. Linear Trend

The linear regression model developed based on the measurement results showing a linear trend as shown in Figure 4, can be developed into a linear equation by finding the coefficients of the line equation calculation model. This model can be used to predict future values, thus providing added value in real-time measurement applications(Atthifa Ryantika et al., 2023; Dao et al., 2024). The resulting model based on the data in Table 2, which uses the calculated area difference, for the resulting equation Y = AX + B is as shown in Figure 5, resulting in the formula Y = 0.2368X-0.3776.

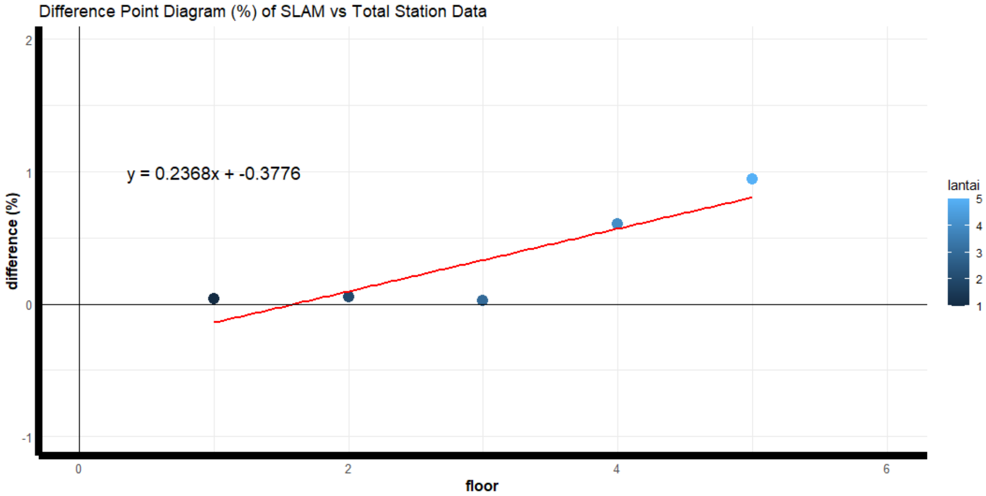


Figure 5. Linear equation

The resulting linear equation can be applied as a prediction of the maximum tolerance value of 10% as stipulated in the Directorate General of Taxes Circular Letter by inserting the 10% parameter into the Y value as shown in Figure 6, the projected increase in Y value in percent units based on the number of floors of the building, using the linear regression equation Y=0.2368X-0.3776. Based on the visualization, the Y-value reaches a maximum limit of 10% at around the 43rd floor, so the area above the limit is marked as an over-tolerance zone. This capability shows the great potential of SLAM in the field of construction and architecture, especially in the measurement of high-rise buildings.

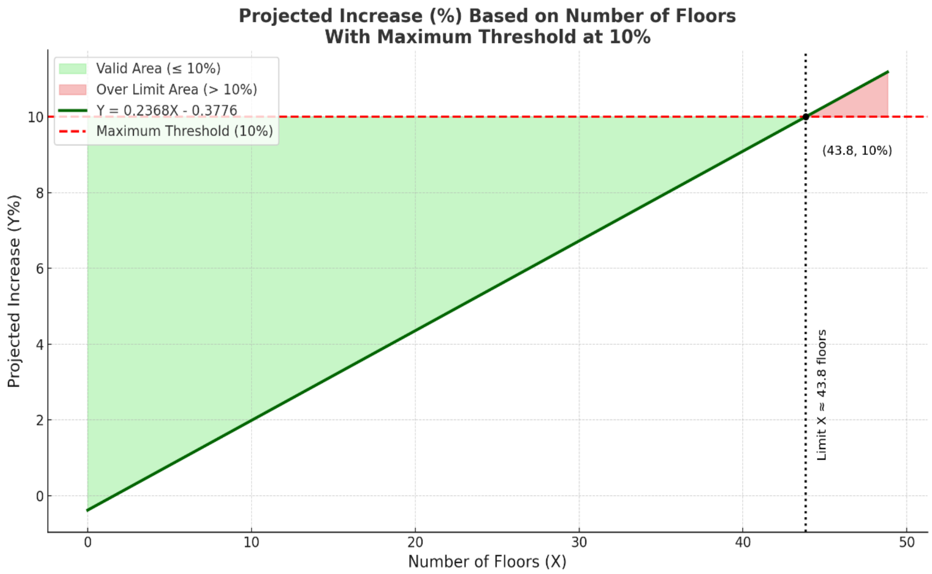


Figure 6. Building Floor Projection

Conclusions

The SLAM (Simultaneous Localization and Mapping) method represents a transformative advancement in cadastral mapping by allowing the real-time capture and updating of spatial data with exceptional precision and efficiency. Unlike conventional techniques that often rely on GNSS connectivity, SLAM utilizes sensors such as LiDAR to independently map environments, making it highly effective in areas with limited satellite access. This autonomy not only accelerates data collection but also improves the flexibility of field operations. In the context of cadastral applications, SLAM has demonstrated the ability to achieve a spatial error margin of less than 10%, as referenced in the Directorate General of Taxes Circular Letter No. SE-19/PJ.6/2003. This level of accuracy is sufficient to map vertical spaces up to the 43rd floor of high-rise buildings, using linear graph-based calculations to model vertical spatial relationships.

This capability positions SLAM as a crucial tool in addressing the growing demand for three-dimensional cadastral data, especially in urban settings characterized by high-rise developments and dense building arrangements. Traditional surveying methods often face significant limitations when mapping within or around tall structures due to obstructions and restricted visibility. SLAM circumvents these challenges by creating detailed 3D spatial models even in complex architectural environments. As cities continue to grow vertically, integrating SLAM into cadast

Acknowledgment

The authors would like to thank colleagues who have provided direction and input during this research process. Gratitude is also extended to the institutions and related parties that have provided data and technical support. The author also appreciates the help and support from family and colleagues who provided encouragement and motivation.

References

Ahdiat, A. (2023). *Jumlah apartemen di Jakarta*. Databoks. https://databoks.katadata.co.id/properti/statistik/dcae4578e6c7adc/ini-pertumbuhan-apartemen-di-jakarta-5-tahun-terakhir

Alkan, M., Gürsoy Sürmeneli, H., & Polat, Z. A. (2021). Design and development 3D RRR model for Turkish cadastral system using international standards. *Survey Review*, *53*(379), 312–324. https://doi.org/10.1080/00396265.2020.1758386

Atthifa Ryantika, H., Parida, M., Afandi, H., Hanika Lubis, S., Afandi, A., & Febry Nugroho, D. (2023). Linear Regression Method Application To Predict Cimory Milk Sales. *International Journal of Information System and Computer Science) IJISCS*, *7*(1), 1–7. https://ojs.stmikpringsewu.ac.id/index.php/ijiscs

BAPPEDA JAKARTA. (2016). *Rencana Pembangunan Jangka Panjang Daerah Jakarta 2025-2045*.

Dao, P., Phan, D., Anh, M., Nguyen, N., Ba, M. A., Nguyen, H. H., Phan, T., Dao, M., Anh, N., & Ba, H. (2024). *Using Linear Regression Analysis to Predict Energy Consumption*. 0–21. https://doi.org/10.21203/rs.3.rs-4590592/v1

FIG. (2023). *FIG Statement on the Cadastre*. FIG. https://www.fig.net/organisation/comm/7/library/reports/cadastre/statement_on_cadastre.html

Giannaka, O., Dimopoulou, E., & Georgopoulos, A. (2014). *Investigation on the contribution of LiDAR data in 3D Cadastre*.

Handayani, A. P., Deliar, A., & Abdulharis, R. (2021). Pola Spasial Harga Tanah Untuk Perencanaan Strategis Dalam Perspektif Pembangunan Berkelanjutan (Studi Kasus: Kota Bandung, Jawa Barat, Indonesia). *Jurnal Sosioteknologi*, *20*(1), 104–113. https://doi.org/10.5614/sostek.itbj.2021.20.1.10

Harahap, F. R. (2013). Dampak Urbanisasi Bagi Perkembangan Kota Di Indonesia. *Society*, *1*(1), 35–45. https://doi.org/10.33019/society.v1i1.40

Harsiti, Muttaqin, Z., & Srihartini, E. (2022). Penerapan Metode Regresi Linier Sederhana Untuk Prediksi Persediaan Obat Jenis Tablet. *JSiI (Jurnal Sistem Informasi)*, *9*(1), 12–16. https://doi.org/10.30656/jsii.v9i1.4426

Kahfi, M., Falgenti, K., Rizqi, L. D., Megawulan, D., Iqbal, M., & Furqon, F. (2023). *Analisis pengaruh suhu udara rata-rata terhadap kelembaban di wilayah DKI Jakarta menggunakan Regresi Linear*. *3*(1), 1–010. http://dataonline.bmkg.go.id/data_iklim

Mappatombong, A. R. E. ., Wahyono, E. B., & Laksamana, R. (2020). Permodelan 3D Cadastre Untuk Penyajian Informasi Penggunaan dan Pemanfaatan Ruang Bawah Tanah. *Tunas Agraria*, *3*(1), 50–69. https://doi.org/10.31292/jta.v3i1.67

Nüchter, A., Lingemann, K., Hertzberg, J., & Surmann, H. (2007). 6D SLAM - 3D mapping outdoor environments. *Journal of Field Robotics*, *24*(8–9), 699–722. https://doi.org/10.1002/rob.20209

Nurhana, A., Hasyim, A. W., & Setyono, D. A. (2021). Pola Spasial Harga Lahan Permukiman Akibat Pembangunan Stasiun LRT Harjamukti, Depok. *Tata Kota Dan Daerah*, *13*(2), 47–58. https://doi.org/10.21776/ub.takoda.2021.013.02.1

Ramadhani, R. (2021). Pendaftaran Tanah Sebagai Langkah Untuk Mendapatkan Kepastian Hukum Terhadap Hak Atas Tanah. *Jurnal Sosial Dan Ekonomi*, *2*(1), 31–40. http;//jurnal.bundamediagroup.co.id/index.php/sosek

Ress, V., Zhang, W., Skuddis, D., Haala, N., & Soergel, U. (2024). SLAM for Indoor Mapping of Wide Area Construction Environments. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *10*(2), 209–216. https://doi.org/10.5194/isprs-annals-X-2-2024-209-2024

Roussillon, T., Sivignon, I., & Tougne, L. (2007). *Discrete Circularity Measure*. http://liris.cnrs.fr/publis/?id=3245

Souza, G. H. B., & Amorim, A. (2012). LiDAR data integration for 3D Cadastre: Some experiences from Brazil. *FIG Working Week, Knowing to Manage the Territory, Protect the Environment, Evaluate the Cultural Heritage, Rome Italy, 6-10 May 2012*, *May 2012*, 6–10.

Surat Edaran Direktorat Jenderal Pajak Nomor SE-19/PJ.6/2003.

Sutaryono, Saleh, R. D. D., Sapardiyono, Salim, M. N., Luthfi, A. N., Utami, W., Pujiriyani, D. W., Kusmiarto, Mujiburohman, D. A., & Puri, W. H. (2021). *Problematika Pengelolaan Pertanahan di Indonesia*.

Syahidan, M. I., Ardiansyah, A. N., & Bahar, S. (2023). Pengaruh Peningkatan Lahan Terbangun Terhadap Penurunan Permukaan Tanah Di Kota Jakarta Utara Tahun 2012-2022. *Jurnal Spatial Wahana Komunikasi Dan Informasi Geografi*, *23*(2), 58–67. https://doi.org/10.21009/spatial.232.07

Yagol, P., Shrestha, E., Thapa, L., Poudel, M., & Bhatta, G. P. (2015). *Comparative study on cadastral survey using total station and high resolution satellite image*. *2*, 6. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.fig.net/resources/proceedings/2015/2015_11_nepal/T.S.6.6.pdf&ved=2ahUKEwji8ZGbxZmKAxX33TgGHZEdBcMQFnoECBgQAQ&usg=AOvVaw07DA4PeMDQx13s4RVfev7W

Yustika, F. P. (2023). *Preferensi generasi milenial dalam memilih hunian di kota semarang*. http://repository.unissula.ac.id/32959/1/Perencanaan Wilayah dan Kota_31202100059_fullpdf.pdf