

Integration of photogrammetry data and 3D modelling GIS for analyzing spatial utilization intensity based on Jambi city government regulations in sustainable spatial planning (Case study: Pasar Jambi Sub-district)

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Abstract. Increasing urbanization in metropolitan areas has led to the emergence of many densely populated areas and illegal buildings [1]. To control this growth, local governments have made various efforts to control the intensity of development or land use. This study evaluates spatial utilization intensity in Pasar Jambi District to address the challenges of rapid urbanization and the proliferation of non-compliant structures. By integrating 3D photogrammetric modeling and Geographic Information Systems (GIS), the research assesses the compliance of Building Coverage Ratio (BCR), Floor Area Ratio (FAR), Green Coverage Ratio (GCR), and Building Setback Lines with Jambi City Regulation No. 3/2015 and Draft Regulation No. 5/2024. The findings indicate that spatial utilization in the study area remains suboptimal, characterized by excessive BCR, deficient GCR, and frequent setback violations, which effectively "lock" land resources and hinder functional adaptation. Conversely, FAR values generally remain below the maximum allowable thresholds, suggesting significant potential for controlled vertical intensification. Shifting urban growth from a horizontal to a vertical trajectory is recommended to alleviate pressure on land availability and ensure the implementation of sustainable spatial planning.

1. Introduction

Under Law No. 26 of 2007, district and city governments have the authority to implement spatial planning, which includes regional spatial planning, spatial utilization, and control of spatial utilization in districts/cities [2]. Based on these regulations, the Jambi City government issued a regional regulation governing spatial planning, as stipulated in Jambi City Regional Government Regulation No. 3 of 2015 concerning harmonizing development, and the draft Jambi City Regional Regulation No. 5 of 2024 on the spatial plan for the Jambi City area for 2024-2044 [3][4]. Therefore, the government needs to implement a more scientific and rational spatial layout and optimize land allocation in order to improve the utilization of existing land resources [5]. The purpose of this study is to analyze and provide input to the government on how regulations align with practices in the field. Based on this, an Intensity of Space Utilization (ISU) analysis was conducted. ISU provides an overview of how space is used and utilized to maintain urban balance, as well as indicating whether the land is being managed optimally in terms of infrastructure load, environmental quality, and urban comfort [6].

The operational variable of spatial utilization intensity refers to spatial planning guidelines in Indonesia. In accordance with the appendix to Minister of Agrarian Affairs and Spatial Planning Regulation No. 16 of 2018, spatial utilization intensity includes Building Coverage Ratio (BCR), Floor Area Ratio (FAR), Green Coverage Ratio (GCR), Basement footprint, Building Setback Line, and Building Density. In this study, the operational variables used to indicate the intensity of space utilization include Building Coverage Ratio (BCR), Floor Area Ratio (FAR), Green Coverage Ratio (GCR), Building Setback Line, and Building Density. In implementing the Detailed Spatial Plan (RDTR) to understand the provisions for spatial utilization, a technique was used to combine 2D and 3D spatial patterns [8]. Where 3D mapping requires other supporting basic data in the form of elevation models, building footprint polygons that can be extracted from orthophoto data as basic data for the formation of Level of Detail (LoD) 2.1 in 3D mapping, as well as polygons of land use zones. The creation of this 3D modelling was carried out using aerial photographs processed using photogrammetry principles, which were then converted into point clouds and subsequently into DTM and DSM data.

The combination of these two methods is expected to meet the need for building information, both vertical and horizontal, generated from the modelling that has been carried out. The resulting 3D model can assist in solving problems related to calculating space utilization intensity variables. BCR, FAR, GCR, Building Setback Line, and Building Density affect space utilization intensity in Pasar Jambi District and have a significant impact on space utilization. The BCR values in the trade and service areas and residential areas indicate that most blocks are in the dense to very dense category, so that the building footprint dominates the land surface and leaves limited open space. Therefore, this research is very important to evaluate the effectiveness of the existing spatial utilization intensity policy in the existing conditions in the Pasar Jambi District with applicable standards, namely based on Jambi City Government Regulation No. 3 of 2015 concerning harmonizing development, and the draft Jambi City Regional Regulation No. 5 of 2024 concerning the 2024-2044 spatial plan for the city of Jambi.

2. Materials and Methods

2.1 Study Area

This research was conducted in Pasar Jambi Subdistrict, one of the subdistricts in Jambi City. This subdistrict covers an area of approximately 168.8 hectares and is one of the urban areas that plays a strategic role in economic, trade, and service activities in the city of Jambi. The characteristics of the area, which is dominated by urban functions, make the Pasar Jambi Subdistrict a relevant location for studying the dynamics of spatial utilization, building density, and urban development patterns.

Geographically, Pasar Jambi Subdistrict is bordered by Palayangan Subdistrict to the north, Jelutung Subdistrict and Telanaipura Subdistrict to the west, Jelutung Subdistrict to the south, and Jambi Timur Subdistrict to the east. These boundaries indicate that Pasar Jambi District is located in the core area of the city, surrounded by other districts with relatively similar urban characteristics, resulting in fairly intensive interaction between regions. This condition has implications for high pressure on land use and the need for integrated spatial control.



Fig 1. Research area Map

2.2 Data Sources

This study applies a geospatial approach to evaluate the intensity of existing land use in Pasar Jambi District. The primary data used comes from aerial photo mapping acquired in October 2024, resulting in orthophoto data with a resolution of 3.3 cm and a horizontal accuracy of 32.5 cm. Digital Terrain Model (DTM) and Digital Surface Model (DSM) data with a resolution of 12 cm and an accuracy of 49.5 cm. This data was further processed to produce a 3D City Model (Level of Detail/LOD-2) where the resulting model has more detailed geometry, including roof representation. The model was created based on the digitization of building roofs and Normalized Digital Surface Model (NDSM) calculations, resulting in a LoD 2 building model. The results of the spatial utilization intensity analysis were then identified and evaluated for compliance based on the spatial planning regulations in force in the City of Jambi (Local Regulation No. 3 of 2015 and Draft Local Regulation No. 5 of 2024).

2.3 Methods

2.3.1 Research Framework

This study was conducted to analyze the intensity of space utilization by developing a 3-dimensional city model using DTM, DSM, and Orthophoto data generated from photogrammetric processing. The parameters used to determine the intensity of spatial utilization include BCR, FAR, GCR, Building Setback Line, and Building Density. The 3D city model was built at Level of Detail/LOD-2 by processing DTM and DSM data to produce a Normalized Digital Surface Model (NDSM), then manually segmenting building roofs based on orthophoto data. In addition, land use grouping was also carried out in existing conditions, resulting in maps of land use, green open spaces (RTH), roads, and water bodies. The creation of building footprints, roof segmentation, and land use maps was carried out through visual classification using on-screen digitization techniques. To ensure data accuracy, field validation was conducted using sampling methods to test the conformity between digitized results and actual conditions in the field.

The nDSm value obtained is used to determine the height of the building, then the building footprint data is added to produce a LOD-2 3D city model. The accuracy of the resulting 3D model is tested to determine the level of precision of the model. Building sampling tests are conducted with reference to the American Society for Photogrammetry and Remote Sensing Edition 2, Version 2 ASPRS Positional Accuracy Standards for Digital Geospatial Data [10]. Where the total number of samples for Horizontal Accuracy and Non-Vegetated Vertical Accuracy is 30 samples for the area, 1000 KM². Where the accuracy value of the building based on CityGML uses the Root Mean Square Error (RMSE) value as a reference. The RMSE value produced in the LOD 2 building model is in accordance with the CityGML standard, which is < 2 meters [11].

The results of the 3D building formation that has met the standards are then analyzed using existing land use area data, and an ISU analysis is carried out in accordance with RDTR regulations. This analysis is related to BCR, FAR, GCR, BSL, and Building Density. The results of this analysis will then be compared with the provisions of the 2024-2044 RDTR for the City of Jambi. This evaluation of compliance will reveal which areas violate or do not violate IPR regulations based on the RDTR regulations.

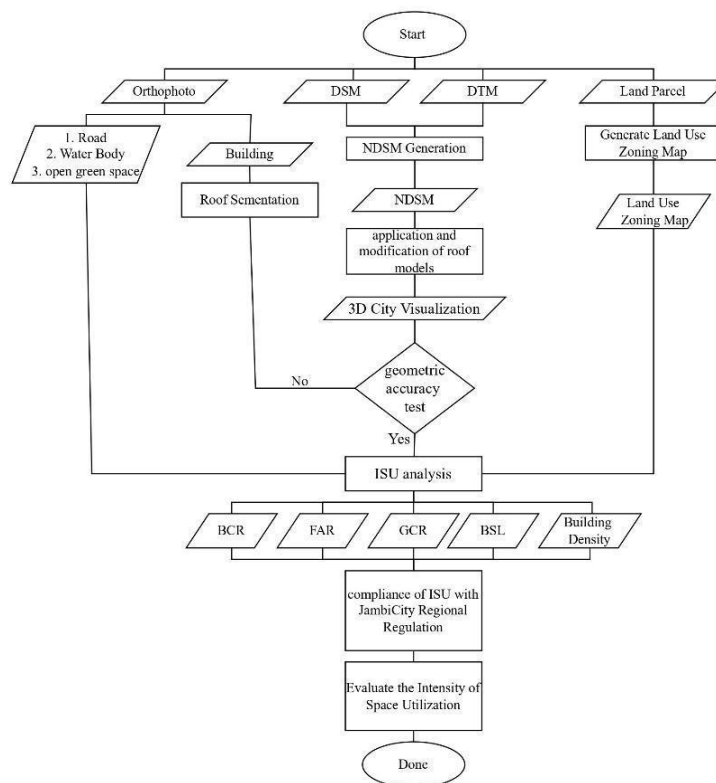


Fig. 2. Research Flow Method

2.3.2 Intensity of Space Utilization (ISU)

The intensity of space utilization is analyzed to determine how often the space is used by humans, so that the direction of development and land use can be regulated [6]. According to Edward Ng (2010), provisions related to Building Floor Area Ratio (BFAR) and Green Floor Area Ratio (GFAR) in an urban context tend to be mechanical in nature, but need to be understood contextually within the overall physical spatial structure. This includes aspects of the urban system and the external environment. The physical form resulting from the control of BCR, GCR, and FAR remains within the framework of the unity of the urban spatial structure to ensure spatial integration [12]. To calculate these variables, you can use the following equation:

$$BCR = \frac{\text{Building Footprint Area}}{\text{Total land Area}} \times 100\% \tag{1}$$

$$FAR = \frac{\text{Total Floor Area Building}}{\text{Total land Area}} \tag{2}$$

$$GCR = \frac{\text{Green Open Space Area}}{\text{Total land Area}} \times 100\% \tag{3}$$

In calculating the BCR value, a comparison is made between the built-up area and the total land area. The FAR is calculated based on the ratio of the total floor area of the building to the total land area, and the GCR is calculated by comparing the open space area to the total land area. Meanwhile, the BSL determines the minimum distance between a building and the boundary of the land or public facilities such as roads, riverbanks, railroad tracks, and high-voltage power lines. The BSL provisions are made with consideration of safety and health aspects to ensure that buildings are at a safe distance from these elements to avoid risks that could endanger residents and the surrounding environment. The calculation of building density in Dangnga's dissertation (2002) explains that the identification of settlement density is done by calculating the total area of the building (building coverage) with the area of the settlement block [13].

2.3.3 Legal Framework for Regional Spatial Utilization in Jambi City

Regulations on spatial planning in Jambi City can focus on two main legal instruments: Jambi City Regional Regulation No. 3 of 2015 concerning Buildings and Draft Jambi City Regional Regulation No. 5 of 2024 concerning the 2024–2044 Spatial Plan for Jambi City. These two regulations form the legal basis for analyzing and evaluating the suitability of land use in the Jambi City area. The 2015 Perda regulates technical and administrative provisions related to buildings, including parameters for land use intensity such as Building Coverage Ratio (BCR), Floor Area Ratio (FAR), and Green Coverage Ratio (GCR). Meanwhile, the 2024 Draft Regional Regulation provides new guidelines on regional spatial structure and patterns, zoning, and building density standards that will serve as a reference for sustainable development in the future. Based on this, the maximum limits for BCR, FAR, and GCR values based on land use zones can be seen in Table 1.

Table 1. Maximum limits of the BCR, FAR, and GCR values.

No	Land Use Zone	BCR	FAR	GCR
1	Commercial and Services Zone	50%	10.0	10%
2	Residential Zone	70%	2.0	5%
3	Public Facilities Zone	60%	4.2	10%
4	Park and Urban Green Space Zone	15%	0.2	85%
5	Tourism Zone	50%	1.0	20%
6	Industrial Zone	50%	1.0	30%
7	Cemetery Zone	5%	0.1	5%
8	Defense and Security Zone	50%	1.5	10%

Based on PUPR Regulation No. 28/PRT/M/2015 concerning the Determination of River Boundaries and Lake Boundaries [14] and PUPR Regulation No. 06 of 2021 concerning the classification of minimum building limits for public facilities as can be seen in Table 2.

Table 2. Building Setback Line Classification

Variable	Classification	Criteria
Building Setback Line (BSL)	Building distance from the road	Arterial roads: 5 – 7 meters
		Collector roads: 3 – 5 meters
		Local roads: 1.5 – 3 meters
	Building distance from the river	Minor (tributary) river: 10 meters
		Medium river: 15 – 20 meters
		Large river: > 25 meters

The calculation of building density in Dangnga's dissertation (2002) explains that the identification of settlement density is carried out by calculating the total area of buildings (building coverage) with the area of the settlement block [13]. Where the Director General of Human Settlements in 1979 classified building density levels, as can be seen in Table 3.

Table 3. Building Density Variable

Building Density Variable	Classification	Criteria
	BCR <40%	Low
	BCR 40% - 60%	Moderate
	BCR 60% - 80%	Dense
	BCR > 80%	Very Dense

2.3.2 3D City Model

The creation of this 3D city model was carried out to digitally represent the earth's surface and surrounding objects, such as the ground, vegetation, buildings, and so on. The 3D modeling was created based on Level of Detail (LoD) 0 to LoD3, but this study used LoD-2 modeling, where the model has more detailed building geometry than LoD-1, but already has a roof shape. 3-dimensional geospatial data defines locations in 3-dimensional space determined by the X, Y, and Z axes. Spatial objects in the real world are regular and irregular in shape. In GIS, these spatial objects are represented in the form of points, lines, and surfaces. There are two categories of spatial object representation, namely surface-based and volume-based. Surface-based object representation is the representation of objects represented by the shape of the primitive object surface. One of the simplest methods of forming 3D objects is by extrusion. Extrusion is the stretching of a 2D flat plane into a 3D object. The footprint or flat plane as the base (initial 2D data) on each side will be pushed upwards according to the specified height to create a polyhedron [12].

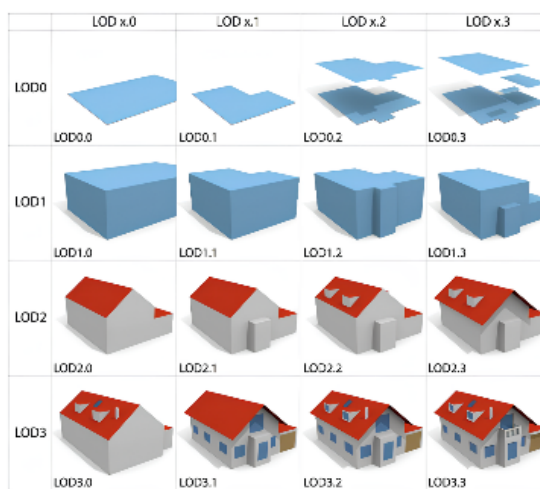


Fig. 3. grouping of levels of detail

3. Result

3.1. Land Use Zone

To regulate the intensity of land use, zoning regulations are implemented based on specific land use zones. These zoning regulations are designed to ensure that each zone is used in accordance with its designated function as stipulated in the RDTR regulations. Land use zones are delineated based on existing land use conditions in the field. Each land use zone in Pasar Jambi Subdistrict can be seen in Figure 2. These land use zoning regulations are listed in the Detailed Spatial Plan document. Zoning regulations in Jambi City are regulated in Jambi City Regulation Number 5 of 2024 concerning the 2024-2044 Jambi City Spatial Plan.

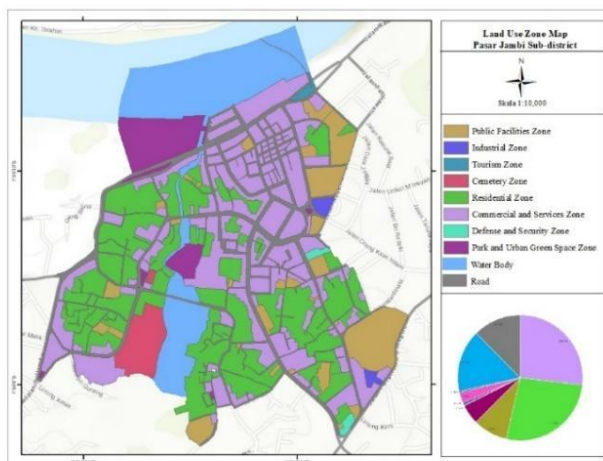


Fig. 4. Landuse Zona Map

Generally, the Pasar Jambi District is dominated by residential areas (26.78%) and trade and service areas (26.83%). The high concentration of trade and service functions is in line with the strategic location of the Pasar Jambi subdistrict, which is often the center of commercial activity. Meanwhile, the smallest land use zone is the tourism zone, at 0.25%. In addition, the land use zones in the Pasar Jambi subdistrict are designated as public facility zones, city park zones, industrial zones, cemetery zones, and defense and security zones. Based on Figure 3, the Pasar Jambi subdistrict is an area with fairly high economic activity, where residential areas, trade, and services dominate half of the total area. This spatial pattern is in accordance with the Detailed Spatial Plan (RDTR) which designates this area for residential and commercial use. This conformity is reinforced by empirical indicators in the form of high levels of economic activity. Based on the types of activities that frequently occur in this area due to the presence of traditional markets, terminals, shopping centers/malls, hotels, schools, places of worship, and government offices.

3.2. 3D Model Visualization

This 3D building model is a representation of existing buildings on the earth's surface in the research area. This model was obtained based on the overlay of DTM, DSM, and building footprint data, as well as the extraction of building roofs, resulting in a LOD-2.1 3D city model. This LOD-2 model presents buildings in the form of simplified outer shells. The 3D modeling of buildings in the Jambi Market area is dominated by residential, commercial, and service areas, where the majority of tall buildings are shops, malls, and hotels. The modeling results can be seen in Figure 5.

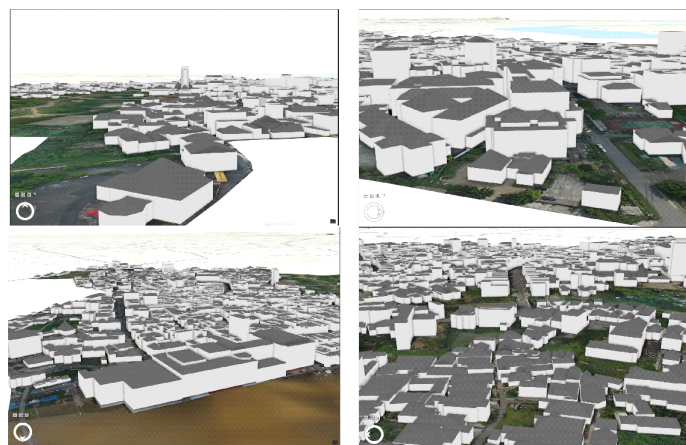


Fig. 5. 3D City Visualization

Based on land use zones, this area is dominated by commercial and service areas, resulting in many shop buildings, most of which are three stories high. In addition, high-rise buildings are dominated by hotels and malls. The roofs of the buildings formed from this modelling are dominated by flat roofs, while there are also buildings with dome, hip, gambrel, spherical, and vaulted roofs. Residential buildings usually have hip and gambrel roofs. The existing modelling was used to test geometric accuracy by reviewing the length and height segments of the model. In this case, the building length and height segment data will be tested and then the percentage of error and Root Mean Square Error (RMSE) will be calculated.

Table 4. geometric accuracy test

Number of Validation Samples	50
Number of Roof Segments	3579
Highest Error Difference	3,13354
Lowest Error Difference	-1,45200
Average Error	0,1951265227
Model Error Percentage	1,16240%
RMSE	0,4417312789

From the model that was formed, 50 samples of building length and height were used, where the distribution of these building samples was evenly spread across various building types, including tall, medium, and low buildings. Based on this data, an RMSE value of 0.441 was obtained, which does not exceed 2 meters. This indicates that the resulting model meets the standards and has good spatial quality and is suitable for use in further mapping and planning analyses, where in this study, the height of the model greatly affects the FAR value that will be obtained, and the length of the model will affect the existing BCR value. Therefore, the model obtained must be of good quality so that it can be used for further ISU analysis.

3.3. Intensity of Space Use Analysis (ISU)

The results of 3D visualization of the city and land use zone maps can be used to calculate the intensity of space utilization in existing conditions, which can then be compared with applicable standards, namely Local Regulation No. 3 of 2015 and Draft Local Regulation No. 5 of 2024 of the City of Jambi. Spatial Utilization Intensity includes Building Coverage Ratio (BCR), Floor Area Ratio (FAR), Green Coverage Ratio (GCR), Building Setback Line, and Building Density.

3.3.1 Building Coverage Ratio (BCR)

Building Coverage Ratio (BCR) is a useful tool for controlling land coverage by buildings. This is done to maintain a balance between the parts of the land covered by buildings and the parts that are still open, as well as to absorb water. The BCR value percentage is obtained from the ratio of building area to land area in the land use zone. The resulting BCR percentage values vary considerably, ranging from 0% to 100%, with 45% of all blocks falling within the 70% to 100% range. Based on the BCR values obtained, a comparison was then made between the existing BCR percentage values and the Jambi city RDTR design, as shown in Figure 6.

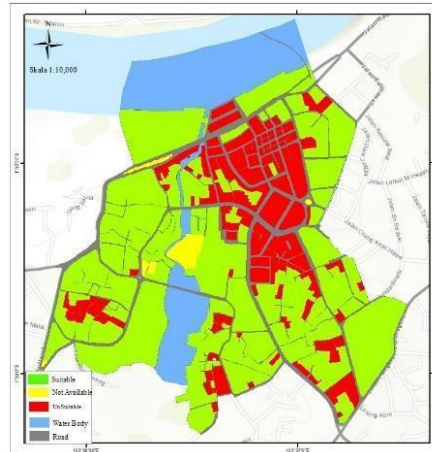


Fig. 6. BCR Compliance Level

Although dominated by compliance, a significant percentage of zones were categorized as Non-Compliant with KDB, namely 42.73%. These non-compliant areas are densely populated, dominated by commercial and service zones. The high level of non-compliance in this zone is due to the presence of retail buildings (shopping centers) where almost all of the land is used for buildings. These results indicate the need for a review and stricter enforcement of regulations in trade and service zones to ensure a balance between economic needs and environmental functions in accordance with the Regional Spatial Plan (RTRW).

3.3.2 Floor Area Ratio (FAR)

Floor Area Ratio (FAR) is the ratio of the total floor area of a building to the land area. The results of the 3D city model can be used to obtain the height of each building, which can then be used to calculate the FAR value. The FAR value in this area ranges from 0 to 5.4. The FAR values in this area are predominantly in the range of 0.6 to 1.0. The obtained FAR values are then compared with the existing conditions and applicable regulations, as shown in Figure 7.

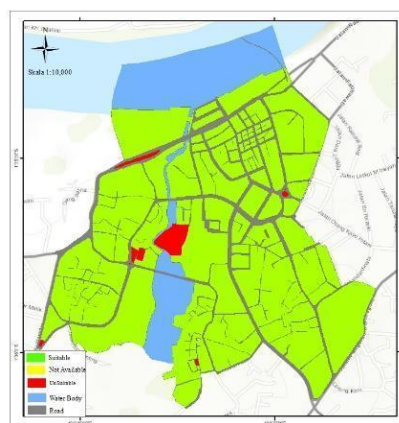


Fig. 7. FAR Compliance Level

Based on the FAR compliance level, the Pasar Jambi subdistrict has a compliance level of 95.91%, where the existing FAR value does not exceed the applicable provisions. And 4.09% of the zone does not have an FAR value. So, looking at the FAR value in the existing conditions, the FAR in the Pasar Jambi area is still far from the maximum FAR value, so this area can still be developed vertically. In general, there are no issues related to building height in the Pasar Jambi District, so vertical development is still possible in this area, as the FAR value obtained is still far from the maximum height threshold and the FAR value in this area. However, in several hotel buildings, there is a row of buildings with contrasting heights compared to other buildings in the vicinity. Therefore, there is a need for building layout guidelines that regulate building height at the micro level.

3.3.3 Green Coverage Ratio (GCR)

Green Coverage Ratio (GCR) is a percentage figure comparing the total area of open space outside buildings to the total area of land parcels. The green base coefficient is inversely proportional to the building base coefficient. The GCR percentage in this area ranges from 0% to 96.52%, with a GCR value of 0% or none dominating 41.82% of all existing zone blocks. A GCR value of 0% indicates that there is no green open space in the block. This is due to significant development pressure and limited green open space. The existing GCR values are compared with the applicable regulations, as shown in Figure 8.

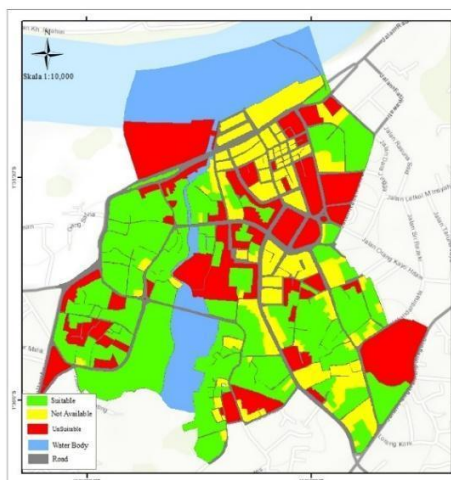


Fig. 8. GCR Compliance Level

Based on the results of comparing GCR compliance levels, 37.27% of zones meet GCR values, while 20.45% of zones do not meet GCR values, and 42.27% of zones do not have GCR values. It can be seen that in the trade and services sector, there are still many zones that do not have GCR values. The GCR aspect requires special attention. In the trade and service zones, there are still many blocks that do not have GCR or do not meet the applicable GCR standards, so that the proportion of green open space in these intensive activity areas is very limited. The rows of shop houses or shops show a tendency towards minimal greening in this zone. This condition has the potential to reduce environmental quality, reduce water absorption, and reduce thermal and visual comfort for area users. Therefore, in the future, the local government can develop green open areas, especially in trade and service areas.

3.3.4 Building Setback Line (BSL)

GSB determines the minimum distance between buildings and land boundaries or public facilities such as roads, riverbanks, railroad tracks, and high-voltage power lines. These GSB provisions are made with safety and health aspects in mind, to ensure that buildings are at a safe distance from these elements in order to avoid risks that could endanger occupants and the surrounding environment. Based on PUPR Regulation No. 28/PRT/M/2015 concerning the Determination of River and Lake Boundary Lines[14] and PUPR Regulation No. 06 of 2021 concerning the classification of minimum building distances from public facilities [15]. The level of compliance of building distances from public facilities can be seen in Figure 8.

Where the level of compliance of BSL that meets the minimum distance requirements for buildings to roads and rivers is 34%, while the distance of buildings that do not meet the requirements for the distance of buildings to roads and rivers is 61.8%.

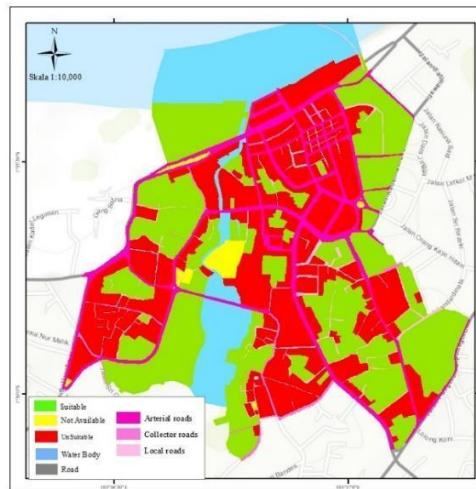


Fig. 9. BSL compatibility level

2.4 Build Density

The calculation of building density in Dangnga's dissertation (2002) explains that the identification of settlement density is carried out by calculating the ratio between the total area of buildings (building coverage) and the area of the settlement block, where, based on the 1979 Director General of Human Settlements, building density is grouped into four categories, namely low density, medium density, high density, and very high density. This can be seen in Figure 10.

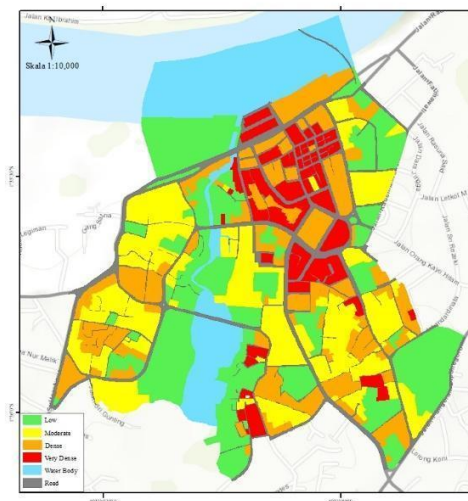


Fig. 10. Building Density Level

Based on the results of building density classification, it can be seen that several buildings located in residential zones and commercial and service zones have relatively high density levels. The high density of these buildings is closely related to the intensity of land use, where almost all available land has been used for development. This

phenomenon is mainly caused by the proliferation of shop buildings that dominate the area, leaving very limited open space.

Table 5. Building Density Classify

Criteria	Classification	Number of blocks	Persentase
<40%	Low	51	23.18%
40% - 60%	Moderate	49	22.27%
60% - 80%	Dense	71	32.17%
> 80%	Very Dense	49	22.17%

The data in Table 5 Building Density Classification shows that Pasar Jambi Subdistrict has a very high building density. This can be seen in Table 5 and Figure 9. Overall, Pasar Jambi Subdistrict has a very high building density. This can be seen from the dominance of the dense and very dense categories. When combined, these two categories cover 120 blocks, which are dominated in the central to northern to southern parts. This shows that the majority of the area in this subdistrict has developed with high building intensity. This indicates the need for spatial control and optimization of the green base coefficient to balance building density and environmental sustainability.

4. Conclusions

Based on the processing and analysis of the results, it was found that 3D modeling of buildings with LoD-2.1 used aerial photo and orthophoto data with a semi-automatic method. From the model formed based on 50 measured length and height samples, the resulting RMSe value was 0.441, which did not exceed 2 meters. This result shows that the model obtained has a good spatial pattern. Thus, the model can be used for further analysis related to mapping and planning for ISU analysis. ISU analysis in Pasar Jambi Subdistrict, based on the influence of Building Coverage Ratio (BCR), Floor Area Ratio (FAR), Green Coverage Ratio (GCR), Building Setback Line, and Building Density on ISU in Pasar Jambi Subdistrict, shows a significant influence on space utilization. The BCR values in the trade and service areas and residential areas indicate that most blocks are in the dense to very dense category, so that the building footprint dominates the land surface and leaves limited open space. This condition is further reinforced by the high building density, which indicates that most of the land has been “locked” into buildings, leaving little flexible space for rearrangement, functional adaptation, or the addition of green open space.

On the other hand, FAR, which is generally still far below the maximum provisions, shows that vertical intensity can actually be increased in a controlled manner, so there is an opportunity to shift some of the growth from horizontal to vertical in order to reduce pressure on the land base. The level of compliance with spatial utilization in Pasar Jambi Subdistrict is still not optimal, as indicated by the high building density, the incompatibility of existing BSLs, and the lack of green open spaces in Pasar Jambi Subdistrict. Overall, the combination of high BCR, potential for increased FAR, low GCR, numerous BSL violations, and building density that has exceeded half of the block area illustrates high but unbalanced spatial utilization intensity. The high building density identified requires a special planning strategy, so that as a policy consideration, ISU management techniques such as the use of land use zones can be applied. This mechanism can be used as an instrument to balance building density with environmental sustainability, thereby providing additional incentives for building intensity for developers who provide green open spaces or public facilities.

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