URBAN LATENT TRANSITION INDEX (ULTI): MAPPING VACANT LAND TRANSFORMATION POTENTIAL IN THE GUATEMALA CITY METROPOLITAN AREA

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ABSTRACT

The Urban Latent Transition Index (ULTI) is a novel spatial tool designed to identify and classify vacant land within the Guatemala City Metropolitan Area based on their potential for urban transformation. Moving beyond traditional approaches that often prioritize central areas, ULTI incorporates accessibility, land price, land cover, and traffic intensity into a composite index, applying K-Means clustering to reveal spatial patterns of latent transition. The results demonstrate that while central zones with higher land value and greater connectivity exhibit strong transformation potential, several peripheral areas also emerge as active transition zones with distinct behavioral profiles. This differentiation underscores the heterogeneous nature of urban change across the metropolitan landscape. By capturing these varied dynamics, ULTI redefines urban vacancy as a latent opportunity for sustainable and inclusive planning; especially in fragmented contexts of developing countries where data infrastructure is limited.

Key-words: *Urban Transformation; Vacant Land; Latent Transition Index (ULTI); Spatial Analysis; Geostatistics.*

1. INTRODUCTION

Urban transition refers to the dynamic processes of spatial change that transform intermediate areas between urban and rural zones, shaped by market pressures, accessibility, connectivity, and territorial appropriation. Unlike static approaches that classify land as either urban or non-urban, this notion acknowledges functional, institutional, and ecological instability that gives rise to hybrid landscapes in constant reconfiguration (Hölscher & Frantzeskaki, 2021; Watson, 2009). In such spaces, transition is not only physical but also political and social, as it responds to both capital-driven logic and informal urbanization processes. In the case of Latin America, and particularly Guatemala, these transitions often occur without formal planning, making them difficult to detect through conventional methods.

Within this framework, the notion of urban latency provides a forward-looking interpretation of territory. As Németh and Langhorst (2014) and O'Callaghan (2024) explain, latency does not imply an absence of use but rather an embedded potential: a state of anticipation in which certain conditions accumulate and may trigger transformation. This perspective is particularly relevant for vacant land, which can generate negative impacts while also containing opportunities for future development. Research highlights that vacant parcels can reduce property values, fragment communities, and delay service provision (Inostroza, 2017; Kim & Newman, 2021; Lee & Newman, 2019; Newman & Lee, 2019), as well as negatively influence neighborhood property values and create localized disamenities (Noh et al., 2021). At the same time, indicators such as land price, proximity to the urban core, traffic intensity, and land cover composition act as indirect signals of predisposition to urban change (Lee & Newman, 2017; Song et al., 2020), positioning vacancy not merely as a void but as a latent element within broader urban transformation dynamics (Rahman et al., 2020).

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Nevertheless, existing indices often leave gaps in identifying where transition pressure is most acute. For example, indices such as the Urban Liveability Index (Higgs et al., 2019) evaluate quality-of-life outcomes but do not address transformation feasibility. Likewise, while theoretical work by Hölscher and Frantzeskaki (2021) emphasizes adaptive governance, it lacks operational tools for detecting sites of transition. In Global South contexts such as Guatemala, limited availability of regulatory and zoning data further complicates this task, reflecting structural challenges shaped by informality and fragmented institutional arrangements. Building on these gaps, the present research introduces the Urban Latent Transition Index (ULTI) as a novel methodological contribution to the study of spatial transformation in metropolitan areas, particularly within developing-country contexts. Unlike traditional approaches that rely on isolated indicators such as distance to the city center or land price (Baba & Asami, 2017; Lee & Newman, 2017; Yamazaki, 2001), ULTI integrates multiple spatial, economic, and infrastructural dimensions into a unified and scalable framework, consistent with recent calls for comprehensive and context-sensitive analytical tools (Naghibi, 2024; O'Callaghan, 2024). One of its core innovations is the combination of diverse indicators such as accessibility measures (distance to the city center and travel time), land market dynamics (price per square meter), traffic intensity (flows of light and heavy vehicles), and land use composition (forest, crops, pasture, water) into a single analytical model. These variables collectively provide a holistic representation of the pressures and opportunities shaping transition readiness.

A further methodological strength of ULTI lies in its continuous scoring system. Rather than relying on binary or categorical classifications, the index assigns normalized values ranging from zero to one, which facilitates nuanced spatial comparisons and prioritization of sites according to relative transformation potential. The use of Min–Max normalization ensures comparability among heterogeneous variables (measured in different units such as quetzales, kilometers, minutes, vehicle counts, and percentages) and prevents variables with large ranges, such as traffic flows, from dominating the analysis. This design enhances interpretability, supports longitudinal monitoring, and is compatible with spatial clustering. Indeed, the integration of K-Means clustering strengthens the analytical framework by grouping vacant land into zones of similar transformation potential. These spatially explicit typologies, built on geographic coordinates and ULTI scores, can be visualized against development patterns, while distance buffers and geospatial overlays enhance the identification of transition gradients and potential priority zones.

The objective of this research is to construct and apply the Urban Latent Transition Index (ULTI) as a spatial analytical tool that integrates variables related to accessibility, land use morphology, traffic intensity, and land market value. The purpose is to identify, classify, and evaluate vacant land in the Guatemalan City Metropolitan Area according to its potential for urban transformation, and to interpret spatial patterns that reflect varying levels of transition readiness. The hypothesis guiding this study is that vacant land with shorter travel times, higher land prices, lower ecological constraints, and greater traffic intensity presents significantly higher latent transition potential than lands located in peripheral or environmentally constrained areas, as measured by the ULTI score.

2. STUDY AREA

This study is grounded in the context of the Guatemala City Metropolitan Area (GCMA), functionally defined by Carvajal and Argueta (2025). The GCMA is a rapidly expanding Latin American region that faces spatial and institutional challenges shaped by limited coordination, unequal infrastructure provision, widespread informal urbanization, and ecological constraints such as ravines and steep slopes. Despite these limitations, it remains Guatemala's principal urban center, concentrating over four million inhabitants and serving as the nation's political, economic, and cultural core. Vacant land is here defined as urban or peri-urban parcels that are unbuilt, abandoned, or used only for temporary functions such as informal parking or open storage, without permanent residential, commercial, or institutional uses. Lands were considered if they exceeded 200 m^2, following thresholds commonly applied in land vacancy studies (Yamazaki, 2001; Song et al., 2020). This definition excludes greenfield agricultural areas in continuous production but incorporates land that, due to location and context, demonstrates latent potential for urban transition. While anchored to the GCMA boundary, the analysis also considers adjacent areas when their proximity and linkages suggest metropolitan relevance.

3. DATA AND METHODS

3.1. Methodology

To develop the Urban Latent Transition Index (ULTI), we constructed a comprehensive dataset of vacant land within the Guatemala City Metropolitan Area. The primary data on vacant land was collected directly by the authors through field surveys and georeferenced mapping campaigns (2023–2025). Complementary variables were obtained from the following sources: (i) land price data compiled from real estate companies, appraisal reports, and market platforms operating in Guatemala (2023–2025); (ii) distance to the urban center and travel time estimated using the Google Maps API (2024–2025), which captured both Euclidean distances and network-based accessibility; (iii) traffic intensity data (light and heavy vehicles) provided by the Unidad de Conservación Vial and the Ministry of Communications, Infrastructure and Housing (CIV, 2024), which report traffic volumes along metropolitan road corridors; (iv) land cover classifications (forest, crops, grasslands, and water) processed from Landsat 8 Operational Land Imager (OLI) imagery supplied by the United States Geological Survey (USGS, May 2023); and (v) administrative boundaries and base maps adapted from Carvajal and Argueta (2025). Each land was georeferenced using the WGS 1984 coordinate system, enabling spatial analysis, clustering, and visualization.

Fig. 1 displays a geospatial map showing the distribution of vacant land within the Guatemala City Metropolitan Area. Each black dot represents a registered vacant land, revealing a high concentration across the urban and peri-urban zones that span multiple municipalities in the departments of Guatemala, Sacatepéquez, and parts of El Progreso, Escuintla, and Santa Rosa. The clustering pattern highlights areas with significant land availability or vacant land within the metropolitan fabric.

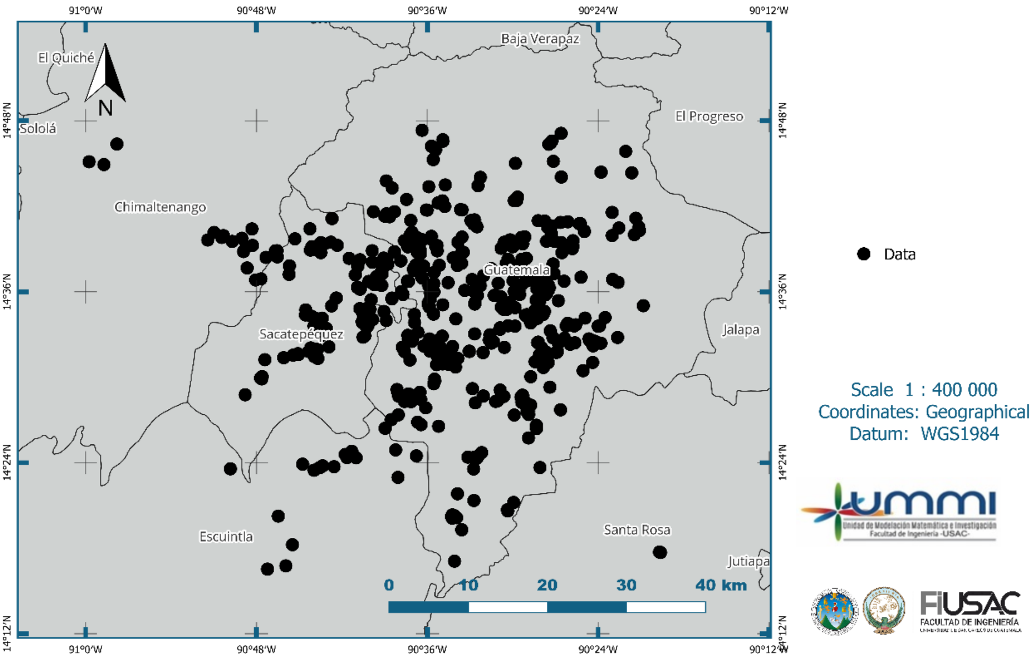

Fig. 1. Spatial Distribution of Data Collection Points in the Guatemala City Metropolitan Area.
Data source: Own field survey and database of vacant land collected by the authors (2023–2025).

Within the Guatemala City Metropolitan Area, **Fig. 2** shows the spatial distribution of vacant land using concentric rings extending from the urban core, delineating zones at 5, 10, 15, 20, and 25 kilometers. This visualization emphasizes the transitional urban peripheral zone, located roughly between 10 and 20 kilometers from the center, where development dynamics are most pronounced.

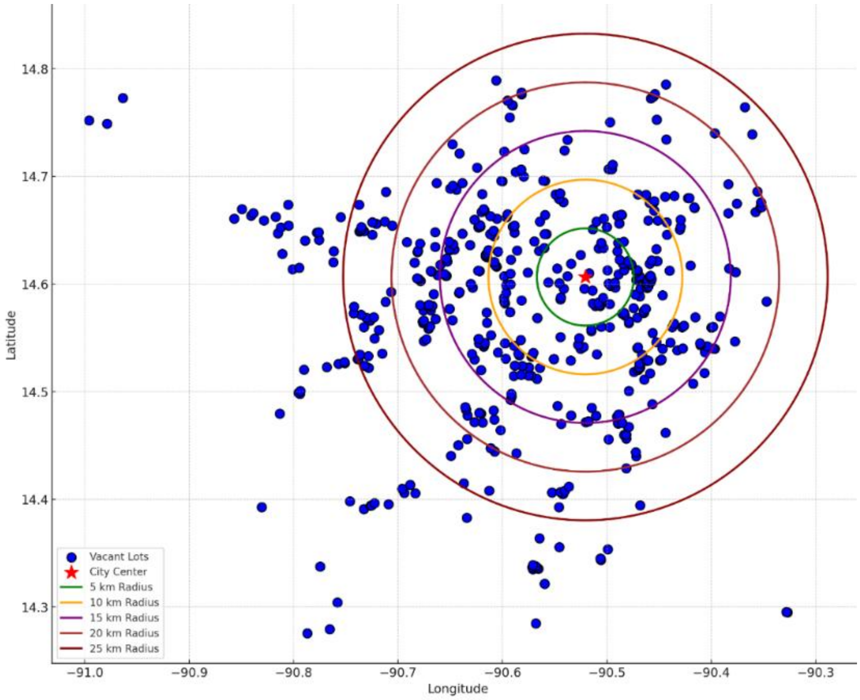

Fig. 2. Spatial Distribution of Vacant Land Around Guatemala City Center with Distance-Based Influence Zones. *Data source: Authors' own field survey and georeferenced database of vacant land (2023–2025)*

To reflect the intensity of urban activity, we included traffic volume data, distinguishing between light and heavy vehicle flows at nearby transport corridors. This indicator serves as a proxy for commercial activity, accessibility, and infrastructure demand. In parallel, we incorporated land cover classifications (forest, crops, grasslands, water) by processing Landsat 8 imagery (USGS, May 2023) through supervised classification techniques. Each land was georeferenced using latitude and longitude coordinates, enabling spatial analysis, clustering, and visualization.

ULTI was designed as a composite spatial index that quantifies latent pressure for urban transformation. It integrates indicators related to urban flow, proximity to the metropolitan core, market signals, and ecological resistance. Specifically, parcels with high traffic volumes, shorter travel distances, elevated land prices, and lower percentages of forest and pasture were assigned higher scores. Because these indicators are measured in heterogeneous units—such as quetzales per square meter, kilometers, minutes, vehicle counts, and percentages—it was necessary to apply a normalization procedure to ensure comparability and balanced influence across variables.

To normalized, the Min–Max normalization (Ahmad et al., 2014) was used, which rescales each variable X to a standardized range between 0 and 1 according to the expression:

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}}$$

where X' is the normalized value, X is the original observation, and X_{min} and X_{max} are the minimum and maximum values of the variable within the dataset.

This transformation preserves the relative distances between observations and maintains the original distribution shape, unlike other methods (e.g., z-scores) that assume normality. By constraining all indicators to the same scale, Min–Max normalization avoids the problem of dominance by variables with large numerical ranges (e.g., traffic counts in thousands versus percentages of land cover). This approach ensures: (i) direct comparability across spatial, market, and environmental indicators; (ii) interpretability of ULTI values as degrees of transformation potential, ranging from 0 to 1; and (iii) balanced contributions in the clustering algorithm, given that K-Means relies on Euclidean distances.

To interpret the spatial distribution of transformation potential, we applied a K-Means clustering algorithm that used both geospatial coordinates and ULTI scores. This method enabled us to group parcels with similar characteristics into distinct transformation typologies. We initially classified the study area into three general clusters (central, transitional, and peripheral) and then refined the analysis into a five-cluster model to capture finer-grained variations. These clusters reveal spatial patterns and allow for the identification of high-priority zones for urban reinvestment or policy attention.

The results were visualized using Python libraries (GeoPandas, Matplotlib). We generated thematic maps displaying spatial clusters, distance rings from the urban core, and convex hulls enclosing cluster boundaries. Additionally, land price gradients were mapped to detect economic patterns associated with transformation potential. These visual tools make the complex relationships in the data more interpretable and actionable for urban planners, policymakers, and stakeholders.

3.2. Theorizing the Variables of the Urban Latent Transition Index (ULTI)

The ULTI is grounded in theoretical recognition that vacant land can act as indicators of urban transformation. Rather than seeing vacancy solely as a sign of decline, ULTI interprets these spaces as thresholds of change. This approach reflects current urban studies literature, which frames vacancy as a condition with latent potential for regeneration and reintegration into the urban fabric (Németh & Langhorst, 2014; O'Callaghan, 2024).

1. Accessibility and Distance Variables: Travel Time and Distance to Center Travel time and distance to the urban core are key indicators of spatial centrality and accessibility. These measures affect land desirability and are often correlated with transformation potential. Lee and Newman (2017) argue that central areas are more likely to attract investment and redevelopment. Similarly, Baba and Asami (2017) and Yamazaki (2001) emphasize that areas close to dense urban centers often experience stronger economic activity and land value appreciation. Accessibility also reflects infrastructure provision and connectivity, both of which are vital for transformation, particularly in peri-urban areas (Naghibi, 2024).
2. Land Use and Morphological Structure: Crops, Forest, Pasture, Water Land cover types serve as indicators of a parcel's environmental function and development constraints. The ULTI includes variables such as forest, crops, pasture, and water to assess ecological resistance or capacity for transformation. Naghibi (2024) note that land cover is a proxy for environmental resilience, and areas with significant forest or water presence may face restrictions despite their locational advantages. Meanwhile, Lee et al (2018) argue that morphology plays a key role in shaping urban expansion trajectories.
3. Traffic Intensity and Urban Flow Traffic data provides insight into the functional role of each area within the urban system. High traffic volumes indicate vibrant activity and accessibility, signaling readiness for land use intensification. As Higgs et al (2019) and O'Callaghan (2024) explain, traffic corridors are often aligned with commercial growth. In areas where formal planning data is scarce, traffic flow serves as an indirect but valuable proxy for spatial transformation. Owusu-Ansah (2018) also highlights how traffic patterns often reflect informal dynamics and bottom-up urbanization processes.
4. Land Price: Speculative and Institutional Value Land price represents both market perception and institutional interest. In contexts with limited planning data, price acts as a synthetic

indicator capturing economic anticipation and development constraints. Lee and Newman (2019) and Yamazaki (2001) suggest that land prices reflect accessibility, desirability, and speculative expectations. O'Callaghan (2024) further points out that in fragmented governance systems, market signals may precede formal policy action, making price data a critical tool for early-stage identification of transformative zones.

The variables incorporated (**Table 1**) into the Urban Latent Transition Index (ULTI) reflect a multidimensional framework for assessing the transformation potential of vacant land. Land price serves as a proxy for speculative demand and urban integration prospects, supported by Song et al (2020) and Yamazaki (2001). Distance to the urban center and travel time capture both static and dynamic dimensions of accessibility, essential for understanding spatial centrality and infrastructure reach, as emphasized by Baba and Asami (2017) and Lee et al (2018). Traffic intensity further enriches this dimension by indicating functional pressure and mobility relevance (Higgs et al, 2019; O'Callaghan, 2024). Environmental constraints are integrated through forest cover and land use typologies such as crops, pasture, and water bodies, which differentiate ecological resilience and productive underutilization (Naghibi, 2024; Rahman et al, 2020).

Table 1.

Empirical Foundations of the Urban Latent Transition Index (ULTI): Variable Selection and Supporting Studies.

Variable	Role in ULTI	Data Source	Justifying Literature
Land Price (per m²)	Serves as a proxy for market demand, perceived land utility, and speculative or institutional value. Higher prices often anticipate future urban integration.	Compiled from real estate companies, appraisal reports, and market platforms (2023–2025).	Yamazaki (2001) links land price to transformation triggers; Song et al. (2020) identifies speculation and insufficient investment as drivers of vacant land.
Distance to Urban Center	Indicates spatial centrality. Proximity to city centers correlates with access to services and infrastructure, increasing likelihood of development.	Calculated from parcel coordinates using Google Maps API (2024–2025).	Baba & Asami (2017); Lee & Newman (2017); Naghibi (2024) support centrality as a key transformation factor.
Travel Time	Adds a dynamic layer to accessibility by considering network and congestion effects beyond physical distance.	Estimated using Google Maps API travel time data (2024–2025).	Lee et al. (2018) use travel time as a critical metric of accessibility and land development viability.
Traffic Intensity	Reflects functional intensity of urban space. Heavy and light traffic volumes serve as proxies for mobility demand and infrastructural relevance.	*Unidad de Conservación Vial* and Ministry of Communications, Infrastructure and Housing (CIV, 2024).	Higgs et al. (2019); O'Callaghan (2024); Owusu-Ansah (2018) argue that traffic density can highlight emerging zones of pressure and informal expansion.
Forest Cover (%)	Signals ecological resilience or environmental constraint. High values indicate protected or less suitable areas for urban development.	Processed from Landsat 8 OLI imagery (USGS, May 2023).	Naghibi(2024); Rahman et al. (2020) link forest coverage to transformation resistance and legal-environmental buffers.
Crops, Pasture, Water (%)	Identify existing land uses with varied transformation potential. Crop and pasture areas may reflect productive rural zones or land banking. Water is a strong spatial constraint.	Processed from Landsat 8 OLI imagery (USGS, May 2023).	Song et al. (2020) treats vacant land as agricultural land as latent vacancy; Naghibi (2024) assess such cover types in urban expansion modeling.
Geographic Coordinates	Used for spatial clustering, mapping, and interpolation of ULTI scores. They do not influence transition directly but enable geographical modeling.	Authors' field survey and georeferenced database of vacant land (2023–2025).	Higgs et al. (2019); Lee et al. (2018) geocode parcels for spatial segmentation in clustering-based typologies.

Data Source: Own elaboration based on reviewed literature and the authors' integrated dataset (2023–2025).

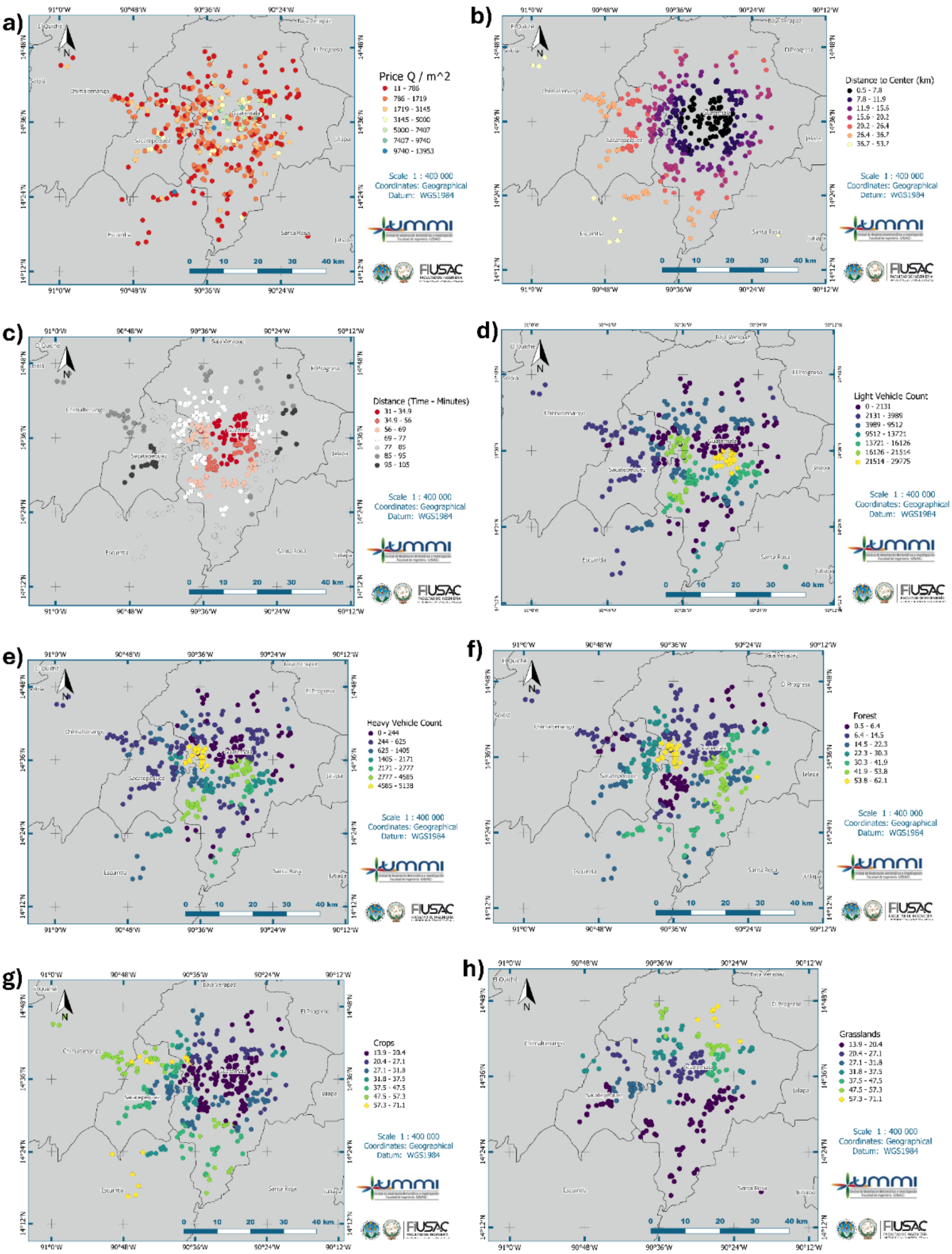

Fig. 3. Spatial Distribution of Key Variables for the Urban Latent Transition Index (ULTI) in the Guatemala City Metropolitan Area. a) land price (in Quetzales), b) distance to the center (in kilometers), c) distance to the center (in minutes), d) light vehicle trips to the center, e) heavy vehicle trips to the center, f) area of forest cover, g) area of crop cover, and h) area of grassland cover.

Data source: Authors' elaboration based on data described in Methods.

Lastly, geographic coordinates support spatial clustering and mapping without directly affecting transition probabilities, enabling the spatial modeling backbone of the ULTI approach (Higgs et al, 2019; Lee et al, 2018). Our findings also support broader methodological arguments that composite indices provide a robust way to integrate heterogeneous urban variables into a single framework (Rahman & Szabó, 2022), especially in data-scarce contexts.

This set of maps (**Fig. 3**) illustrates the spatial distribution of key variables used to calculate the Urban Latent Transition Index (ULTI) within the Guatemala City Metropolitan Area, integrating economic, accessibility, mobility, and land-use dimensions. Variables such as land price, distance to the center (both in kilometers and minutes), and vehicle counts (light and heavy) reflect urban intensity and connectivity, while the presence of forest, crops, and grasslands indicates environmental and rural land-use contexts. The combined analysis of these layers allows the identification of zones with latent potential for urban transformation, particularly those that balance high accessibility and mobility with lower land values and compatible land cover types, offering a comprehensive view of areas likely to experience spatial transitions.

4. RESULTS

Fig. 4 presents the distribution of ULTI scores for vacant land in the Guatemala City Metropolitan Area, ranging from 0 to 1. Higher values, represented by lighter tones, are concentrated in the central and eastern sectors, reflecting zones with stronger transformation potential. In contrast, lower values, indicated by darker tones, predominate in peripheral areas, where transition conditions are comparatively weaker. This spatial variation provides a quantitative representation of differentiated transformation potential across the metropolitan area.

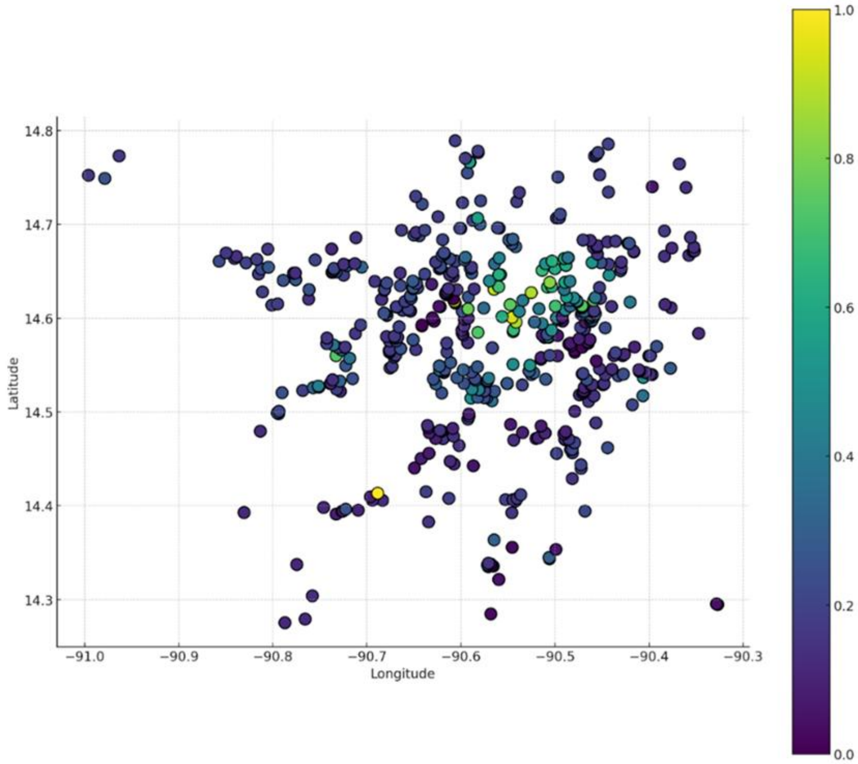

Fig. 4. Spatial Distribution of Vacant Land Classified by Urban Latent Transition Index (ULTI) Scores in the Guatemala City Metropolitan Area.

Data source: Own elaboration based on the variables considered (land price, distance to urban center, travel time, traffic intensity, forest cover, crops, and grasslands).

Fig. 5 presents a reclassification of vacant land into three latent transition categories: low, medium, and high potential. This categorization sharpens the differentiation of spatial patterns by consolidating the underlying variability into interpretable zones. Parcels with high transition potential are concentrated in the central and northeastern sectors of the metropolitan area, where accessibility, land value, and urban activity converge. By contrast, low-potential parcels extend outward into peri-urban and rural zones, reflecting areas where ecological constraints and limited infrastructure reduce the likelihood of transformation. The medium-potential category forms intermediate bands between these extremes, capturing transitional conditions that may evolve under favorable planning or investment strategies.

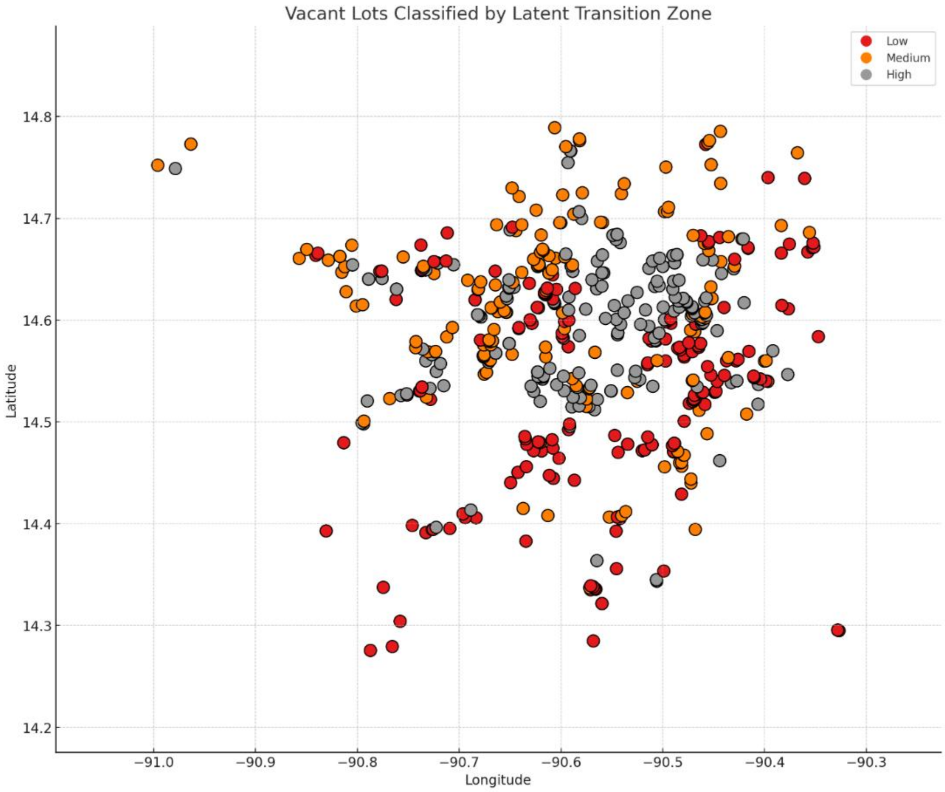

Fig. 5. Classification of Vacant Land by Latent Transition Zones in the Guatemala City Metropolitan Area.
Data source: Own elaboration based on the variables considered (land price, distance to urban center, travel time, traffic intensity, forest cover, crops, and grasslands).

Each cluster reflects a specific combination of variables including accessibility, land value, traffic intensity, and land cover. Cluster 2 (orange) predominates in the southern and peripheral areas, which are characterized by limited connectivity and reduced readiness for transformation. In contrast, Clusters 4 (red) and 5 (purple) are concentrated in the central and northeastern sectors, where stronger urban pressures suggest higher latent transition potential. Clusters 1 (green) and 3 (blue) appear as transitional bands around core activity centers, representing intermediate conditions. This classification demonstrates differentiated spatial typologies and provides a systematic basis for identifying where transformation processes are more likely to occur and what type of intervention may be required in each case.

Fig. 6 presents the spatial cluster analysis of vacant land in the Guatemala City Metropolitan Area, organized into five transition groups. The convex hull boundaries delineate the spatial extent of each cluster and illustrate zones that share similar transition characteristics. The clusters, represented in green, orange, blue, red, and purple, capture distinct patterns of transformation potential derived from land price, accessibility, ecological constraints, and traffic intensity.

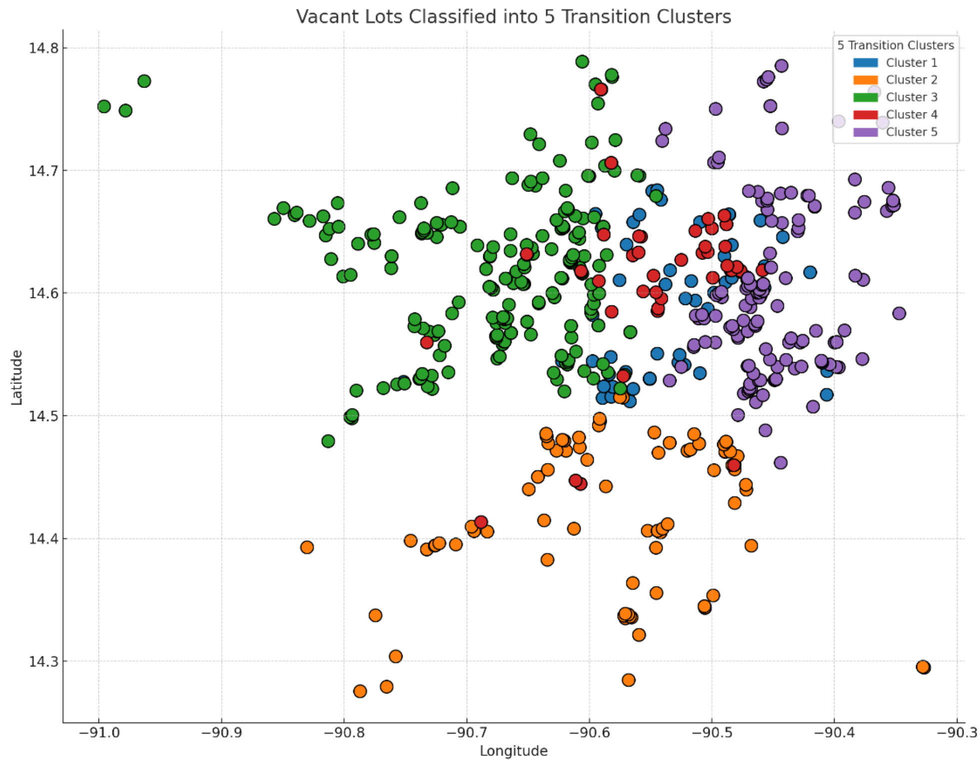

Fig. 6. Vacant Land Classified into Five Spatial Transition Clusters in the Guatemala City Metropolitan Area. *Data source: Own elaboration based on the variables considered (land price, distance to urban center, travel time, traffic intensity, forest cover, crops, and grasslands).*

Cluster 1 (green) extends across the northwest, encompassing dispersed rural and semi-urban parcels with limited integration. Cluster 2 (orange) is more clearly defined in the southern sector, where peripheral conditions constrain transformation readiness. In contrast, Clusters 3 (blue), 4 (red), and 5 (purple) are concentrated in central and northeastern areas, forming compact zones influenced by stronger urban activity and higher transition potential. These patterns reveal how vacant land follows differentiated trajectories of change across the metropolitan area. Beyond their descriptive value, the clusters provide a framework for interpreting the drivers of spatial transformation, thereby setting the basis for the discussion of how land-use dynamics, accessibility, and ecological constraints interact to shape urban transition pathways.

5. DISCUSSION

The convex hull boundaries of the five clustered transition zones, derived from the spatial analysis of vacant land in the Guatemala City Metropolitan Area, are presented in **Fig. 7**. Panel (a) shows the classification of vacant land into five clusters, each enclosed by convex hull perimeters. Panel (b) abstracts these results into aggregated polygons that emphasize the territorial extent of each cluster. Together, these visualizations reveal not only the discrete geography of each group but also the relational dynamics that emerge where clusters intersect.

A notable feature of this visualization is the overlapping areas among clusters, particularly near the urban center. Rather than interpreting these overlaps as classification ambiguities, they can be understood as transition interfaces that reveal hybrid conditions where multiple urban, environmental, and market dynamics converge. These areas differ both from the consolidated core and the homogeneous peripheries, functioning instead as spaces of uncertainty.

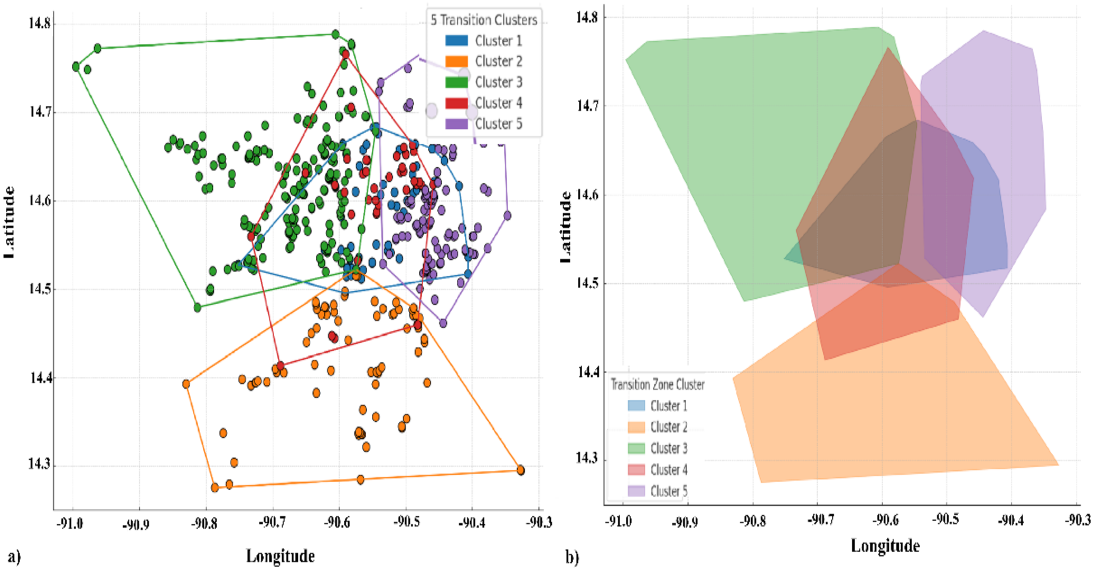

Fig. 7. (a) Vacant land classified into five transition clusters with colored convex hull boundaries, showing the distribution of parcels according to accessibility, land price, traffic intensity, and land cover. (b) Aggregated convex hull polygons representing the spatial extent of each cluster, highlighting overlapping and peripheral zones that define broader transition regions.

Source: Own elaboration based on land price, distance to urban center, travel time, traffic intensity, and land cover variables (forest, crops, and grasslands).

Their recognition introduces a novel perspective to the ULTI framework, suggesting that overlaps themselves constitute distinct transition areas requiring tailored planning approaches.

Table 2 highlights how the interaction of clusters generates distinct spatial interfaces that reveal the tensions of urban transition in the GCMA. Core–Intermediate overlaps illustrate zones where the metropolitan core expands into adjacent intermediate areas, where high land values and accessibility dominate but ecological or infrastructural limits prevent uniform consolidation. These areas point to opportunities for targeted densification if mobility networks and basic services are reinforced. In contrast, Intermediate–Peripheral overlaps capture the expansion frontiers of the city, where semi-urban and rural uses coexist under growing development pressure. These areas embody the dilemma of metropolitan growth, since strategies must carefully balance ecological conservation with controlled expansion to avoid unchecked sprawl.

Table 2.

Typology of Transition Overlap Areas in the Guatemala City Metropolitan Area.

Transition Type	Cluster Interaction	Key Characteristics	Planning Implications
Core–Intermediate Overlap	Cluster 3 with Clusters 0 and 2	High land values, strong accessibility, moderate ecological or infrastructural constraints	Suitable for managed densification and reinforcement of services and mobility networks
Intermediate–Peripheral Overlap	Clusters 0 or 2 with Clusters 1 and 4	Mix of rural and semi-urban uses, moderate accessibility, ecological presence, rising urban pressure	Require balanced strategies between conservation and controlled expansion
Multi-Cluster Intersection	Central overlaps of 3+ clusters	Hybrid environments with competing pressures (accessibility, market demand, ecological restrictions)	Represent critical transition corridors; demand flexible and adaptive planning tools

Data Source: Own elaboration.

Finally, the multi-cluster intersections reveal complex urban corridors where three or more clusters converge. Rather than simple overlaps, these are hybrid spaces shaped simultaneously by accessibility, market demand, and environmental constraints, making them critical arenas for adaptive and flexible planning.

Together, the three categories in **Table 2** show how cluster interactions mark not only geographical overlaps but also the strategic challenges for steering metropolitan transformation. This interpretation underscores that vacant land dynamics in the metropolitan area cannot be reduced to discrete clusters alone. By incorporating the notion of overlaps as transition interfaces, the analysis highlights relational geographies that extend beyond administrative divisions and introduces a critical dimension for urban policy: whether planning interventions reinforce consolidated cores, mediate contested intermediate belts, or adapt to the complexities of hybrid overlap zones.

The classification of vacant land into five transition clusters reveals a diverse spatial and functional landscape across the Guatemala City Metropolitan Area (**Table 3**). Cluster 3 stands out with the highest land price (Q 6,497/m²), short travel time (46.65 minutes), and proximity to the urban core (7.54 km). These attributes, combined with moderate traffic intensity and low ecological resistance, yield the highest ULTI score (0.67), positioning this cluster as the primary candidate for reinvestment and densification.

Table 3.

Descriptive Statistics of Transition Clusters and Key Variables for the Urban Latent Transition Index (ULTI).

Variable	Cluster 0	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Price (Q/m²)	2,998.53	753.41	1,207.95	6,497.01	1,019.46
Distance to Center (km)	7.94	23.27	17.62	7.54	121.59
Travel Time (min)	56.35	75.51	78.46	46.65	71.89
Light Vehicle Count	9,008.74	8,444.57	7,549.63	3,222.29	13,796.73
Heavy Vehicle Count	1,202.11	1,949.37	1,428.49	645.95	2,006.49
Forest (%)	19.61	26.27	24.47	16.71	34.72
Crops (%)	21.66	43.74	38.09	18.36	22.09
Grasslands (%)	21.86	14.50	17.72	20.71	27.97
ULTI (Scaled)	0.38	0.13	0.19	0.67	0.15
Notable Traits	Balanced zone, moderate price, central	Distant, lowest price, high % crops	Mid-periphery, moderate crops/pasture	Urban core, very high price, fast access	Rural outlier, long distance from center

Data Source: Own elaboration based on ULTI clustering calculus (2025).

At the other extreme, Clusters 1 and 4 represent peripheral or rural zones with very low land values (Q 753 and Q 1,019/m², respectively) and long distances from the center (23.27 km and 121.59 km). Despite relatively high traffic volumes, likely associated with industrial or corridor functions, their ecological constraints and limited centrality result in very low ULTI values (0.13 and 0.15). Cluster 2, located in the mid-periphery, exhibits moderate land prices (Q 1,207/m²), longer travel times, and a high presence of crops and pastures. Its ULTI value (0.19) indicates only limited potential for transition under current conditions.

Cluster 0 occupies an intermediate position with moderate prices (Q 2,998/m²), relatively central location (7.94 km), and high traffic volumes. Its mixed land cover and somewhat high travel time (56.35 minutes) constrain its potential, reflected in a moderate ULTI score (0.38).

Overall, the cluster typology reveals a clear gradient of vacant land dynamics. Cluster 3, as the urban core, concentrates the strongest development pressures, while Clusters 1 and 4 highlight peripheral or rural contexts with minimal readiness for transformation. Cluster 0 shows potential consolidation zones if infrastructural bottlenecks are addressed, and Cluster 2 represents transitional lands where rural and urban dynamics overlap. These findings confirm that spatial centrality, land market value, and ecological resistance are decisive variables shaping the likelihood of urban transformation.

This gradient is not unique to Guatemala. Comparable patterns have been documented across the Global South, where high-value, well-connected cores concentrate reinvestment, while peripheral lands remain ecologically constrained or dominated by informal uses. Inostroza (2017) highlights similar dynamics in Latin America, where informal urbanization often emerges in peri-urban zones despite low market value and high ecological sensitivity. Watson (2009) describes parallel tensions in African cities, where centrality and infrastructure access accelerate selective reinvestment while peripheral landscapes are marginalized by regulatory and institutional gaps. Likewise, Song et al. (2020), Lee & Newman (2017) and Lee & Newman (2019) emphasize that vacancy in the Global South frequently embodies both market anticipation and structural exclusion, producing a duality of constraint like that observed in Guatemala City Metropolitan Area. By situating the ULTI results within this comparative context, the analysis reinforces its broader relevance and underscores how metropolitan transitions in the Global South are shaped by uneven accessibility, ecological resistance, and fragmented governance.

6. CONCLUSIONS

The findings of this study confirm and extend key arguments in the existing literature regarding urban transformation, particularly in the context of vacancy and land use dynamics. Previous research has emphasized the importance of accessibility, market value, and infrastructure in determining urban transition potential. For example, Baba and Asami (2017) and Lee and Newman (2017) showed that proximity to central urban areas and high land prices are often correlated with redevelopment and reinvestment. This aligns closely with our results, which demonstrate that the most transformation-ready clusters in the Guatemala City Metropolitan Area are those with shorter travel times, central locations, and elevated land prices. However, while studies like Higgs et al (2019) and Saeed et al (2022) relied heavily on structured urban environments with formal planning mechanisms, the present research demonstrates that a composite index like ULTI can still function effectively in fragmented and informally governed settings. By spatially identifying these opportunities, this study operationalizes that conceptual shift and offers a practical approach to capturing transitional urban dynamics in cities with complex growth patterns and limited institutional coordination.

This research set out to construct and apply the Urban Latent Transition Index (ULTI) to assess the potential of vacant land to undergo urban transformation in the Guatemala City Metropolitan Area. By combining variables related to accessibility, land value, traffic flow, and ecological composition, the ULTI offers a comprehensive way to understand which areas are more likely to transition into active urban use. The findings support the initial hypothesis: vacant land that is closer to the city center, has higher land prices, lower ecological constraints, and more intense vehicle traffic tend to show a much greater potential for transformation.

One of the key contributions of this study is the ability of ULTI to offer detailed spatial insights in a context where formal urban planning tools and consistent datasets are limited. While many urban models have been developed for cities in the Global North or in data-rich Asian regions, this study demonstrates that meaningful urban analysis can still be achieved in places like Guatemala, where informal processes shape much of the city's growth. The results confirm what the literature has suggested: land value, accessibility, and infrastructure demand are strong indicators of where transformation pressure is building. At the same time, this research brings new clarity by organizing this information into clear spatial patterns using clustering techniques.

Theoretical contributions from authors such as Lee and Newman (2019), Németh & Langhorst (2014), O'Callaghan (2024), emphasize that vacant land is not simply leftover or failed space. This study aligns with that view and moves it forward by providing a way to identify and classify these opportunities in practical terms.

Using geospatial tools and data analysis, ULTI helps visualize the city's hidden potential and guides attention to where intervention or investment might make the most difference.

The Urban Latent Transition Index offers a valuable step toward more informed and adaptive urban planning. It helps bridge the gap between academic insight and real-world decision-making, especially in settings where cities grow faster than institutions can plan. ULTI not only highlights where transformation is likely to occur but also offers a replicable framework for understanding urban change in other cities facing similar challenges.

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