https://doi.org/10.4233/uuid:bd8a2cd4-fa19-42fd-bc3e-a4572ad2db12

The Role of Positioning Infrastructure and Mapping Surveys in 3D Cadastre Implementation for Mass Rapid Transport Infrastructures – Indonesia Case

Dedi ATUNGGAL, Nurrohmat WIDJAJANTI, Trias ADITYA and Agus WAHYUDI, Indonesia

Key words: Cadastre, Positioning Infrastructure, Reference System, Validation Survey, First Registration

SUMMARY

In response to recent increases in the utilization of 3D spaces situated below and above land surfaces, both users and registrar increasingly demanding a reliable positioning infrastructure for a cadastre. This paper discusses some challenges and requirements for establishing a reliable positioning infrastructure to support 3D cadastre implementation in Indonesia. Since three decades ago, ground survey marks (TDT) have been conventionally used for parcel mapping and only have 2D coordinates. TDT can be used for 3D cadastre implementation by assigning the TDT height to the national height datum. Surveyors can define the TDT height by referring to the orthometric height pillars (TTG) or the Indonesian national geoid (InaGeoid). These two references are sub-elements of the 2013 Indonesia Geospatial Reference System (SRGI 2013), which since 2013 has been used as a reference for various geospatial data nationally. 2D parcel mapping practices in Indonesia are still referring to the previous reference system used by Indonesia, namely the 1995 National Geodetic Datum (DGN95). This condition makes an integrated 3D survey to support first registration and right transfers for 3D Cadastre is challenging. At the same time, a 3D validation survey for 3D cadastre aiming to validate X, Y and Z coordinates of 3D parcels to be registered needs to be done efficiently and accurately. This paper discusses challenges regarding coordinates shift, inconsistencies between 2D and 3D parcels, missing height references and lack of coordinate redefinition of GPS coordinate services. This paper will examine the 3D cadastral validation survey results done in the Mass Rapid Transit (MRT) stations in Jakarta City and evaluate the positioning infrastructure in Jogjakarta City where an MRT connecting the new airport to the city center will soon be built.

The Role of Positioning Infrastructure and Mapping Surveys in 3D Cadastre Implementation for Mass Rapid Transport Infrastructures – Indonesia Case

Dedi ATUNGGAL, Nurrohmat WIDJAJANTI, Trias ADITYA and Agus WAHYUDI, Indonesia

1. INTRODUCTION

The use of 3D space above and below land surfaces in Indonesia is increasing. The Indonesian government regulates the use of 3D space through Law no. 14/2020. Details of regulations are stipulated through Government Regulation no. 18/2021 which is then detailed through the Regulation of the Minister of Agrarian Spatial Planning/National Land Agency No. 16/2021. To implement the regulation, support from a reliable positioning infrastructure is needed.

Since three decades ago, ground survey marks (TDT) have been conventionally used for parcel mapping and only have 2D coordinates. TDT can be used for 3D cadastre implementation by assigning the TDT height to the national height datum. Surveyors can define the TDT height by referring to the orthometric height pillars (TTG) or the Indonesian national geoid (InaGeoid). These two references are sub-elements of the 2013 Indonesia Geospatial Reference System (SRGI 2013), which since 2013 has been used as a reference for various geospatial data nationally. 2D parcel mapping practices in Indonesia are still referring to the previous reference system used by Indonesia, namely the 1995 National Geodetic Datum (DGN95). This condition makes an integrated 3D survey to support first registration and right transfers for 3D Cadastre is challenging. At the same time, a 3D validation survey for 3D cadastre aiming to validate X, Y and Z coordinates of 3D parcels to be registered needs to be done efficiently and accurately.

This paper discusses challenges regarding coordinates shift, inconsistencies between 2D and 3D parcels, missing height references and lack of coordinate redefinition of GPS coordinate services. MRT was chosen as a case study because this infrastructure was developed as a solution to overcome transportation problems faced by big cities in Indonesia. Implementation of 3D cadastre in different cases at different countries as described and explained in Best Practices 3D Cadastres (van Oosterom, 2018) used as a basis for analyzing the implementation of 3D cadastral in this case study

2. EXISTING POSITIONING INFRASTRUCTURES IN INDONESIA

The existing positioning infrastructure in Indonesia consists of horizontal ground survey marks, vertical ground survey marks, national geoid model and Continuously Operating Reference Stations (CORS).

2.1 Horizontal Ground Survey Marks

The horizontal ground survey marks in Indonesia consist of zero order to 4th order control points. The zero order and 1st order control points were established in the early 1990s by the National Mapping Coordination Agency (Bakosurtanal) which in 2011 became the Geospatial Information Agency (BIG). The 2nd order, 3rd order and 4th order control points were established by the Ministry of Agrarian Affairs & Spatial Planning/National Land Agency (MoASP/BPN, formerly known as BPN) from 1994 to 2007. The distribution of the horizontal ground survey marks is shown in Figure 1. Interdistance of each order is presented in Table 1.

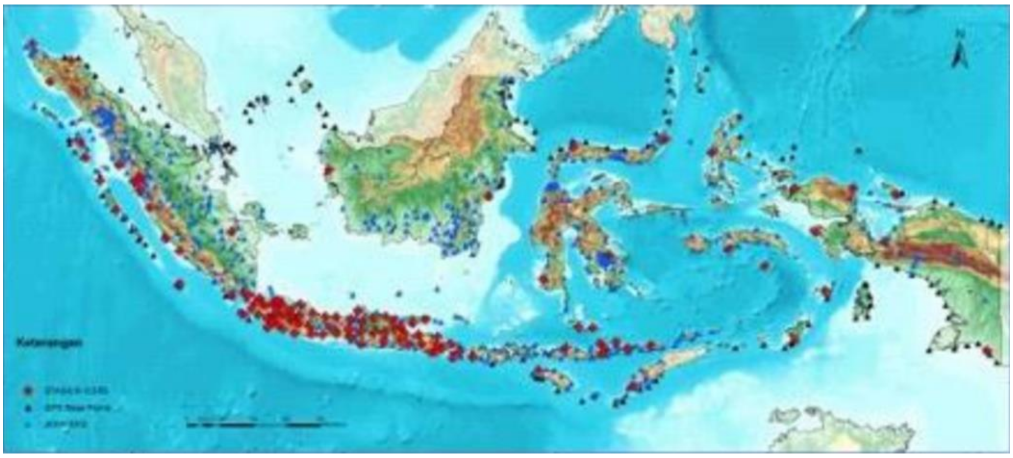


Fig. 1. Distribution of the horizontal ground survey marks (https://srgi.big.go.id)

Table 1: Interdistance of horizontal ground survey marks

Order	Interdistance (km)	Control Points
0	500	National geodetic control points
1	100	Regional geodetic control points
2	10	Local geodetic control points
3	2	Densification control points
4	0.1	Mapping control points

The total number of zero order and 1st order is 1,266 points of which 363 points also have height coordinates and serve as vertical control points. These horizontal ground marks were initially defined to the first geocentric datum used by Indonesia, the DGN95. The realization of DGN95 was done using the zero order control points and referred to International Terrestrial Reference Frame 1991 (ITRF91) 1992.0. In 2013, along with the establishment of the new datum – SRGI 2013, coordinates of these ground survey marks were updated and referred to ITRF08 2012.0 (Abidin et al., 2015). After the establishment of the SRGI 2013, various geospatial data have been referred to this new reference system.

The 2nd, 3rd and 4th order control points are approximately 10,000 points and have only horizontal coordinates. These horizontal ground survey marks were defined by referring to the zero order or the 1st order control points and the previous datum (DGN95). These control points are used for 2D cadastral mapping, e.g. to produce the cadastral base map and land parcel map.

2.2 Vertical Ground Survey Marks

Indonesia's vertical ground survey marks consist of zero order to 4th order control points established by Bakosurtanal. The control points are distributed along the main connecting roads between provinces, as shown in Figure 2. The spacing of the control points is determined based on each segment's slope value, as presented in Table 2.

Fig. 2. Distribution of the vertical ground survey marks (source: https://srgi.big.go.id**)**

Table 2: Interdistance of vertical ground survey marks

Criteria	Slope (%)	Interdistance (km)
I	0-5	4-5
II	>5	2-4

These control points were defined by precise leveling and terrestrial gravity survey. The total number of vertical survey marks is 5747 points, of which 4860 points have both vertical coordinate and gravity value, and 524 points only have vertical coordinate.

2.3 National Geoid Model

The Indonesian Geoid Model is generated using gravity data, global geoid models, and digital elevation models (DEM). Gravity data were obtained from both terrestrial and airborne gravity surveys. The global geoid model and DEM used for the modeling are the Earth Gravity Model 2008 (EGM 2008) 360 degrees and the Shuttle Radar Topographic Mission (SRTM) with a resolution of 30 meters. The geoid modeling method is carried out using the Remove - Restore Technique and the Fast Fourier Transformation (FFT) approach. Figure 3 shows geoid undulation from InaGeoid.

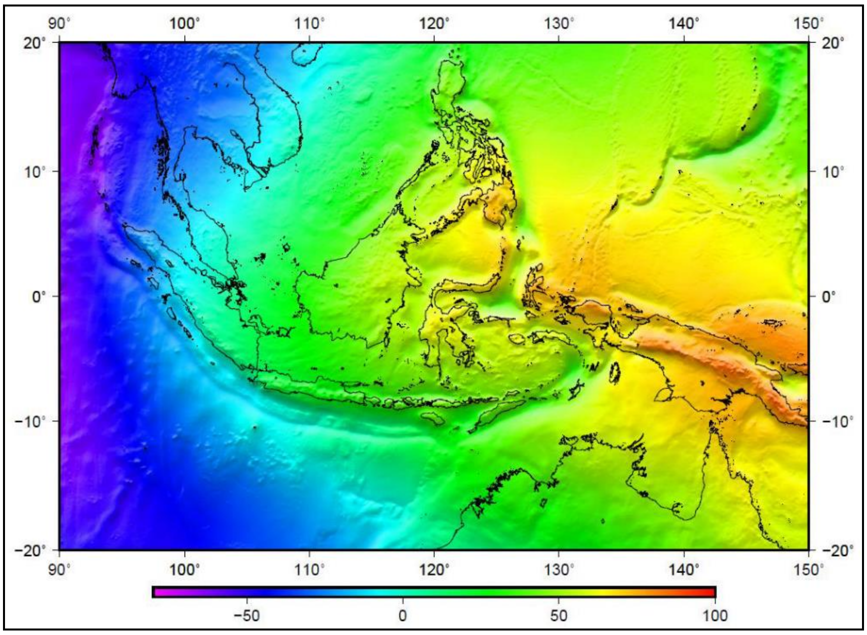


Fig. 3. Geoid undulation model from InaGeoid (Source: Pahlevi, Sofian, Pangastuti, & Wijanarto, 2019)

BIG has carried out verification of the accuracy of InaGeoid. It was conducted by comparing the value of the geometric undulation of the vertical control point used as a sample with the gravimetric undulation of InaGeoid. Geometric undulations are obtained by differentiating the geometrical height or ellipsoid height resulting from GNSS observations with orthometric height values resulting from precise leveling measurements that have been corrected with gravity data. The gravimetric undulation is obtained by interpolating the undulation values from the InaGeoid geoid model. The accuracy of the Indonesian geoid model is calculated per island. The accuracy of geoids is only available for five major islands in Indonesia due to the limited number of vertical control points that can be used for verification. The accuracy of the Indonesian geoid model can be seen in Table 3.

Table 3: The accuracy of InaGeoid (https://srgi.big.go.id)

Island	Number of Verification Points	Min (cm)	Mean (cm)	Max (cm)	Deviation Standard (cm)
Jawa	186	-12.8	0.03	30.4	5.1
Bali	184	-38.3	-0.3	31.1	10.3
Sumatera	26	-8.38	21.4	51.3	17.3
Sulawesi	53	-60.1	-10.5	41.3	22.4
Kalimantan	35	-35.7	23.3	69.5	24.7

2.4 Continuously Operating Reference Stations (CORS)

CORS in Indonesia was developed by BIG and MoASP/BPN starting in 2010. The CORS managed by BIG is known as InaCORS. The number of InaCORS stations until 2019 consisted of 295 stations whose distribution can be seen in Figure 4. InaCORS was developed to support establishing the Indonesian Geospatial Reference System (SRGI), monitoring tectonic activity and making Indonesian deformation models. BIG in 2018 has carried out densification of 30 stations in Sumatra (Mundakir & Chabibi, 2019) and will add another 50 stations in Kalimantan in 2021. As part of the SRGI 2013, the coordinates of InaCORS has been referred to the ITRF 2008 2012.0

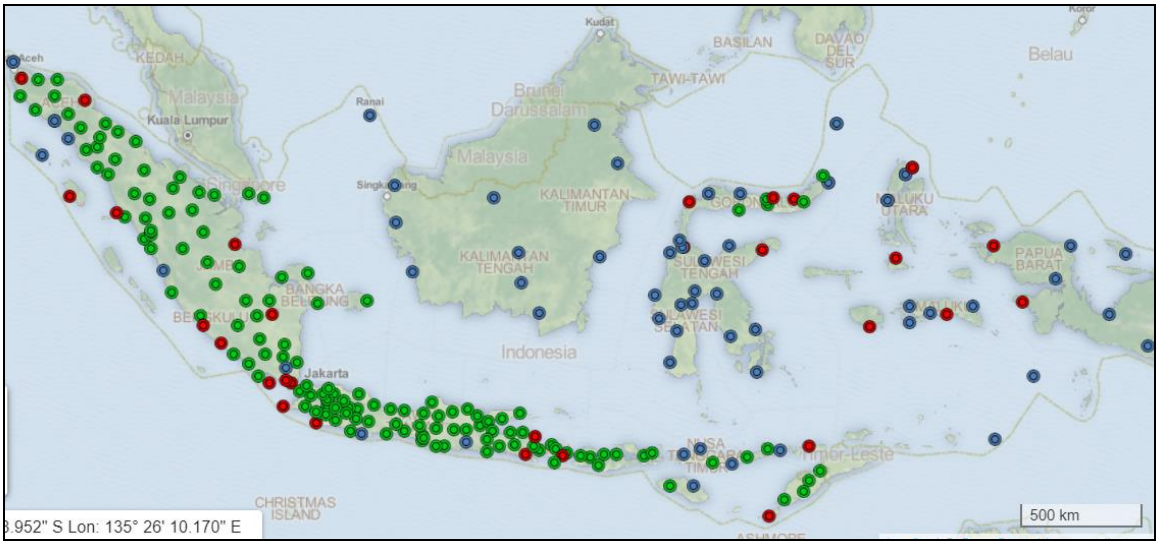


Fig. 4. Distribution of InaCORS (https://nrtk.big.go.id)

CORS managed by the MoASP/BPN is known as the Land Satellite Reference Network (JRSP). The number of reference stations managed by the MoASP/BPN is about 120 stations as shown in Figure 5. JRSP was developed to support cadastral mapping for land registration. Hence, the development was prioritized for Land Offices with high volumes of land transactions and with complex land issues. The coordinate of JRSP still referred to DGN95. Currently, JRSP is being unified and integrated with InaCORS and will be managed by BIG.

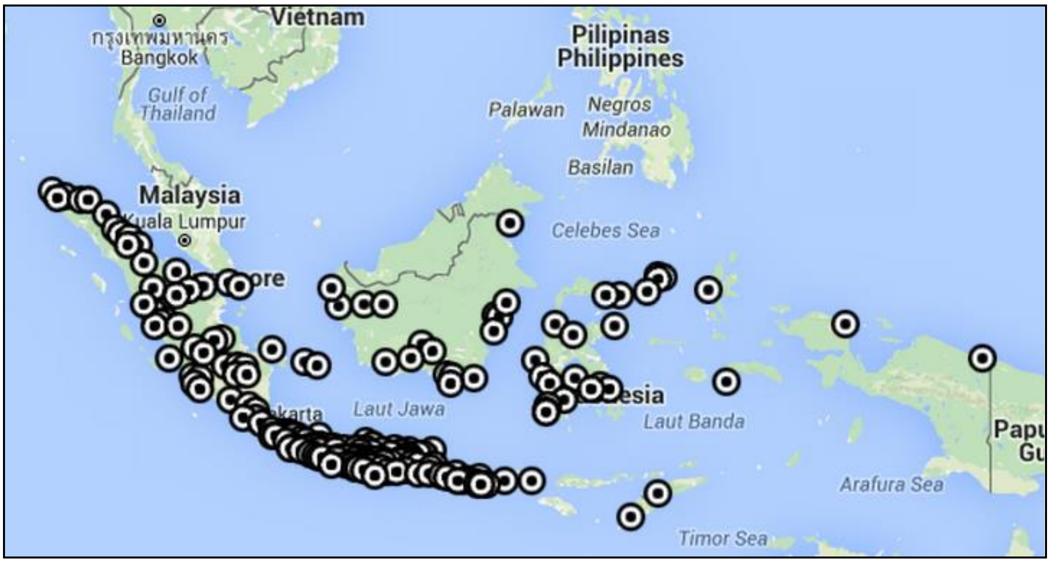


Fig. 5. Distribution of JRSP

3. 2D AND 3D CADASTRAL MAPPING SURVEYS IN INDONESIA

3.1 2D Cadastral Mapping Surveys

In the past, 2D cadastral mapping in Indonesia was mostly done without referring to control points. This resulted in many maps of land parcels that could not be georeferenced. In the last decade, the Indonesian government has made serious efforts to solve this problem. Two of them are implementing complete systematic land registration (PTSL) activities and improving the quality of land parcel maps. These two activities can be carried out quite well in recent years because awareness of the use of control points is increasing.

3.2 3D Cadastral Mapping Surveys

3.2.1 3D Cadastral Mapping Surveys for Strata Titles

3D cadastral mapping surveys began to be implemented in Indonesia following the implementation of the strata titles (Law no. 20/2011). According to this law, the physical buildings referring to mixed-use apartments and condominiums can be divided into three legal spaces: shared properties or shared objects (e.g., parking lots, stairs, corridors, and elevators), shared structures (e.g., columns and partition walls), and strata titles/apartment ownership rights.

Ownership rights or strata titles of mixed-use apartments can be granted as soon as three mandatory requirements for the first can be fulfilled, i.e., the underlying land rights, description of the parcel and space division, and the site plan (Aditya et al., 2020). A field survey or field validation is required to determine the geometry of strata titles at the time of property registration. Many survey methods can do this, but measurements using a laser distance meter or measuring tape are sufficient to validate the distance and area based on the data on the separation deed submitted by the applicant.

With the enactment of Law no. 14/2020 and Regulation no. 18/2021, rights to 3D space are regulated in one cluster with Land Rights and different from Strata Titles.

3.2.2 3D Cadastral Mapping Surveys for Legal Spaces Above and Below Land Surface

According to Law no. 14/2020 and Government Regulation no. 18/2021, a 3D cadastral mapping survey is required to verify the geometry of legal spaces and the 3D position of each 3D cadastral object. This can be performed using either terrestrial survey methods (e.g., Global Navigation Satellite System (GNSS) Survey, Total Station, Terrestrial Laser Scanner and Distometer/laser distance measurers, or a combination) or photogrammetry methods.

3D cadastral objects may be easily validated in the field using local heights. Still, for 3D cadastral objects to be visualized and integrated into a 3D cadastral information system, the use of a national height system is essential (Drobež et al., 2017, Atazadeh et al., 2021).

Given that cadastral control points in Indonesia so far only have 2D coordinates, then assigning heights to TDT may be one of the challenges that need to be solved. The alternative of 3D cadastral mapping using CORS as regulated in Regulation of the Minister of Agrarian Spatial Planning/National Land Agency No. 16/2021 may offer a practical solution to this.

Validation of 3D cadastral objects using CORS will be efficiently carried out when combined with the Indonesian National Geoid model. Research needs to be done to define best practices in the use of such systems in Indonesia. Hybrid local geoid can also be used as an alternative in areas that have not been covered by the national geoid or in cases where the geoid accuracy is not sufficient (Putraningtyas, Heliani, Widjajanti, & Aditya, 2021).

Referring to Government Regulation No. 18/2021 article 74, the use and utilization of land parcels owned by the holder of Land Rights are limited by:

- height limit which is specified according to the building coefficient and the floor coefficient which are set in the local spatial plan; and
- depth limit which is specified in the local spatial plan or determined to 30 meters below the ground in case the limit has not been regulated by the local spatial plan.

3D parcels with separate structures or functions of rights with their land's surface are classified as land/space managed by the government. For that reason, it is crucial to validate the position of the 3D cadastral objects during the validation survey. This validation should be carried out by referring to the validation survey control point on the ground surface.

4. CASE STUDIES

This paper discusses the 3D cadastral validation survey results done in the Mass Rapid Transit (MRT) stations in the Capital City Jakarta. In addition, this paper evaluates the positioning infrastructure in Special Region Yogyakarta Province, where an MRT connecting the new airport to the city center will soon be built. The study area is shown in Figure 6.

Fig. 6. Locations of case study in Indonesia

4.1 Validation Survey of MRT in Jakarta

The 3D cadastral object validation survey at MRT Jakarta was carried out through several stages:

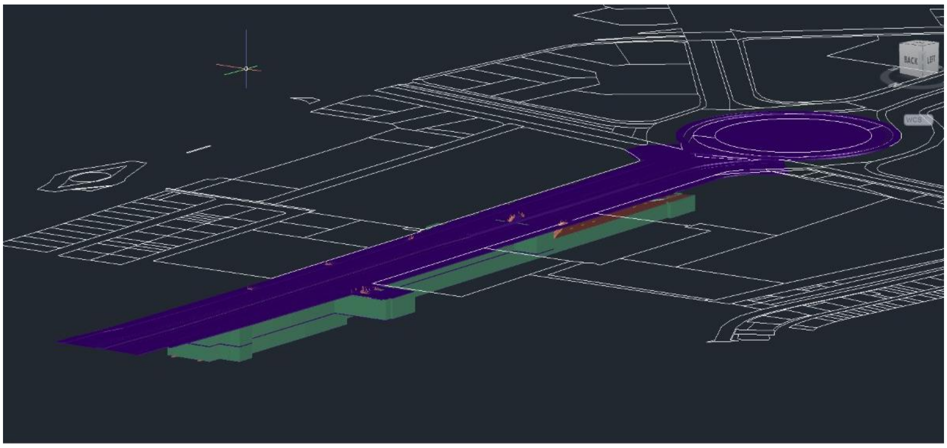
- Creating a work plan map;
- Measuring control points at ground level;
- Conducting a validation survey of 3D cadastral objects above and below ground surface;
- Making validation results document.

The validation survey was conducted based on 3D models of two MRT stations (Bundaran HI Station and Blok M Station) converted from each as-built drawings. The use of 3D models converted from as-built drawings is expected to stimulate and facilitate the implementation of 3D cadastral because it is cost effective. The 3D model is used as a requirement for submitting rights to the 3D cadastre and the cost to create the 3D model is borne by the applicant.

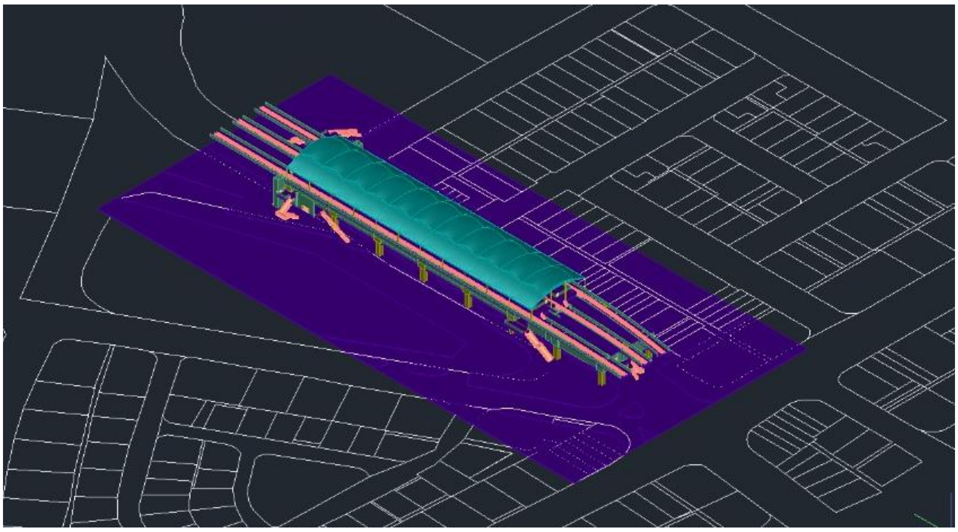
4.1.1 Work Plan Map for Validation Survey

Before the validation survey was carried out, work plan maps for the validation survey at the two MRT stations were prepared. Each 3D model was overlaid with land parcel maps where the two facilities are located (Figure 7). In this initial process, it is identified that there are coordinate shifts and inconsistencies between the 3D models and the land parcel maps at the two stations. It was recognized that the land parcel map uses the Transverse Mercator 3° projection system (or often known as TM3) and refers to the DGN95 datum, while the as-built drawing uses the Universal Transverse Mercator (UTM) projection system and no information about the datum used in the document.

The absence of metadata related to the datum used in the as-built drawing causes difficulties in creating the work plan map. This information is important and becomes the basis for performing datum transformations (in casaes that different datums are used). This problem was overcome by switching the projection to TM 3 using DGN95 and SRGI2013 alternately as the reference system of the as-built drawing. This process was then followed by checking several features (common points) that can be recognized on the land parcel map and on the as-built drawings. Further verification was done by field measurement on several common points. From these processes, it can be concluded that the as-built drawings tend to refer to SRGI 2013. Hence the coordinate shifts and inconsistencies probably are due to the different reference systems and projections used by the two data.



(a)



(b)

Fig. 7. 3D Model of MRT stations combined with 2D land parcels: (a) Bundaran HI Station, (b) Blok M Station (source: Atunggal et al., 2020)

4.1.2 Measurement of Control Points for Validation Survey

The validation survey begins with determining the 3D position of control points at each station. Measurements were carried out using geodetic GNSS receiver referring to horizontal ground survey marks (TDT0902022) and vertical ground survey marks (TTG0267) located approximately 5 kilometers from the two stations shown in Figure 8. The same procedure was applied to define the second control point at each station. The height of the control points was defined by two methods, namely GNSS heighting by referring to the orthometric size of the vertical control point (TTG0267) and online processing by using InaGeoid service. Example of InaGeoid service processing result is shown in Figure 9.

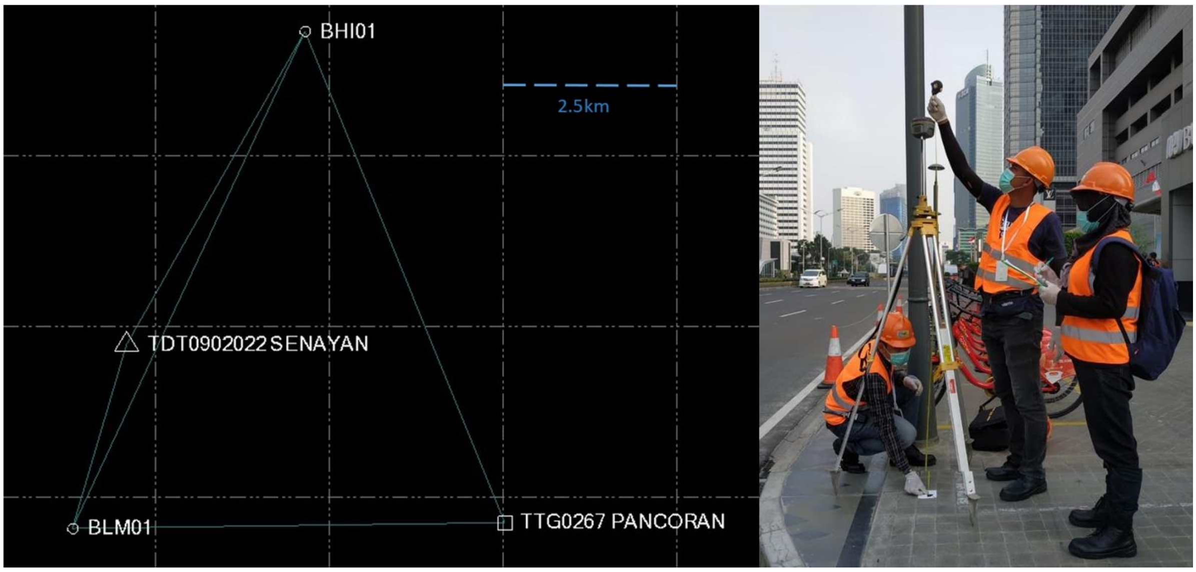


Fig. 8. GNSS observation of validation survey control points

As shown in Table 4, the height difference in each control point is approximately 10cm between GNSS heighting and InaGeoid. In this case, both methods show results with a fairly good level of conformity. As claimed by the InaGeoid online service, the accuracy of the height defined by the service is 5 centimeters. These results look promising but further research on different cases in Indonesia needs to be conducted to see the applicability of such a system on a national scale. An important factor regarding height referencing, as highlighted by Navratil & Unger (2013) and Gulliver & Haanen (2014) needs to be considered for evaluating the application of the system on a national scale.

Table 4: Coordinates of control points for validation survey

Control Point	TM3 Easting (m)	TM3 Northing (m)	GNSS Heighting (m)	InaGeoid Height (m)
BHI01 (Bundaran HI)	235720.086	815452.031	2.139	2.027
BHI02 (Bundaran HI)	235715.697	815436.155	2.341	2.229
BLM01 (Blok M)	233048.109	809638.426	20.509	19.940
BLM02 (Blok M)	233063.734	809623.166	20.110	20.008

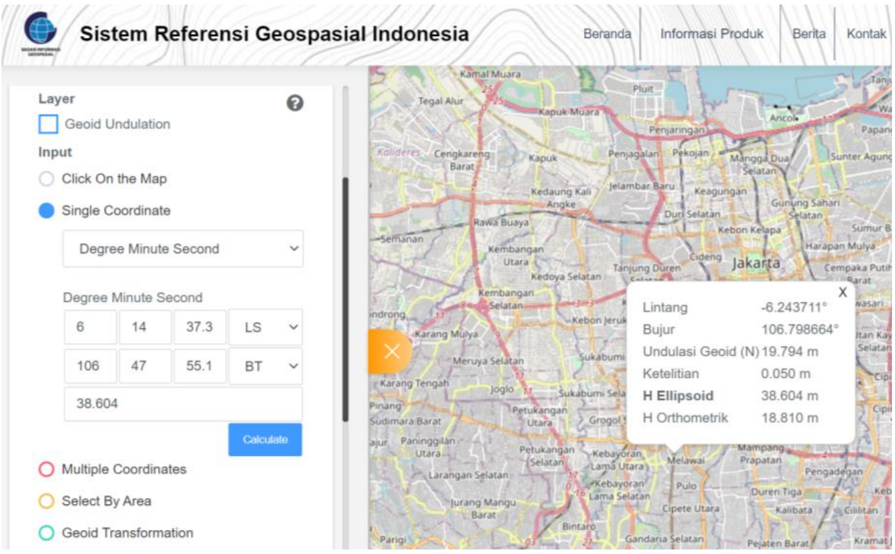


Fig. 9. Example of InaGeoid service processing result

4.1.3 <u>Validation Survey of 3D cadastral objects</u>

Validation survey at each station includes validation of position, length, area and volume of 3D cadastral objects. Of the four validations, the one directly related to the positioning infrastructure is position validation. While the validation of distance, area and volume is related to the quality of the 3D model used.

Position validation at the Bundaran HI station is carried out by using Total Station. Measurements are carried out to determine the height value and the maximum depth of the underground facility at the Bundaran HI station. This is done by measuring trigonometric leveling referring to control points BHI01 and BHI02, which are located near the station entrance at ground level. Validation of 3D cadastral objects in Bundaran HI station was then followed by measuring distances, areas and volumes of several 3D cadastral objects. This measurement is carried out using Total Station combined with a laser distance meter (Figure 10).

Fig. 10. Validation survey by using Total Station and distometer (Atunggal et al., 2020)

Results of the measurements show that the underground facility at the Bundaran HI station is located from 0-17 meters below the land surface. The height of the lowest infrastructure is at 14.973 meters below MSL. Because the Bundaran HI station is located under a public road, the station which is located from ground level to a depth of 17 meters is in accordance with existing legal provisions, see the illustration (Figure 11). In cases MRT infrastructure is located below land rights which are owned by individuals/companies, it is necessary to ensure that the infrastructure is located below 30 meters or in accordance with the depth limits determined by the site.

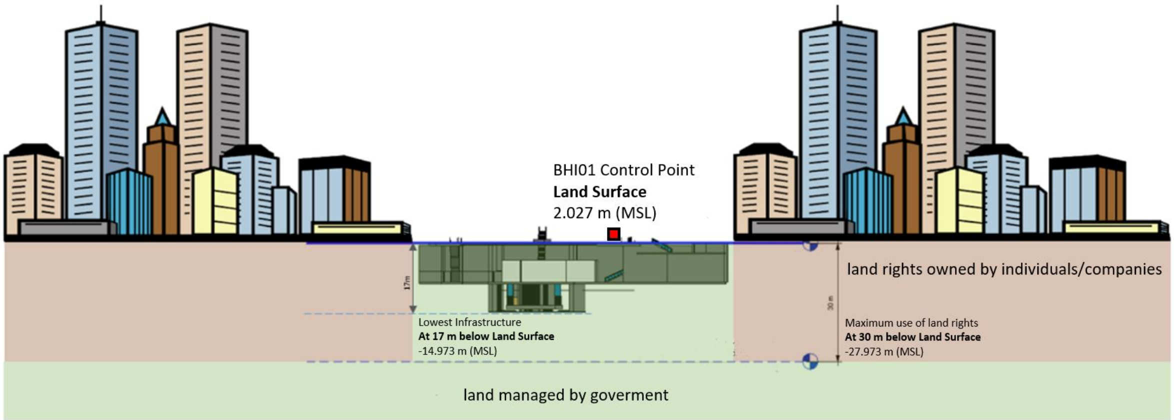


Fig. 11. Illustration of Bundaran HI Station position (Atunggal et al., 2020)

Position validation at Blok M Station is simpler because this 3D cadastral object is located above a public road. From the Total Station measurements, it is known that the maximum height of the building is in accordance with the provisions.

The results of the validation of distance, area and volume at both stations showed promising results. The results from measuring length with the Total Station and diameter with data from the 3D model differ only in millimeters to 1 -2 centimeters. The difference in areas and volumes of validation results with 3D models is mostly less than 2%.

4.2 Evaluation of Positioning Infrastructure in Yogyakarta

In order to illustrate the geospatial infrastructure for 3D cadastre, this paper will also describe relevant findings based on surveys and evaluation of positioning infrastructure in the Special Region of Yogyakarta Province. The total number of horizontal ground survey marks in Yogyakarta is 290 points consisting 15 2nd order control points and 275 3rd order points. BPN produced these ground survey marks from 1994 to 2007. It is necessary to evaluate the number of cadastral ground survey marks that are still reliable to be used as reference points, considering that these ground survey marks are almost 3 decades old. It is necessary to ensure that the control point monument is still in good physical condition and that the surrounding environment has minimum obstructions so that it is conducive to using GNSS observations. Considering the 30 years and the tectonic velocity in Yogyakarta is approximately 2cm/year, the coordinates of the control point and its actual position in the field may differ by up to 54cm. Hence, it is crucial to redefine the coordinates of those control points to SRGI 2013. This would benefit land offices since land parcel mapping will represent its actual position, making it easier to integrate with other geospatial data. The existing vertical ground survey marks and the InaGeoid model in Yogyakarta are also described to picture the current height reference in Yogyakarta.

4.2.1 Horizontal ground survey marks in Yogyakarta

A preliminary survey of 109 ground survey marks sample was carried out. From the results of the preliminary survey, it is identified that 65 control points are still in good condition, 8 control points are physically damaged, and 36 points are missing or cannot be found (see Figure 12). This means that about 60% of the existing ground survey marks can still be used as a control point for cadastral mapping surveys. However, it should be underlined that those 65 control points have varying environmental conditions and obstructions. The number of horizontal ground survey marks that has a minimum obstruction is 45 points.

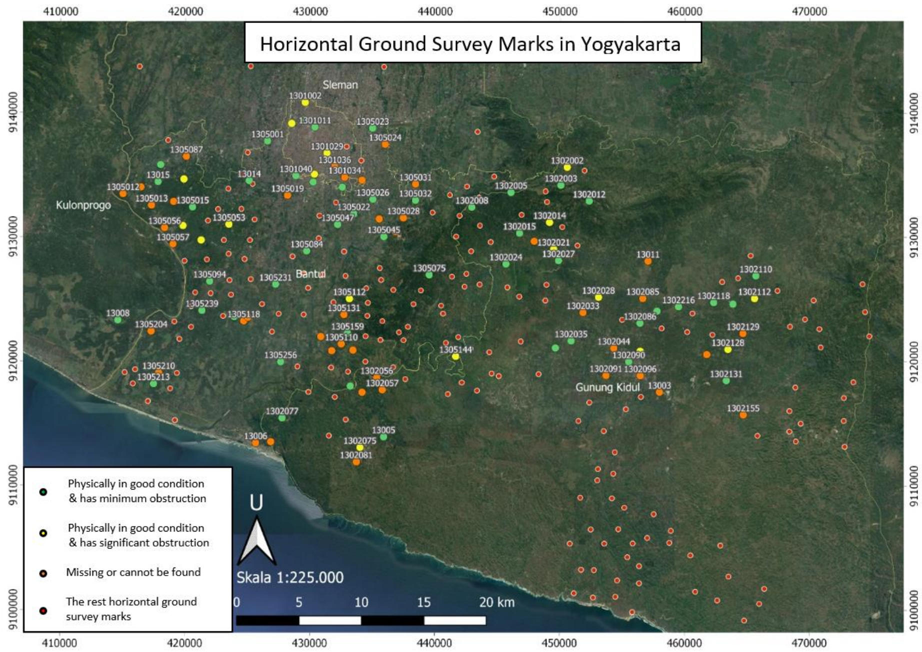


Fig. 12. Horizontal ground survey marks in Yogyakarta

For the purpose of updating the coordinates of cadastral control points in Yogyakarta, static GNSS survey were conducted on those 45 cadastral ground survey marks. The processing of the static GNSS network was done by sciencetific GNSS processing software by referring to zero order control point and CORS in Yogyakarta. Results of the processing produces coordinates of the control points which refer to the SRGI 2013. The accuracy of the results is in the range 1-6cm. This coordinate was then compared with the coordinate values listed on the site log (known as Buku Tugu) when the control points were established. The coordinate shift between the latest processing result (SRGI 2013) and its initial coordinate from the site log (DGN95) range from 0.8-1.5 meters with a systematic shift direction as shown in Figure 13.

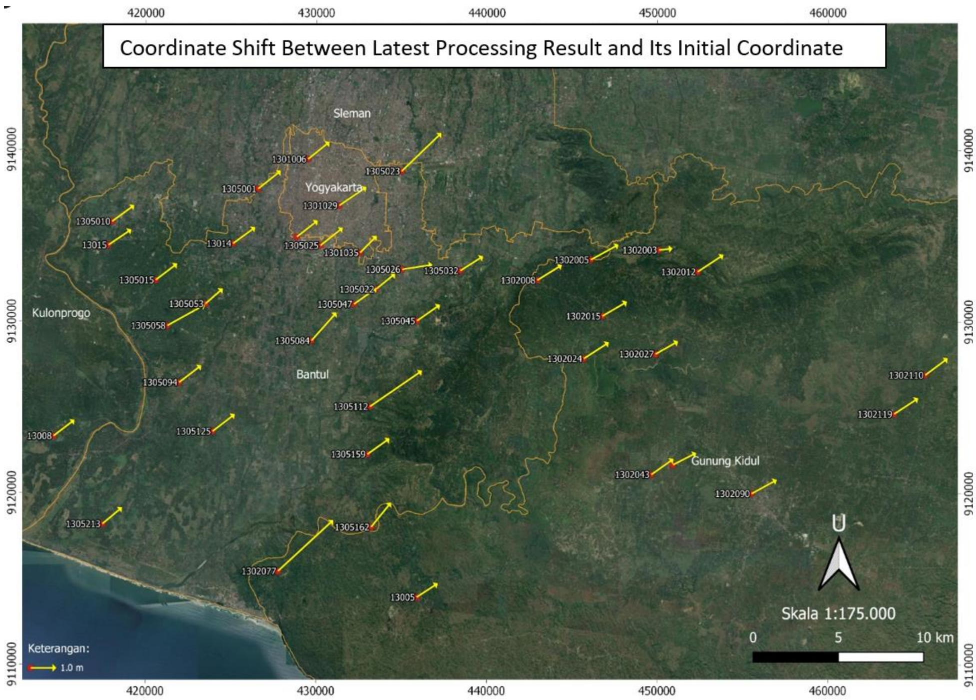


Fig. 13. The coordinate shift between the latest processing result (SRGI 2013) and its initial coordinate from the site log (DGN95)

4.2.2 <u>Height reference in Yogyakarta</u>

A preliminary survey was also conducted to check the availability of vertical survey marks in Yogyakarta. Result of the survey shows that from 22 vertical ground survey marks sample, 16 points are physically still in good condition and the rest of the control points are missing or cannot be found (Figure 14). It means that about 70% of the existing vertical ground survey marks can still be used as height reference for validation survey of 3D cadastral object in Yogyakarta.

As claimed by the InaGeoid online service, the accuracy of the height referencing by using InaGeoid in Yogyakarta is about 5 centimeters. Further investigation needs to be done to verify the consistency of height referencing between vertical ground survey marks and InaGeoid in Indonesia.

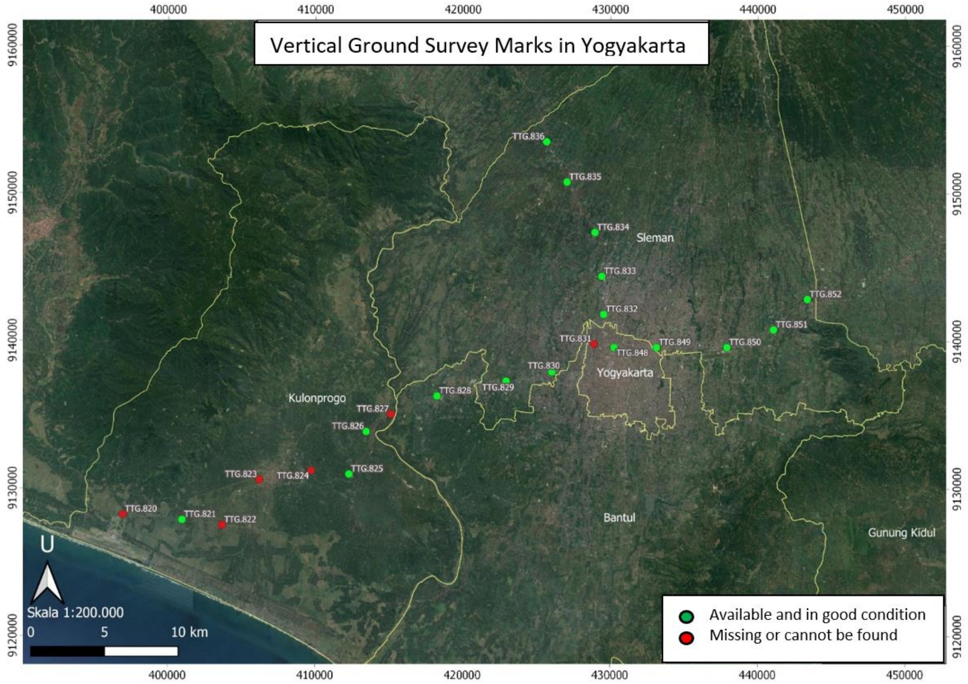


Fig. 14. Distribution of vertical ground survey marks in Yogyakarta

5. CONCLUSIONS AND RECOMMENDATIONS

From this case study, we can conclude that positioning infrastructure plays a vital role in validating the position of 3D cadastral objects below and above ground level. Positioning infrastructure in Jakarta can be used to validate the position, distances, areas, and volumes of 3D units with good results. The use of GNSS heighting refers to ground survey marks, and the determination of height using the InaGeoid online service is different at the decimeter level. However, the availability and reliability of positioning infrastructure in other regions or cities in Indonesia need to be further investigated.

From the evaluation of positioning infrastructure in Yogyakarta, it is identified that the availability of the horizontal ground survey marks is at 60% of its total number and 70% for vertical ground survey marks. Meanwhile, about 30-40% of the ground survey marks are missing or cannot be found on the field. The reduced number of ground survey marks in the field may hinder the implementation of 3D cadastral. Therefore, the Indonesian government needs to increase the number of ground survey marks or increase the number of CORS stations.

The result of the latest processing of horizontal ground survey marks shows that the coordinate shift between the latest processing result (SRGI 2013) and its initial coordinate from the site log (DGN95) range from 0.8-1.5 meters with a systematic shift direction. As claimed by the online service, the accuracy of InaGeoid online height referencing in Yogyakarta is about 5 centimeters. Further investigation needs to be done to verify the consistency of height referencing between vertical ground survey marks and InaGeoid.

REFERENCES

Abidin, H. Z., Susilo, S., Meilano, I., Prijatna, K., Subarya, C., Syafi'i, M. A., … Effendi, J. (2015). On the Development and Implementation of a Semi-Dynamic Datum for Indonesia. In *International Association of Geodesy Symposia* (Vol. 1974, pp. 145–153). https://doi.org/10.1007/1345.

Aditya, T., Laksono, D., Susanta, F. F., Istarno, I., Diyono, D., & Ariyanto, D. (2020). Visualization of 3D Survey Data for Strata Titles. *ISPRS International Journal of Geo-Information*, *9*(5), 310. https://doi.org/10.3390/ijgi9050310.

Atazadeh, B., Halalkhor Mirkalaei, L., Olfat, H., Rajabifard, A., & Shojaei, D. (2021). Integration of cadastral survey data into building information models. *Geo-Spatial Information Science*, *00*(00), 1–16. https://doi.org/10.1080/10095020.2021.1937336.

Atunggal, D., Laksono, D. P., Susanta, F. F., Susanto, Y. B., Lukman, H. H. S., Widjadjanti, N., & Aditya, T. (2020). *3D Cadastre Pilot Project of Jakarta's MRTs*. Jakarta.

Drobe, P., Fras, M. K., Ferlan, M., & Lisec, A. (2017). Transition from 2D to 3D real property cadastre : The case of the Slovenian cadastre. *Computers, Environment and Urban Systems*, *62*, 125–135. https://doi.org/10.1016/j.compenvurbsys.2016.11.002.

Gulliver, T., & Haanen, A. (2014). Developing a Three-Dimensional Digital Cadastral System for New Zealand. *FIG Congress 2014. Engaging the Challenges - Enhancing the Relevance.*, (June 2014), 1–14.

Navratil, G., & Unger, E. M. (2013). Requirements of 3D cadastres for height systems. *Computers, Environment and Urban Systems*, *38*(1), 11–20. https://doi.org/10.1016/j.compenvurbsys.2012.11.002.

Pahlevi, A. M., Sofian, I., Pangastuti, D., & Wijanarto, A. B. (2019). Updating Model Geoid Indonesia. *Seminar Nasional Geomatika*, *3*, 761. https://doi.org/10.24895/sng.2018.3-0.1063

Putraningtyas, E. M. L., Heliani, L. S., Widjajanti, N., & Aditya, T. (2021). Determination of a Local Hybrid Geoid as a Height Reference System for 3D Cadastre. *Indonesian Journal of Geography*, *53*(2).

van Oosterom, P. (ed). (2018). *Best Practices 3D Cadastres*. (P. (ed) van Oosterom, Ed.). Copenhagen Denmark: FIG. Retrieved from https://www.fig.net/resources/publications/figpub/pub72/figpub72.asp

BIOGRAPHICAL NOTES

Dedi Atunggal is lecturer and PhD student at the Department of Geodetic Engineering, Universitas Gadjah Mada (UGM), Indonesia. His research interests include positioning infrastructures, GNSS applications, Cadastre, 3D modeling and navigation

Nurrohmat Widjajanti is Associate Professor at the Department of Geodetic Engineering, Universitas Gadjah Mada (UGM), Indonesia. Her research interests include satellite positioning, deformation, geodynamics, adjustment and computation.

Trias Aditya is Associate Professor at the Department of Geodetic Engineering, Faculty of Engineering, Universitas Gadjah Mada (UGM), Indonesia. His research interests include 2D/3D cadastre, geospatial data infrastructure, cartography and collaborative mapping.

Agus Wahyudi is The Director of Basic Surveying and Mapping at the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency (MoASP/BPN).

CONTACTS

Dedi Atunggal
Department of Geodetic Engineering
Faculty of Engineering, Universitas Gadjah Mada
Jl. Grafika No. 2
Yogyakarta
INDONESIA
Phone: + 62-274-6249191
Fax: + 62-274-520226
Email: dediatunggal@ugm.ac.id
Web site: www.geodesi.ugm.ac.id