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Ejidos, Urbanization, and the Production of Inequality in Formerly Agricultural Lands, Guadalajara, Mexico, 1975–2020

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Abstract: The ejido is an institution of communal land tenure and governance administered by the Mexican government. This paper assesses the current visual appearance of landscapes and implicit land use in ejidal lands on the periphery of Guadalajara, Mexico, using Google Street View (GSV) images tagged for signs of urban distress. Distressed landscapes are associated with the temporal process of urban expansion—newer settlements tend to be more visibly impoverished. Concentrations of vulnerable housing are correlated with encroached-upon ejidal lands in a process that was underway by the 1970s, well before Mexico's neoliberal turn. Ejidos on the urban periphery, created to support agricultural communities during Mexico's radical period of agrarian reform, are now sites of urban sprawl and impoverishment. Nevertheless, these communities remain legally salient as federal entities with respect to the disposition of land. Their presence complicates the historical evolution of land use in the urban periphery in ways that do not fit into classical central place models. We conclude that the presence of ejidos is associated with rapid and chaotic urbanization by migrants and the loss of agricultural capacity in Guadalajara's periphery.

Keywords: land use; land reform; remote sensing; computer vision; urbanization; agriculture

1. Introduction

Guadalajara and its metropolitan region (Área Metropolitana de Guadalajara, AMG) comprise Mexico's second largest urban area. Founded in 1542, Guadalajara featured a pastoral economy dominated by large private estates. Beginning in the 1870s, the city transformed into a vital hub boasting industry, manufacturing, and infrastructure [1]. Modernization attracted increased migration from the hinterland and exacerbated precarity, food insecurity, and land loss. These factors contributed to the outbreak of the Mexican Revolution in 1910, with Guadalajara representing a key national nexus of urban development and migration. This socio-spatial phenomenon intensified after World War II as automobility, industrialization, and migration expanded dramatically. The population of the municipality of Guadalajara grew rapidly after 1960, totaling nearly 1.5 million residents by 2010 [2].

The AMG comprises eight municipalities with over 4.6 million inhabitants located in the central region of the state of Jalisco. The AMG's six core municipalities are: Guadalajara, Zapopan, San Pedro Tlaquepaque, Tonalá, Tlajomulco de Zúñiga, and El Salto. Located in western Mexico, Jalisco is partially situated within the region known traditionally as the Bajío. The AMG occupies the Atemajac Valley, situated at over 1524 m in the Sierra Madre Occidental, and resides within the Lerma-Chapala hydrological basin (see Figure 1). With its conducive climate and soils, the Bajío has historically featured

some of Mexico's richest farmland and is nationally recognized for its agricultural productivity [3]. From 1990–2010, the AMG's population grew at an average annual rate of 1.86 percent, in keeping the the trend seen in Figure 2 below, which shows a take-off in population growth around 1950. The Guadalajara metropolitan area currently ranks second behind Mexico City's metropolitan area in total population among all Mexican urban areas [2].

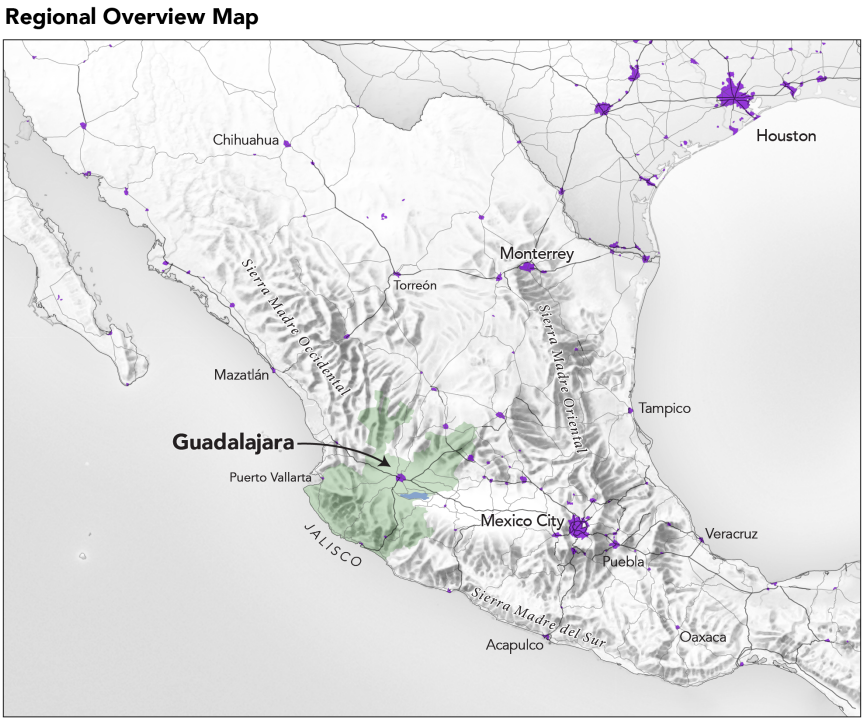

Figure 1. Regional context.

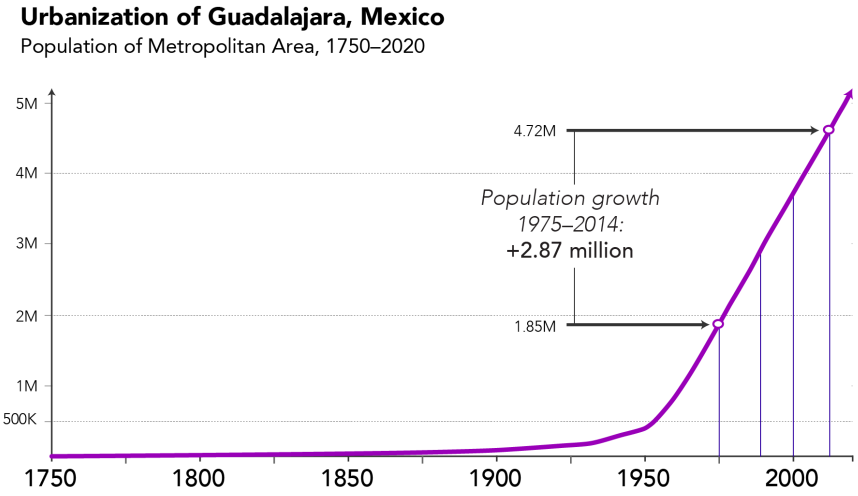

Figure 2. Population growth in Guadalajara.

1.1. The Ejido

The ejido is an institution of communal land tenure and governance with origins in Mexico's 1917 Constitution [4]. Under the ejido system, the state redistributed nationalized land and natural resources to peasant farmers in the decades following the Mexican Revolution (1910–1920). With land ownership vested in the state, ejidatarios possessed usufruct rights, not title, to ejidal lands. President Lázaro Cárdenas (1934–1940) redistributed around 18 million hectares nationwide [5]. This "Agrarian

Reform" spawned federal bureaucracies to administer ejidos, transforming ejidatarios into clients of the state. Kourí (2015) argues that the ejido's reorientation of Mexican space and land tenure was based on preconceptions of rural populations and an imagined indigenous past [6–9]. Due to its flaws, ambiguity of ownership, and corporatist structure, the ejido was plagued by conflict from the outset.

The erosion of ejidal rights began soon after the Agrarian Reform. Miguel Alemán (1946–1952) altered constitutional protections limiting the sale of national lands and size of private landholdings [10]. Under pressure from internal and external economic forces, ejidatarios increasingly rented their lands, which consolidated and effectively alienated them [11]. Ejidal lands—legally prohibited from rental or sale—were frequently expropriated by the state for public works and, beginning in the 1960s, represented the "major source of illegal land supply for low-income housing" in Mexico [12]. In a series of neoliberal reforms beginning in 1991, Carlos Salinas (1988–1994) deregulated the ejido, legalizing the sale or rental of ejidal lands [12]. In 1994, the North American Free Trade Agreement (NAFTA) inaugurated an intense period of land privatization and consolidation throughout rural Mexico.

Guadalajara's ejidos reflect broader national trends. The city's peri-urban ejidos, comprising lands primarily granted before 1940, underwent a sustained process of urban encroachment and government expropriation beginning in 1949 [13]. While many expropriations were officially attributed to public projects, most legalized unauthorized settlements in the city's periphery [13]. Additionally, many of Guadalajara's peri-urban ejidatarios took steps to privatize their lands after the 1991 reforms [14]. This contributed to the patchwork of formally and informally privatized ejidal lands that exist on the AMG's margins today, a patchwork more akin to an archipelago of peripheral/polycentric development of varying degrees of urban density and investment than to classic central place models [15]. This pattern of fragmented urbanization has been identified in other contexts in the Latin American region. Notably, it is reported in the similarly-sized city of Belo Horizonte, Brazil, where Canettieri shows a "fractal" expansion with a concomitant correlation between peripheral urban growth and poverty [16]. Appendix A provides a list of ejidos within the range of the AMG's urban periphery and summary statistics.

1.2. Urbanization, Migration and Land Use Change on the Urban Periphery: Guadalajara's Ejidos in Context

The destruction of the ejido in peri-urban zones has been documented throughout Mexico in the years following the nation's neoliberal turn in the 1980s [17,18]. Because ejidos are ultimately governed by federal law, as well as overlapping municipal and state jurisdictions, the legal disposition of land and the source of changes in land use can be difficult to disentangle. Thus, while legal acts and changes in zoning pertaining to the ejidos in focus are germane to our study, our analysis centers on data sources independent of state institutions. We do not assume that government zoning designations or decrees necessarily correspond to the facts on the ground in the AMG's periphery [19]. Rather, our principal data sources derive from remote sensing (RS) and Google Street View (GSV) panoramas.

Patterns in RS and GSV data can assess both the process and degree of urbanization of Guadalajara's peripheral and formerly agrarian and inalienable spaces. Unlike processes hypothesized in classical central place models [20], wherein growth of the city and transformation of land use is related to markets and land prices [21], the presence of ejidos ringing Guadalajara's perimeter disrupted this spatial model at least up to the 1990s era of neoliberal reform due to restrictions on the sale or rent of common lands. As a result of the ejido's unique legal and political status, former agricultural lands were often replaced by chaotic and *informal* urban housing and ambiguous or overlapping zoning. This produced landscapes of vulnerability and generated clear patterns of impoverishment and inequality on the periphery of the city. These clusters, we suggest, are formed by local politics (local land speculators, community leaders), as well as chance and opportunity (migrant agency). Although Guadalajara is much smaller by comparison, earlier work on Mexico City by Aguilar and his coauthors argued for a similar process of peripheral chaos induced by fragmented and overlapping jurisdictions, which were in turn associated with informality and poverty [22].

Migration is key to urbanization and inequality in the AMG. Guadalajara's inhabitants tripled to nearly 1.2 million between 1950 and 1970 [23]. As Guadalajara's population swelled, neighboring municipalities also experienced precipitous increases. Zapopan's population, for example, grew at an average annual rate of 7.86 percent from 1970 to 1990, reaching one million inhabitants by 2000. During this era transnational migration intensified, especially in western Mexico [24]. These trends were fueled, in part, by Guadalajara's strategic position as an economic and transportation hub linking western Mexico's hinterland to the U.S.-Mexico border. Consequently, impoverished migrants and AMG residents, desperate for affordable housing in a context of extreme competition and rapid urbanization, often sought informal accommodations in legally and socioeconomically vulnerable ejidal lands.

Conversion of ejidal lands on the AMG's urban periphery resulted in lost agricultural capacity in exchange for chaotic, often dense settlement. Much of the built environment there is improvised and informal. De jure zoning designations often generate little or no de facto effects. These areas of the city, owing to their visible impoverishment, represent a shift from relatively sparse settlement with some degree of implicit food security and economic sustainability for inhabitants to dense settlement with little or no local capacity for food production. Furthermore, they feature an implicit pattern of living in the periphery and commuting to jobs in the center, a pattern also identified by Souza in the case of Belo Horizonte, where many residents moved outward from the urban core to the cheaper and often informal settlements on the margins [25]. In sum, the evidence shows a transition from the 1970s to the present wherein a semi-rural hinterland dominated by potentially self-sufficient ejidos became the site of intense urbanization, clusters of inequality, and implicit food insecurity [26,27].

The AMG's pattern differs from urban development driven by private initiative in higher income ejidos, a process observed in other Mexican regions. Schumacher et al. offer key observations in their comparative study of two municipalities in the Puebla-Tlaxcala urban region. Our analysis follows these authors' lead by situating the problem of land use change in terms of "rural-urban ambiguity." According to this view, the struggle for land rights in contemporary urban Mexico centers on these spaces and processes. Additionally, Schumacher et al. provide a useful contrast between two salient forms of urbanization: one exemplified in San Andrés Cholula by a strong government role and planning; the other represented by Santa Clara Ocoyucan, which was urbanized via unplanned private initiative [17]. Our data provides substantial evidence of the latter, privately-led process in Guadalajara, distinguished by a greater preponderance of unplanned and impoverished informal urban settlement in ejidal lands revealed in the GSV imagery. This suggests that aspects of the pattern found in Santa Clara Ocoyucan also exist in certain areas of Guadalajara, but that many of these urbanizing areas are of older vintage and more impoverished aspect.

The transformation of ejidal land use in the periphery of Guadalajara predates legal privatization (e.g., 1991 reform), with major expropriations and formalizations occurring in the 1970s largely driven by urban growth and unplanned settlement by impoverished migrants. Given that scholars have found some evidence of improved nutrition in Mexico following the Agrarian Reform of the 1930s [28], this loss of access to agriculture in the periphery of a large city and concomitant chaotic urbanization may have increased food insecurity in the AMG starting in the 1970s. This hypothesis is supported by the related work of Harner, which showed that traditional public markets were rarely constructed after 1990 and rarely located in or near the most impoverished zones of the periphery [29]. Given that the original purpose of the ejidos was to provide stable access to land for agricultural communities, the historical transformation of these lands into dense and informal urban housing represents a complicated and contradictory legacy. On one hand, rural communities and the spirit of the ejido in these zones have been eroded or erased; on the other hand, these ambiguous spaces have provided much of the room for inexpensive housing for rural to urban migrants.

2. Sources and Methods

Recent studies of rapid urban growth normally use a combination of RS and GIS data [15,17,30,31]. Our analysis adds a third variable in the form of GSV imagery. RS data and GSV imagery allow for independent measures of informal and impoverished urbanization and its degree of association with ejidal lands. The advantage of using data from RS and GSV is that both sources are as close as we can come to direct, unfiltered observation of the built environment without recourse to preconceived categories, such as census definitions or political boundaries. GSV imagery also permits the assessment of visual features that are unrecognizable or invisible in the top-down view of RS, such as constructions' external appearance and small objects, like trash and bordered-up windows. By placing GSV images in the context of urban sprawl, our method adds a temporal dimension to them, complementing the used in the studies mentioned above.

This section provides an overview of our sources and methods (Figure 3). Additional detailed information relating to our methods, as well as links to publicly accessible data files and examples of our own code, can be found on the project website at the Center for Spatial and Textual Analysis. https://web.stanford.edu/group/spatialhistory/cgi-bin/site/pub.php?id=131.

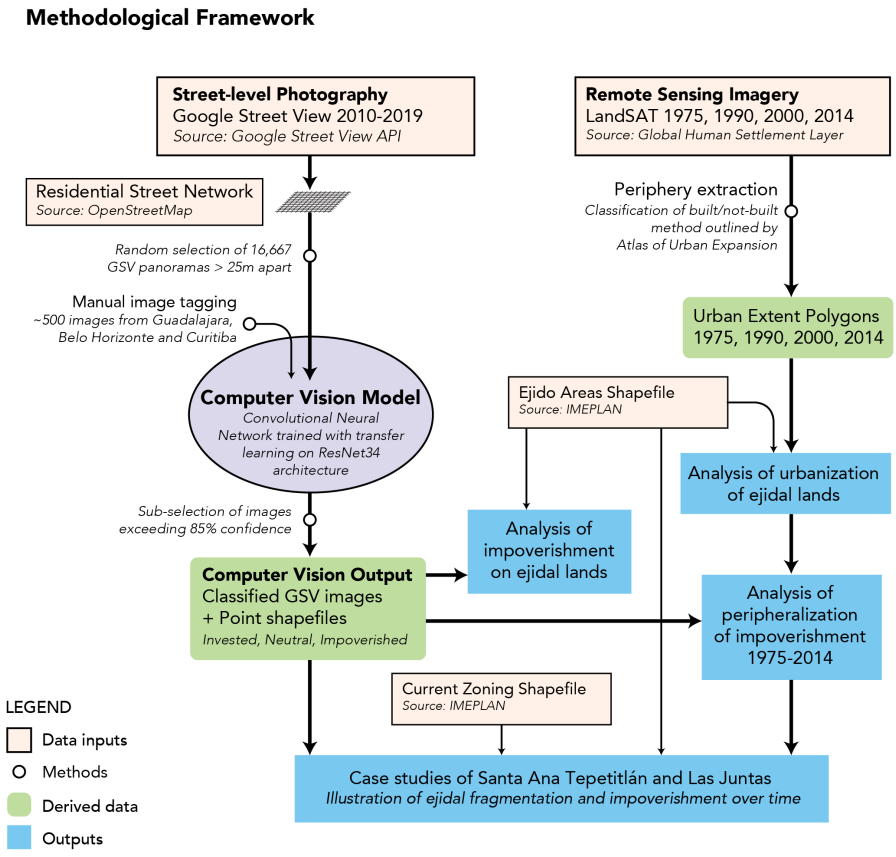

Figure 3. Summary of methodological framework.

2.1. Remote Sensing (RS), Urbanization Levels, and Agricultural Land

The growth of Guadalajara's urban area was measured using the Global Human Settlement Built-up Grid dataset (GHSBUILT) [32]. Derived from Landsat satellite images, this dataset indicates the presence of human built-up structure in a pixel grid of 30-by-30 m. Based on the method developed by the Atlas of Urban Expansion, we calculated percentage of "built" pixels in "as a circle with a one-square-kilometer area and a 584-m radius, roughly a ten-minute walk" [33] for the four years (1975, 1990, 2000, 2014).

The pixels were classified into three categories according to percentage of "built" pixels in their urbanization level: urban (≥0.5), periphery (≥0.25 and <0.5), and rural (<0.25). We rectified the resulting dataset by removing small pockets (smaller than 5 ha) of peripheral zones within the urban core, and vice-versa. This process allowed us to track changes over time in the AMG's urban extent and periphery (Figure 4).

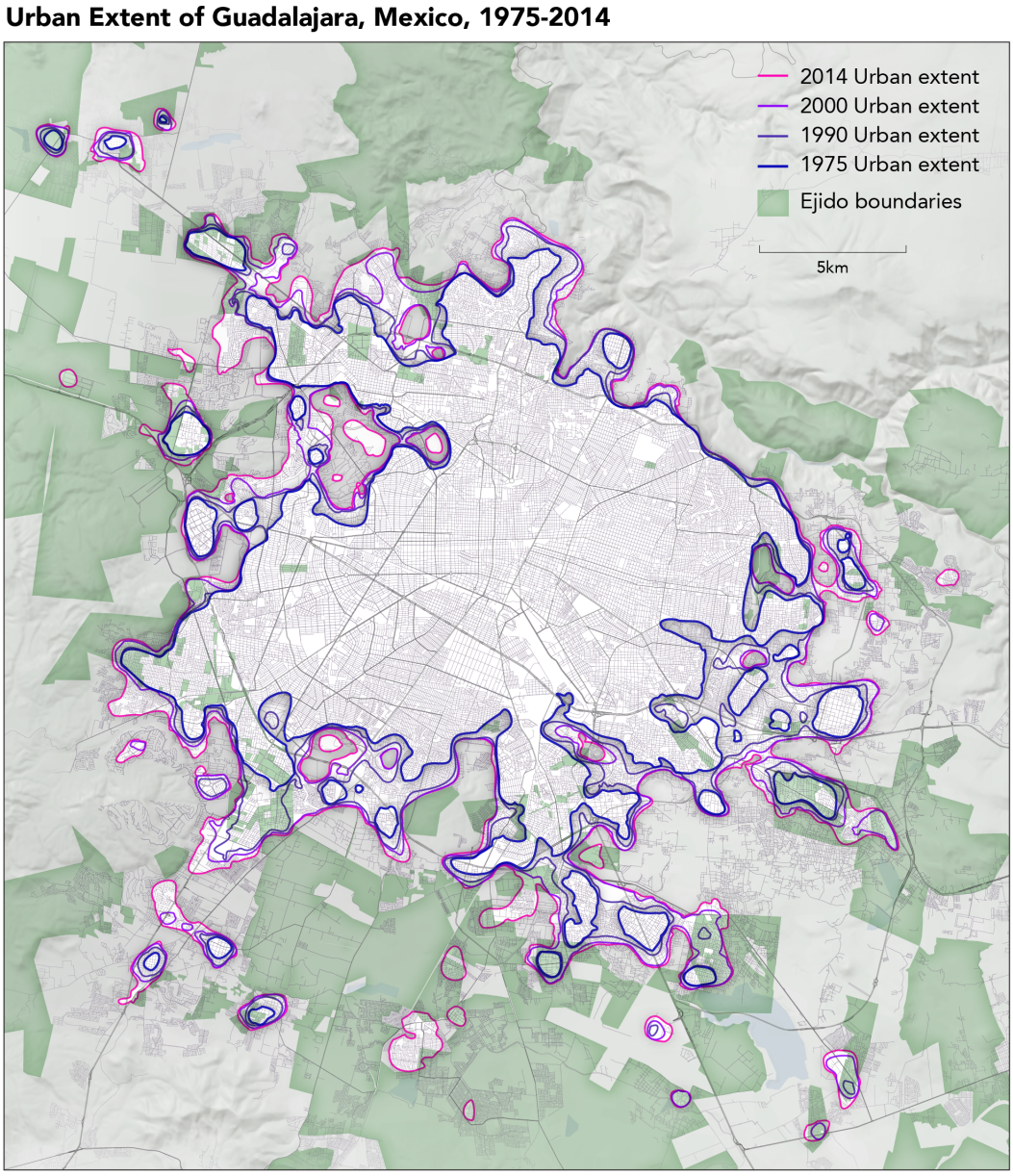

Figure 4. Urban extent over time.

Our method and results can be viewed and understood more clearly when we zoom in to the landscape. The temporal bands derived from RS classifications provide a general sense of the age of the built-up urban environment visible in the underlying contemporary satellite image. Furthermore, the landscape within and beyond the border of the ejido, which is clearly homogeneous at many points along the interface, indicates the manner in which urban encroachment proceeded temporally and proceeded to blur the distinction between the de jure status of ejido land and the de facto morphology of the built environment, while also producing gaps and open zones in the urban periphery.

The historical space of the city (defined by our parameters for core-periphery-rural zones) overlaps, in time, with the present built environment. This layering of space and time generates conditions of fragmentation, informality, and concentrations of impoverished landscapes.

This process can be summarized graphically on a generalized basis, as well, as we can see how formerly rural or peripheral zones transition, over the decades, into fully urbanized landscapes (Figure 5).

As Figure 6 makes clear, there is a gradual but distinctive shift in the origins and destination of land uses over the past four decades in Guadalajara's metropolitan region. In essence, as would be expected in a gradual filling out process, rural landscapes transition to peripheral, and peripheral, partially urban landscapes transition to fully urban. The relative contributions shift over time as urbanization picks up steam and the remaining rural lands are rapidly incorporated into the periphery of the urban core or, to a greater degree than ever before, converted directly in a short span from rural to fully urban in the 2000–2014 period. The periphery, which can be construed as the ambiguous [17] interface between the two other land use regimes, is reproduced and extended over time, encroaching, as we will show, into the hitherto agricultural lands of surrounding ejidos.

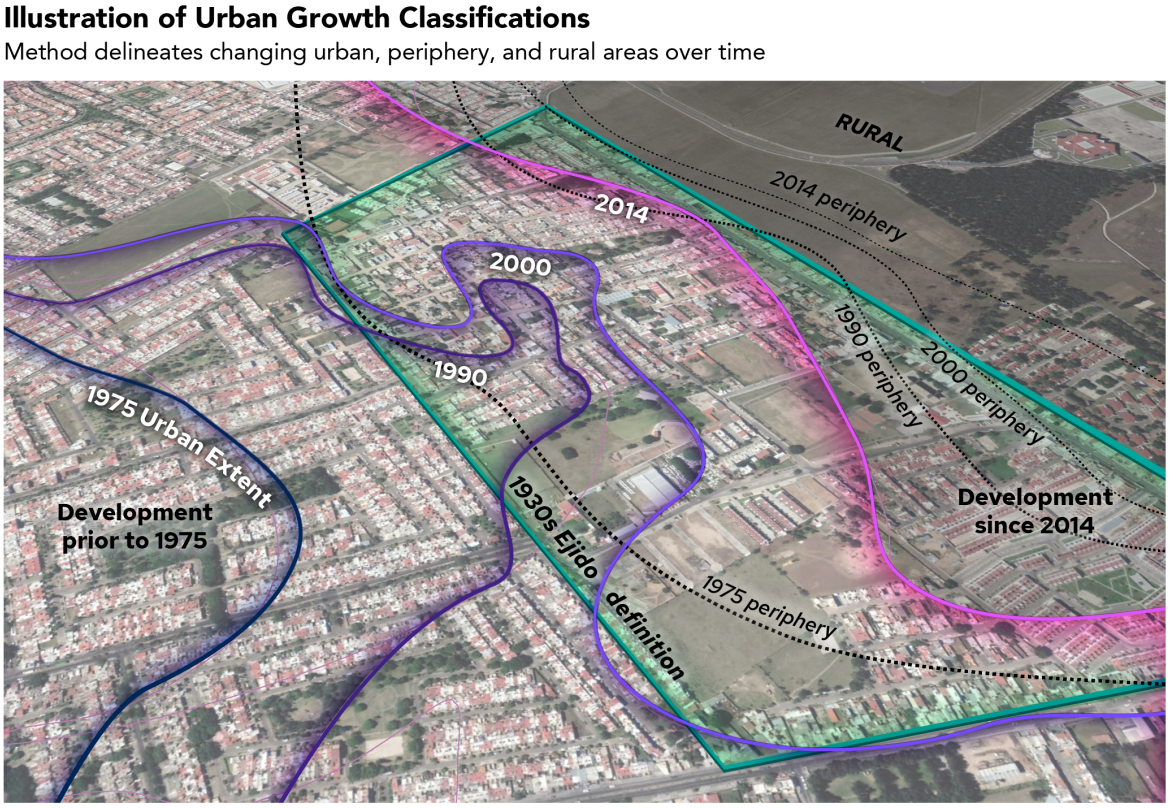

Figure 5. Urban extent over time—close view.

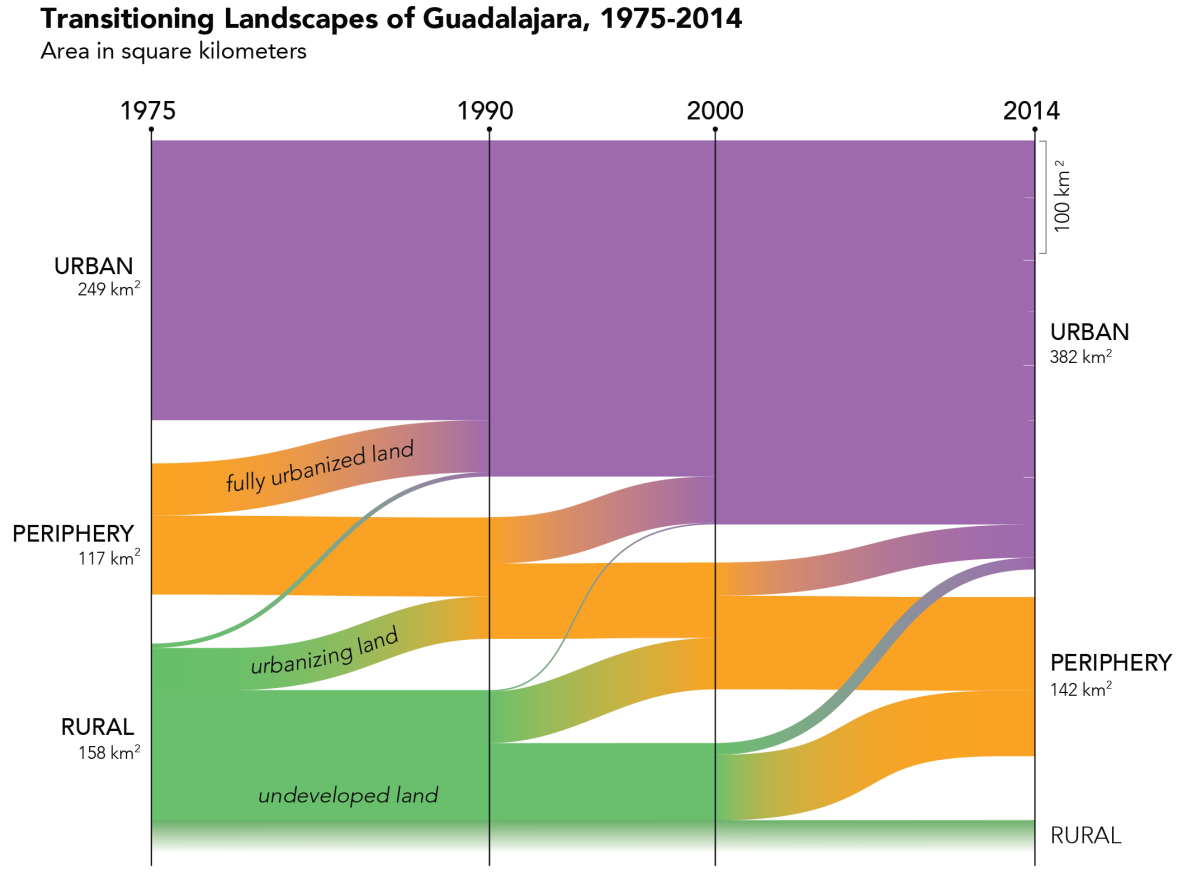

Figure 6. Change in land use.

2.2. GSV and Computer Vision

In order to complement and extend the analysis made possible through the use of RS, we employ street-level imagery sampled from Google's Street View platform, which we analyze using computer vision models. We used Guadalajara's residential street network to select 20,000 points randomly in the urban extent enforcing a minimum distance of 25 m between points to assure uniformity in coverage.We then downloaded one image for each point (chosen randomly from the existing images dating from 2010–2019). Due to limitations in the GSV coverage, some observations did not have a corresponding GSV image. The resulting dataset provided a sample of 16,667 points associated with a GSV panorama.

The images were then analyzed using computer vision, an application of artificial intelligence that handles visual information. Our computer vision models tagged each image based on signs of impoverishment and lack of investment visible in the panoramas. We paid attention to the level of public and private capital invested in the landscape, such as infrastructure and building conditions. For example, landscapes with well-maintained streets and tended gardens were labeled invested; graffiti, makeshift housing, and unpaved roads were considered signs of impoverishment. (See Appendix B for examples of these landscapes.) Our approach to building and implementing this computer vision model with respect to GSV imagery builds upon the small but growing literature on this subject, which has generally attempted to assess urban change, such as gentrification, with reference to Street View data [34–38].

We were initially inspired to look into the use of machine learning and computer vision in order to assess levels of impoverishment owing to recent efforts of Stanford colleagues along these lines using RS data [36]. In our work, the models learned to recognize visual patterns based on a given set of examples or "training data". We created our training data by manually tagging a randomly generated subset of the GSV images multiple times by a group of team members. We then

selected the examples that were mostly agreed upon to be representative of that particular variable. Training images were from different cities in Latin America—Guadalajara, Mexico; Belo Horizonte, Brazil; and Curitiba, Brazil—that we considered visually similar. The decision to include GSV images from other representative cities is part of a larger effort to create a robust model for Latin American cities in general. Although it might decrease the accuracy of Guadalajara's predictions, it allowed us to enlarge the training set and control for the models' capacity of generalization of visual patterns, helping us avoiding overfitting.

We trained a single classification using transfer learning with ResNet34, a state-of-the-art residual convolutional neural network architecture, using fast.ai library [39,40]. Images were classified as "invested", "impoverished", or "neutral". The details of the training sets and models are summarized below. Besides the usual metrics, we adopted two approaches to increase the reliability of the model. First, we only considered for this analysis images tagged with a $\geq$0.85 degree of confidence. Second, because of the accuracy was decreased by mispredictions related to the "neutral" category, we used an alternative measure: misclassification. It refers to cases in which the model predicted the opposite class, not considering the neutral one. As shown below in Table 1, cases in which the "invested" landscape was misclassified as the impoverished (or vice-versa) were very rare when tagged by the computer vision (CV) model.

Table 1. Description of CV models and training sets.

CV Model	Upper	Lower	Neutral	Accuracy	Misclassification
investment	295	200	72	0.655	0.053

Note, also, that we will not be presenting visual examples of the full GSV images, notwithstanding the inclination to let a picture say a thousand words. We consider this an ethical question relating to privacy. This aspect of research relating to GSV imagery is woefully underexamined, although we were able to find a couple of examples of papers that make explicit reference in their titles to issues of privacy [41,42]. Given that we cannot reasonably obtain permission from the residents of the houses visible in the GSV images, we conclude that the metadata and tags (as well as the general spatial patterns they reveal) are usable, whereas the specific images are not. We believe other researchers working with GSV imagery should follow a similar procedure and avoid publishing these images or crop them in order to hide people and obvious identifying features. This is particularly important when referring to the houses and neighborhoods of the poor, of people of color, or of other historically disadvantaged groups. In raising this issue, the authors wish to acknowledge the extraordinary cultural moment in which this paper has been written, as well as to acknowledge that previous studies were written before these concerns may have fully come into focus for researchers. For reference, see Appendix B for cropped examples of GSV landscapes representing the "impoverished" and "neutral" tags, respectively.

2.3. Additional Data

Lastly, we combined these datasets with existing GIS information from a range of public sources. For zoning and land use designations throughout the metropolitan region, we base our analysis on the 2016 area classification provided by IMEPLAN, which can be downloaded from datamx (http://datamx.io/dataset/activity/ordenamiento/). For the present-day boundaries of the ejidos and agricultural communities in the AMG, the data also exists as a shapefile downloadable from the same source as above. The road network for the AMG was accessed from Open Street Map using OSMnx library [43,44].

3. Results and Discussion

For the metropolitan region of Guadalajara, our sample includes 3133 images of ejidal land. There are 1186 GSV images tagged as "impoverished" using the methods described in the previous section—30.94 percent of these images are part of ejidos/zones.

When plotted on a map, the distribution of these tagged images tells an unambiguous story of the peripheralization of poverty in the AMG. By overlaying the GSV points with data from RS, we can identify the time period during which the locations in question first began to shift from rural to urban landscapes. Whereas there are scattered images tagged as impoverished throughout the metropolitan area, most of the points appear in clusters around the periphery of the central city in areas that only became urbanized beginning in the 1970s.

Of the points strongly associated with impoverishment at the level of 0.85 or higher, 641 are within the band of urbanization derived from RS data for 2014. Five hundred and eighty-eight are within the band of 1975 (some overlap with 2014 data). Only 107 of 1186 points fall within the core urban zone that was built up prior to 1975, a result which strongly indicates the importance of timing and historical nature of land use change. An additional 130 are outside either band. In other words, 237 points tagged as impoverished are not in the peripheral growth areas identified by RS. The vast majority of such points, therefore, fall in the zones of urban expansion from 1975 to the present.

3.1. The Urban Periphery and the Ejidos of the AMG

As we have indicated, poverty is produced or extruded at the edge of urban agglomerations. Understandably, the related literature has tended to focus on the dynamic forces emanating from central cities and pushing the poor and working class to the margins. Yet, there is another equally important story to tell. The expansion of Guadalajara reveals a process by which vital agricultural lands and traditional agricultural communities are transformed into poor, often informal housing with little or no visible agricultural potential remaining in the zones of occupation. Much of this urbanization can best be described as occurring through a process of accretion rather than extrusion, as migrants from rural areas and smaller towns arrive on the periphery and find themselves unable to find housing within the incorporated and fully built up urban setting of the city proper [45].

When the GSV points tagged as indicating impoverished urban landscapes are plotted against the territories of the ejidal lands surrounding Guadalajara, we find that 367 (31 percent) of them are within the boundaries of these formerly agricultural areas (Figure 7).

In order to further illustrate the evolution of landscapes in Guadalajara, Figure 8 presents the ratio of GSV images tagged for either "impoverished" or "invested" in over time and according to the underlying classification of the land use regime (rural, periphery, urban). The ratio here is derived by joining tagged observations to a 100-m grid overlaid on the entire metropolitan region. Ejidal lands contain a consistently higher ratio of impoverished landscapes across all land use classifications. In addition, this analysis highlights the way that early disturbances in the rural fabric, that is ejidos that experience encroachment of urbanization in the 1970s and 1980s, appear to lead to much higher concentrations of impoverished landscapes in contemporary GSV images.

3.2. Modeling Changing Land Use with RS, GSV Imagery, and Contextual Spatial Data

Viewed broadly, patterns of land use and urbanization revealed in Figures 7 and 8 raise questions of local versus regional factors, general versus idiosyncratic forces, as well as issues relating to the temporal sequence of change. In order to address these questions and clarify the manner in which these variables and processes interact, regression analysis provides insight into the possible relationship between patterns of urban expansion and the subsequent production of housing vulnerability. We begin with the following nested set of hypotheses:

- The presence of substantial "peripheral" urban growth in a given ejido or community during the 1970s will be associated with a greater number of GSV images tagged as impoverished in the 2010s.

A longer period of peripheral growth produces a greater density of impoverishment. Note that we focus here on the peripheral, which in this context is defined as land use that is neither clearly urban nor clearly rural, and is located at the margin of the unambiguously urban core.

- Peripheral growth precedes and predicts levels of urban consolidation. This hypothesis rests on the notion that urbanization in the ejidos and other peripheral zones of Guadalajara was a gradual and unplanned process rather than the kind of process that would result in rapid and definitive urbanization in a short period of time. As such, this is a story that unfolds on the timescale of decades, not years.
- Density of impoverished GSV images is going to be associated with greater recent measures of urbanization.
- As with the first hypothesis, we also expect that peripheral urbanization in the 1970s will strongly predict major loss of (potential) agricultural land within a given ejido or community. Again, the logic of the argument hinges upon the idea that land use changes are cumulative and possibly compounding over time.

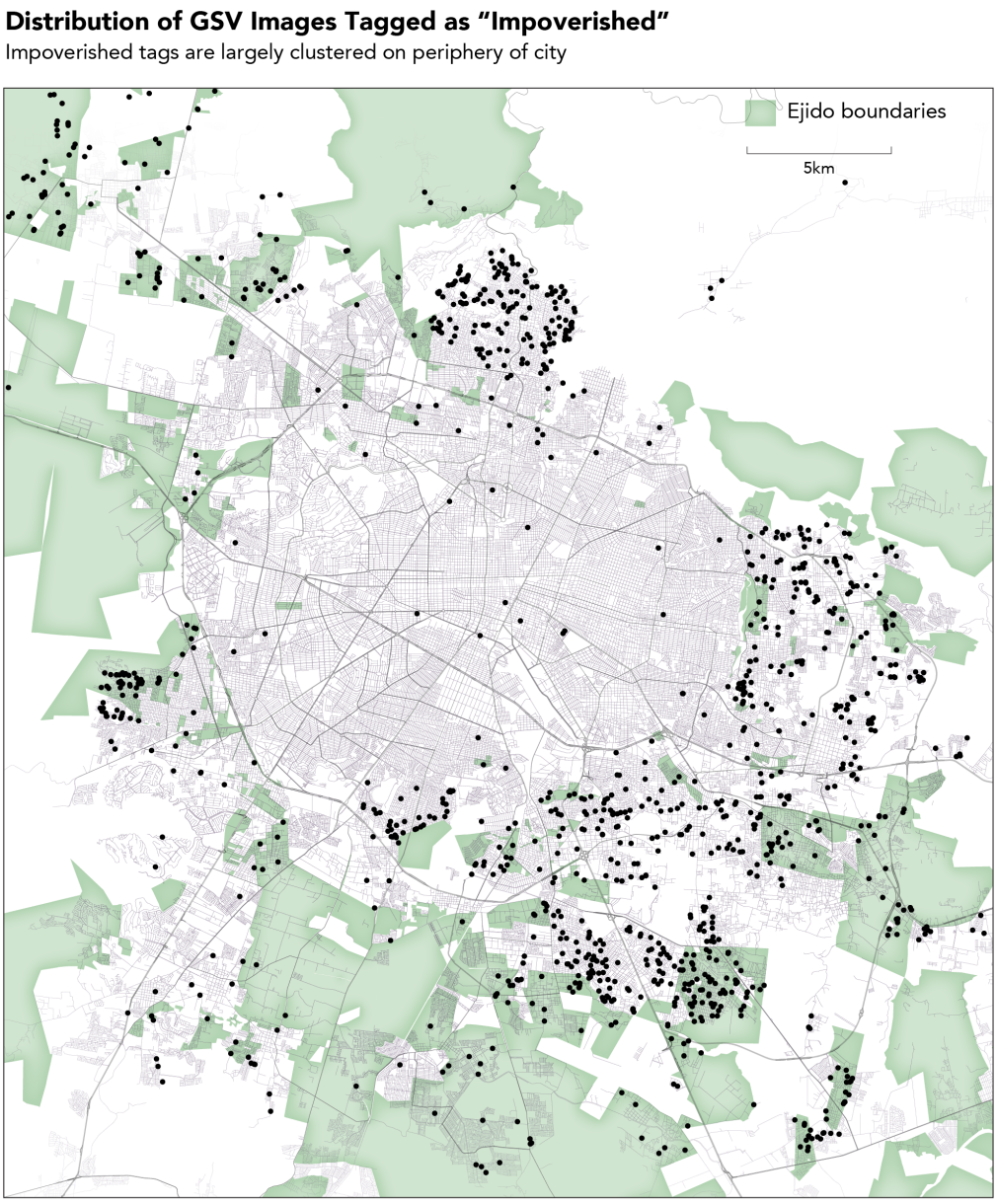

Figure 7. Google Street View (GSV)-impoverished tags.

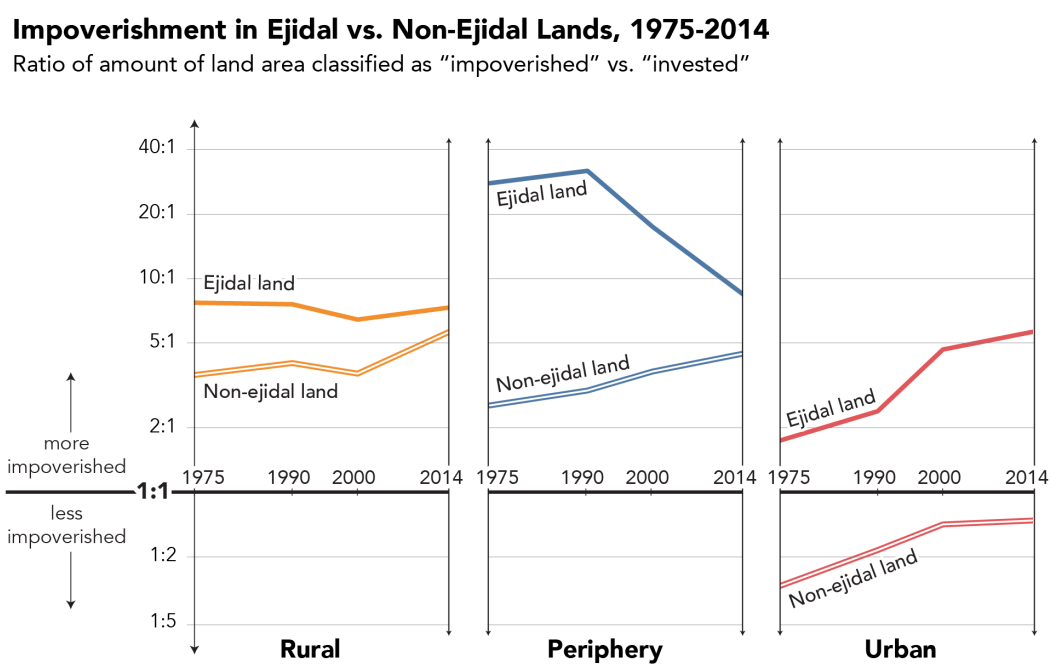

Figure 8. Ejidos and ratio of invested/divested GSV landscapes.

We begin with a simple test of the first hypothesis. The model asks whether the extent of the area within a contemporary ejido that was coded as "peripheral" in our RS data for 1975 can help to predict the presence of impoverished landscapes revealed by GSV images today. The spatial container for these calculations is the ejido.

The dependent variable GSVimp refers to all tagged images denoted at impoverished by our machine learning model at 85 percent confidence. The variable Periphery 1975 refers to the area in a given ejido or government-designated agricultural area in the AMG that we classified as a zone of incipient urbanization (peripheral growth) on the basis of RS data. A simple OLS regression shows that there is a substantial and positive relationship between the early presence of peripheral urbanization and present-day landscapes of impoverishment (Table 2). We take this as plausible confirmation of the intuition behind our first hypothesis. This suggests that there is a deeper history to the impoverished landscapes in Guadalajara than would be immediately obvious either on the basis of the GSV images alone or on the basis of common narratives about the onset and intensity of disruption in ejidal lands during the 1980s and especially the "neoliberal" 1990s.

The analysis in Table 3 confirms our intuition that early histories of peripheral urbanization drive subsequent processes of urban consolidation and explain the variation in the urbanized area of formerly agricultural zones of the AMG. More area in the 1975 periphery translates strongly into more area in the 2014 urban-defined category. Meanwhile, by contrast, in the case of the Periphery 2000 measure, this is negatively associated with the total area in consolidated urban settlement as of 2014, indicating that the process is still in the early phase in the ejidos where such "new" settlement is salient.

Table 2. Landscapes of impoverishment and the historical urban periphery.

GSVimp	Coefficient	SE	t-Value	*p*-Value
Periphery 1975	0.1148	0.0154	7.42	0.000
Constant	1.434			
R2	0.524			
N Obs.	52			

Table 3. Historical peripheries and contemporary urban areas.

Urban 2014	Coef.	SE	t-Value	*p*-Value
Periphery 1975	1.896	0.410	4.62	0.000
Periphery 1990	0.599	0.572	1.05	0.300
Periphery 2000	−0.900	0.316	−2.85	0.006
Constant	14.54			
R2	0.855			
N Obs	52			

The results reported in Table 4 confirm that areas that have become *fully urbanized* more recently are more likely to contain GSV images tagged as impoverished. Where there were already significant urban areas as of 1975 (in contrast to significant peripheral areas), the relationship turns negative, indicating that the oldest urbanized zones in the periphery (as of 1975) have matured to a point where there are fewer impoverished landscapes. The contrast here with the results indicated with respect to the presence of Periphery 1975 is striking. Where urbanization was incipient circa 1975, we see a strong tendency toward the presence of impoverished urban landscapes in formerly agricultural lands.

Table 4. GSV-impoverished and urbanized areas in ejidos.

GSVimp	Coef.	SE	t-Value	*p*-Value
Urban 1975	−0.247	0.050	−4.93	0.000
Urban 2014	0.171	0.024	7.21	0.000
Constant	0.582			
R2	0.647			
N Obs	49			

3.3. Peripheral Urbanization and the Loss of Agricultural Lands in the Ejidos of the AMG

Visual inspection of the current distribution of land zoned primarily for agricultural use, the present boundaries of ejidos, and the location of impoverished GSV tags tells a clear story. Where the urban periphery has expanded since the 1970s it now abuts or encircles the remaining agricultural land. Clear evidence of the fragmentation of ejidos can also be seen in areas where there are a concentration of impoverished GSV tags. On the other hand, it is also evident that areas of urban sprawl and impoverishment are sometimes, though not predominantly, located near the agricultural perimeter, perhaps indicating some residual access to land or the food it produces.

Readers should remember that all of the area bounded in grey polygons in Figure 9 is legally defined as ejidal land or other related agricultural settlements. Historically, starting in the decades prior to the Second World War, all of this area was originally meant to be designated for agriculture, particularly small-scale. Most of the area within the ejidos surrounding the urban core is no longer zoned explicitly for agricultural use.

The arrival of migrants, in increasing numbers from the 1970s onward, shifted the urban periphery into the ejidos located closest to the urban center. GSV tagged images cluster in areas that show significant fragmentation (degradation of ejidal continutity), which, in turn, appear to be areas where agriculture is absent or in the process of encroachment and decline. Example regions are denoted in the map as "areas of fragmentation", where ejidos have been broken apart by expropriation following degradation of agriculture and its replacement by informal housing. On a large scale, this "shattered" urban/rural space corresponds to the concept of urban fragmentation developed in García-Ayllón's recent study of five Latin American cities [46].

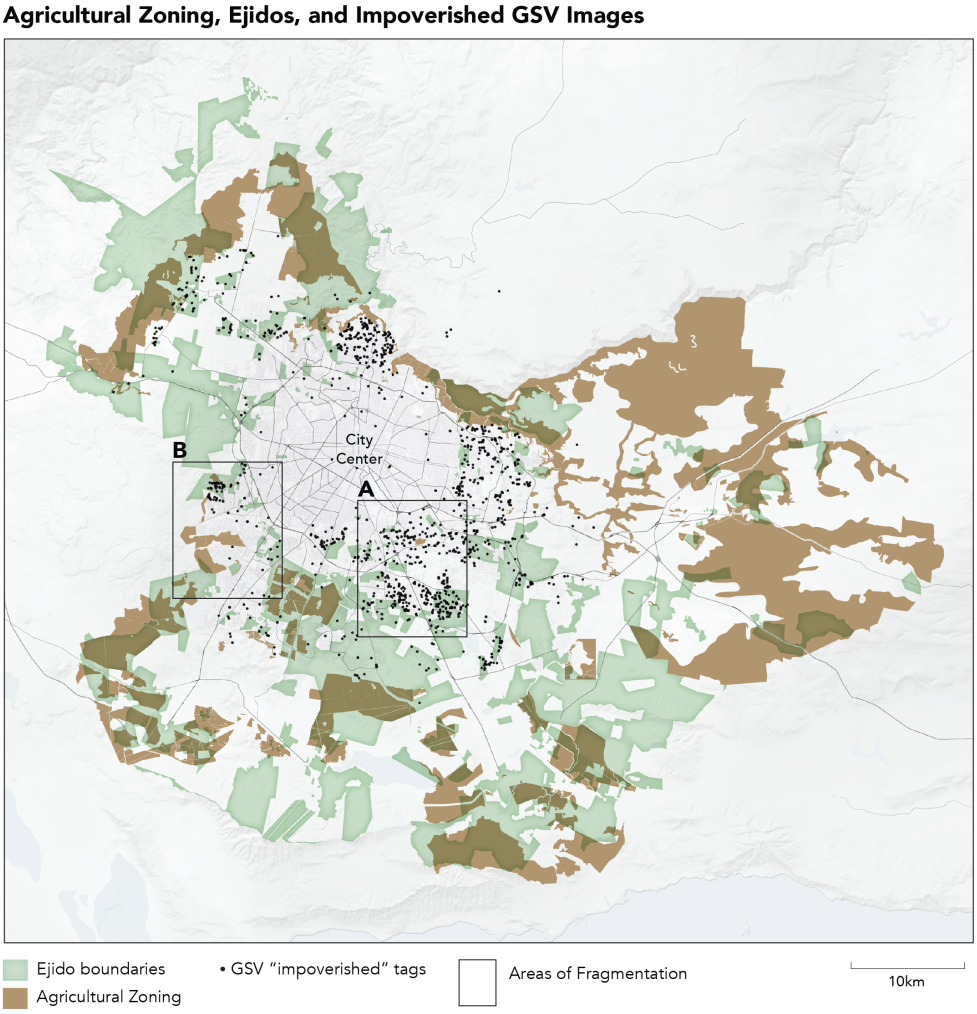

Figure 9. Agricultural zoning, ejidos, and impoverished-GSV images.

The GSV cluster indicated to the southeast of the city center is focused around the ejido of Las Juntas. The cluster indicated on the western edge is Santa Ana Tepetitlán. Both of these ejidos trace their origins to land reforms during the early period following the conclusion of the Mexican Revolution.

The ejido of Santa Ana Tepetitlán was formed in 1924, with 2178 hectares being distributed as of 1926 [47]. The ejido grant was augmented in 1966, suggesting some continued agricultural vitality at this late date, by an increase of 641 hectares [47]. Within a decade of this expansion, the first expropriation of 275 hectares occurred during the Echeverría regime in 1976. The official reason for the federal government's expropriation of ejidal land was to "improve existing [unauthorized] settlements by formalizing and legalizing land tenure through the sale of parcels to residents who currently occupy them and the sale of any unclaimed parcels to third parties, as well as the creation of a reserve of land to fulfill the future planned, sustained growth of the aforementioned communities" (expropriation requested by the *Comisión para la Regularización de la Tenencia de la Tierra*) [48]. As of 1991, the official population of ejidatarios was a mere 456 in a context where multiple expropriations for urban formalization were on the near horizon. The official and nominally agricultural residents were a tiny minority at this point [49]. Two more large expropriations took place in 1992 (344 ha) and 1996 (325 ha), both of which involved the same logic of formalizing urban settlement on the periphery of the city [47]. These expropriations resulted in the loss of about one third of the ejido's total hectares, leaving a gerrymandered remnant with limited agricultural zoning present, according to the AMG zoning plan. The process described here and evident in the combined RS, GSV and zoning data follows the general outline of the logic of migrant incorporation through informal urbanization

described in Hernando de Soto's influential study *The Other Path* [50]. Although de Soto's work has been criticized in the literature, the sequence of invasion, occupation, informal development, and final government recognition as a *fait accompli* is the most reasonable and parsimonious explanation for the fragmentation of agricultural lands in the ejidos surrounding Guadalajara.

The pulverization of Las Juntas tells a similar tale of dismemberment and loss of agricultural land owing to urban sprawl. Founded in 1936 on 859 hectares granted by the Cárdenas regime, Las Juntas began the process of fragmentation via expropriation in the same year, 1976, as Santa Ana Tepetitlán, with a loss of 103 hectares for the purpose of formalizing informal urban settlements [51]. Additional major expropriations for the same purpose, of 224 hectares and 70 hectares, followed in 1993 and 2003, respectively [51].

In order to place these two ejidos and their history of land use change in broader perspective, we collected similar data for an additional eight ejidos distributed around every side of the metropolitan core (sampled ejidos denoted in italics in the data appendix). In this sample of ten communities, we found that four were created between 1917 and 1934, before the major land reform associated with the Cárdenas presidency. Five ejidos were created during Cárdenas's regime (1934–1940), and one was created much later, in 1970. Eight out of ten ejidos in the sample suffered at least one expropriation by the government. Contrary to the idea that these land use changes began after a watershed reform in 1992 during the Salinas administration, our sample indicates that some expropriatons sanctioned by the Mexican government took effect in all eight of these ejidos prior to the Salinas reforms. The reasons given for expropriation ranged from the "formalization" of existing informal settlement in these peripheral zones bounding the metropolitan core, as was the case in Los Ranchitos in 1976, to other forms of expropriation linked to urban growth, such as an airport expansion in El Verde in 1975 [52–54].

Fragmentation of ejidal lands appears clearly when we zoom in to look at the specific cases of Santa Ana and Las Juntas. For instance, the entire middle section of Santa Ana has disappeared in the Figure 10. The upper left and lower right green polygons both belong to the ejido, but most of the land in between is now fully urbanized. In keeping with our findings regarding land tenure regimes and levels of impoverishment, the GSV tags are clearly clustered in or near the two remaining areas of ejidal land. Spaces that have resisted formal incorporation into the urban zone also remain the primary spaces for concentrations of informal housing. A similar, if less striking pattern appears in Las Juntas.

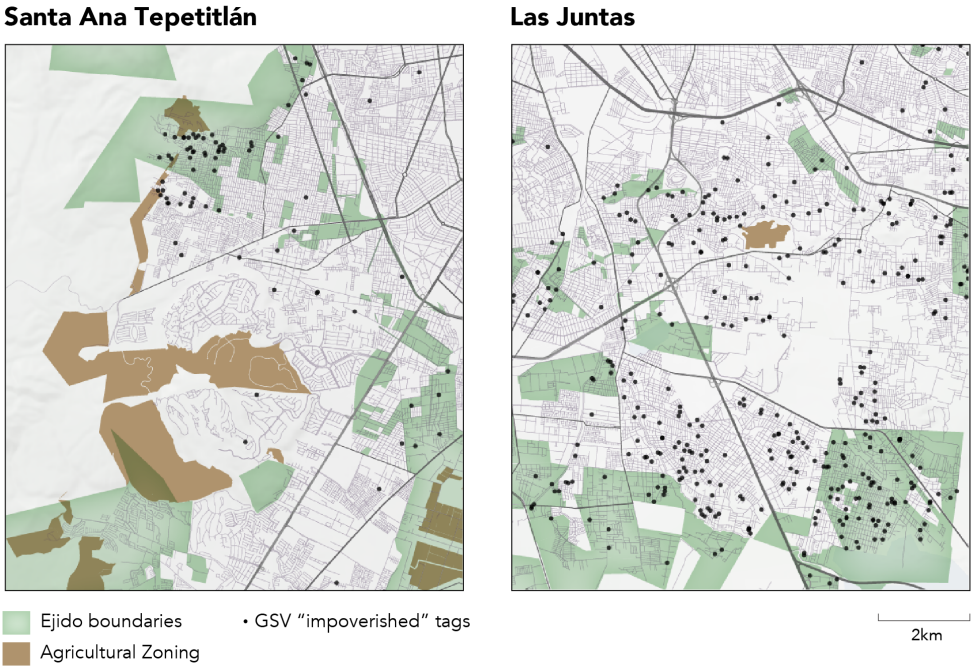

Figure 10. A tale of two ejidos.

4. Conclusions

Writing in 2008, Perramond observed that "the fate of any individual ejido depends largely on its location and socioeconomic context", and that an era of state-led land reform ended in 1992 with market-led reform underway from that point forward [3]. Mexico's long history of struggle for access to agricultural land certainly entered a new phase during the 1990s. The outcomes, as Perramond insists, differed greatly in the aftermath of this watershed, such that no simple story of neoliberal unravelling of the ejidos will suffice to account for the changes observed. Our research compliments and also complicates this interpretation. We find support for the idea that ejidos, even in the same metropolitan region, differed widely in the past and present of their land use. Yet, our research also finds, by pushing the period of analysis back into the 1970s, that these processes of urbanization and expropriation *predate* the supposed 1992 watershed moment of privatization, demarcation, and market-led reform.

The emblematic cases of Santa Ana and Las Juntas (see Figure 10) illustrate our conclusions by highlighting the historical depth in the fragmentation of agricultural land and the informal urbanization of the periphery of the AMG. Historical RS data provide the first clues as to the location and timing of the process of migrant occupation and informal construction. GSV images offer a direct means to observe the conditions of the urban landscape in the present, indicating where impoverished communities have developed in peripheral urban zones overlapping with the historically, culturally, and legally distinct peri-urban ejidos. In the early and decisive phases of occupation, these lands were technically zoned for agricultural use and were not available for legal sale, purchase, or lease. Rather than serve to protect agricultural lands and farming communities, the ejidos appear to have mainly prevented orderly urbanization and investment in urban infrastructure owing to the legal complications of land tenure within their boundaries.

Looking ahead, we see two important avenues for further research. First, along the lines of the suggestions made by Schumacher et al. regarding greater detail in RS, we suggest that GSV imagery will develop into a key independent source of data for high-resolution analysis of land use and housing quality. This will be one more important tool in the toolkit that can be combined with the high-resolution RS data. Second, our study points toward further work in the legal and institutional history of the ejidos of Guadalajara (and Mexico more generally). By pushing back the RS data to the 1970s, we were able to complicate narratives that center the 1990s reforms in land tenure as the primary watershed or causal explanation relating to urbanization in the ejidos. This will mean getting more information on the legal and political maneuvering that is implicated in the earlier period of urban encroachment.

Although we are encouraged by the results of this exploratory analysis centering on the use of GSV images in conjunction with other more conventional sources of data concerning land use, we note that there are limitations and challenges posed by this approach, especially in regard to extending our findings beyond the Mexican case. The unique nature of Mexico's land reform and the complex history of the ejido as a legal and social entity limits the degree to which these findings regarding urban change can be compared with other world regions. Moreover, as other authors have also shown, there is a diversity in the historical pathways of nearly every individual ejido (there are 1000s of them), meaning that even within the Mexican case, it will be a challenge to construct a robust model of urban change and the generation of informal and impoverished housing. In spite of these challenges, the promise of this new kind of visual data coupled with advances in computer vision and AI make for a compelling research agenda.

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Abbreviations

The following abbreviations are used in this manuscript:

AMG	Área Metropolitana de Guadalajara
INEGI	Instituto Nacional de Estadística, Geografía e Informática
IMEPLAN	Instituto de Planeación y Gestión del Desarrollo del Área Metropolitana de Guadalajara

Appendix A. Ejidos in the Periphery of the Guadalajara Metropolitan Area

Table A1. Area of ejidos, area designated periphery, and GSV observations.

EJIDO	GSV Tags2	GSV Imp Tag	Area HA	Percent Periphery 1975
CAJITITLAN	4	0	2989	0.00
CONCEPCION DEL VALLE	145	2	696	0.00
COPALITA	9	4	491	0.00
COYULA	34	9	498	0.00
CUESCOMATITLAN	158	5	2424	0.00
EL COLLI	18	4	205	0.18
EL CUATRO	96	7	833	0.00
EL ROSARIO	6	0	30	0.13
EL VERDE	202	67	1069	0.21
EL ZAPOTE	141	15	1322	0.03
GENERAL LAZARO CARDENAS	35	1	2364	0.08
JESUS MARIA-EL SALTO	5	0	539	0.00
JOCOTAN	16	0	813	0.00
LA CALERILLA	4	0	283	0.00
LA PRIMAVERA	25	1	508	0.00
LAS JUNTAS	100	20	581	0.24
LAZO	17	0	258	0.00
LOMAS DE TEJEDA	56	0	1698	0.00
LOS BELENES	20	0	442	0.03
LOS GUAYABOS	5	0	56	0.00
LOS PUESTOS	63	14	509	0.26
LOS RANCHITOS	33	6	831	0.11
MATATLAN	9	0	1672	0.00
MESON DE COPALA	5	0	951	0.00
N.C.P.E. LOS TRES GALLOS	2	1	156	0.00
NEXTIPAC	67	14	2283	0.01
SAN AGUSTIN	46	0	2373	0.00
SAN GASPAR DE LAS FLORES	6	1	499	0.00
SAN JOSE DEL CASTILLO	99	23	1101	0.05
SAN JOSE DEL VALLE	24	1	383	0.00
SAN JOSE TATEPOZCO	96	14	1102	0.11
SAN JUAN DE OCOTAN	17	1	447	0.41
SAN PEDRO TLAQUEPAQUE	31	3	142	0.36
SAN SEBASTIAN EL GRANDE	159	4	1713	0.02
SAN SEBASTIANITO	3	1	217	0.02
SANTA ANA TEPETITLAN	257	39	1886	0.15
SANTA ANITA	65	2	1337	0.00
SANTA CRUZ DEL VALLE	161	7	2096	0.03
SANTA LUCIA	51	12	5370	0.02
TESISTAN	157	29	4213	0.05
TETLAN	8	0	80	0.34
TOLOLOTLAN	7	0	931	0.00
TOLUQUILLA	56	6	846	0.04
TONALA	101	14	1377	0.01
VENTA DEL ASTILLERO	27	2	2037	0.02
ZALATITAN	27	4	206	0.32
ZAPOPAN	280	25	1122	0.22
ZOQUIPAN	32	0	430	0.06

Sources: Google Street View, Instituto Nacional de Estadística, Geografía e Informática (INEGI), Global Human Settlement Built-up Grid dataset (GHSBUILT) raster data, European Commission Joint Research Centre (JRC), 2018.

Appendix B. GSV Samples and Model Statistics

In order to ensure the privacy of residents in GSV images, as well as to avoid overt visual stigmatization of particular neighborhoods, we offer instead a randomly selected sample of cropped images referring to the tags "impoverished" and "neutral" derived from our computer vision model. The images are meant to convey to readers the general appearance to be expected given one or the other kind of tag from roughly the edge of the street to the lower edge of the houses or other structures.

Figure A1. Impoverished.

Figure A2. Neutral.

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