Title: Identifying, projecting, and evaluating informal urban expansion spatial patterns

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Abstract

Informal urban land expansion is produced through a diversity of social and political transactions, yet "pixelizable" data capturing these transactions is commonly unavailable. Understanding informal urbanization entails differentiating spatial patterns of informal settlement from formal growth, associating such patterns with the social transactions that produce them, and evaluating the social and environmental outcomes of distinct settlement types. Demonstrating causality between distinct urban spatial patterns and social-institutional processes requires both high-resolution spatial temporal time series data of urban change and insights into social transactions giving rise to these patterns. We demonstrate an example of linking distinct spatial patterns of informal urban expansion to the institutional processes each engenders in Mexico City. The approach presented here can be applied across cases, potentially improving land projection models in the rapidly urbanizing Global South, characterized by high informality. We conclude with a research agenda to identify, project, and evaluate informal urban expansion patterns.

Keywords: Urbanization, Informality, Mexico City, Politics, Spatial Patterns, Remote Sensing

Introduction

Land system science increasingly addresses urban land dynamics and their consequences (Seto & Reenberg, 2014). Planning for more sustainable urban land use demands an accurate understanding of the sociodemographic, institutional and environmental drivers of urban land change. In the Global South, where over 90% of all urban growth is taking place (UN Habitat, 2016), the institutional drivers of informal urban land change are particularly salient, yet poorly addressed in land change models. Inhabitants of informal urban settlements have little to no tenure security and lack basic services. Growth of informal urban settlements is often associated with political transactions, because settlements outside the urban zone are commonly prohibited from official access to urban services, titles, and infrastructure, which politicians may facilitate in exchange for electoral support. Spatial-temporal patterns of land change may identify where informal political and economic transactions, such as rent-seeking, clientelism, and corruption, take place. Despite the recognizable differences in informal urban spatial patterns from formal growth (Graesser et al., 2012; Hofmann et al., 2015; Kerins et al., 2021; Kohli et al., 2012; Kuffer et al., 2014; Owen & Wong, 2013), models of urban land change often incorrectly assume spatial signatures of urbanization from the Global North are transferrable to model informal urban growth in the Global South. Urban land change models fail to capture drivers of change in the Global South, including the institutions guiding the process. As a result, models of urban growth projections are likely inaccurate and problematic for urban planning efforts. In this perspective, we argue that a better understanding of urban land systems requires understanding institutional drivers of change and linking them to subsequent spatial patterns of informal settlement growth.

Understanding urban land systems can be assisted by systematic, empirical analysis, addressing how much and what kind of land is consumed and the process at play (Solecki et al., 2013). Quantifying land-use change is key to understanding what drives urban form in many cities worldwide, with implications for sustainability. Nevertheless, while most spatial urban growth models include landscape (e.g., slope or land use), location (e.g., distance to city center, road, or amenities), and zoning constraints (Irwin, 2010) as predictive variables, models do not disaggregate formal and informal growth. The conflation of informal and formal urban growth in these analyses display mixed performances for cities in which informal growth plays a dominant role. Models perform reasonably well in Kampala, Uganda, for example (Vermeiren et al., 2012), while modeling patterns in other places of the Global South has proved challenging (Pontius et al., 2008). A recent review of the few existing informal urban expansion growth models (D. Roy et al., 2014) found only one that incorporated political transactions (Patel et al., 2012). No model disaggregates informal urban growth into component types. Most models of informal urban expansion rely on physical or environmental variables only (Augustijn-Beckers et al., 2011; Dubovyk et al., 2011). Failing to incorporate social and political transactions shaping informal urban settings into land change models limits understanding of how to manage and project urban expansion (Nagendra et al., 2018). As a result, existing efforts to simulate and project patterns of urbanization in the developing world often fall short of adequately capturing the dynamics at play (Pontius et al., 2008).

We argue that improving monitoring, modeling, and understanding informal urban expansion requires addressing at least three challenges: i) understanding the mechanisms, rules, and payoffs associated with distinct land change patterns, ii) distinguishing dominant spatial patterns of informality associated with dominant institutional mechanisms, and iii) evaluating the implications of the social and environmental outcomes specific patterns of informality. We describe each of these challenges and illustrate them using the case of informal urban expansion in Mexico City. We conclude with a research agenda key to address the challenges identified.

Three challenges to understand drivers and consequences of informal urban expansion

The first challenge is to understand the mechanism, rules, and payoffs to actors associated with informal urban expansion. Urban informality is a form of land use that is challenging to study, given its frequent association with undocumented, illegal, or illicit transactions and intentionally hidden exchanges. Despite narratives by urban authorities that urban informality is “chaotic” (Gilbert & De Jong, 2015; Lerner et al., 2018), research shows that informality is shaped, co-produced, and “ordered” by power relations, incentives, and rules of interaction amongst those selling, regulating, and urbanizing land parcels (Duhau & Giglia, 2008; Fernandes & Smolka, 2004; McFarlane, 2012; A. Roy, 2005; Tellman et al., 2021). Systematically documenting the contemporary mechanisms defining informal urban expansion across a megalopolis requires social science methods (mainly qualitative) to systematize the dominant rules at play (Banks et al., 2020; Connolly, 2009; Doshi, 2018; Fernandes & Smolka, 2004; McFarlane, 2012; Pradilla Cobos, 1995; A. Roy, 2005, 2009; Tellman et al., 2021; Van Gelder, 2013; Varley, 1998). In any complex megalopolis, there will likely be multiple forms of informal urban expansion, each with differing sets of rules and norms (i.e., institutions) (North, 1990; Ostrom, 2011). These institutions are often shaped by powerful actors or institutional entrepreneurs (Pacheco et al., 2010; Tellman et al., 2021).

Once distinct institutional mechanisms and associated entrepreneurs of urban expansion are identified and categorized, the second challenge is to determine if each category is associated with a distinct spatial pattern. Linking social and institutional processes to land-use patterns is particularly challenging in these cases, but possible, via two approaches (Tellman, Magliocca, et al., 2020). One approach is to use causal inference to link variation in observed spatial patterns to "pixelizable" social data (Belhabib et al., 2020; Jain, 2020; Ordway et al., 2019; Tellman, Sesnie, et al., 2020). The other approach is to use understanding of social mechanisms to identify the process generating distinct spatial patterns (Curtis et al., 2018; Sesnie et al., 2017) or generate spatial patterns with social rules using Agent Based Models (N. R. Magliocca et al., 2019). Agent Based Models are commonly used to link land-use pattern to process to understand what drives change in both forest (Curtis et al., 2018; De Oliveira Filho & Metzger, 2006; Manson & Evans, 2007) and urban systems (Irwin et al., 2009; N. Magliocca et al., 2011). The increasing availability of both high-resolution time series satellite data and deep learning classification models that identify contextual spatial patterns (e.g., convolutional neural networks or CNNs) (Dolley et al., 2020; Isikdogan et al., 2017; Jean et al., 2016; Kerins et al., 2021; Wang et al., 2020; Zhang et al., 2018) enables researchers to identify distinct patterns of land change and link them to illicit processes, even in urban settings.

The third challenge is to understand the social and environmental consequences of distinct patterns of informal urban expansion. Disaggregating different types of urbanization patterns is important for improving modeling of urbanization, and understanding how distinct urban growth patterns generate distinct assemblages of land system architecture (Turner et al., 2013), or the spatial arrangement of heterogeneous land uses in a given landscape. These spatial patterns influence urban climate (Benson-lira et al., 2016), energy budgets and emissions (Frolking et al., 2013), flood risk (Wheater & Evans, 2009), biodiversity (Stuhlmacher et al., 2020), and human health (Ahern, 2011), among other sustainability factors. While informality plays an important role in mega-urban development worldwide, little is known about how it affects urban form and the aforementioned environmental services (Henderson et al., 2016). The spatial patterns produced by urban informality remain unexplored, despite the importance these land patterns represent for urban socio-ecological systems and the implications they have for urban sustainability management and planning.

Do distinct orders of social processes driving informality produce similarly ordered spatial morphology? If so, can we identify the different underlying processes by way of detecting the morphological development in satellite imagery? We believe the answer is yes, and demonstrate though an example in Mexico City. While various typologies of informality for Mexico City have been developed (Azuela de la Cueva, 1987; Cymet, 1992; Jones & Ward, 1998; Tellman et al., 2021; Ward, 1976), they have not been linked to specific spatial morphological patterns each may produce on the landscape (e.g. see Bazant, 2001; Nurko et al., 2016) . One study disaggregated spatial morphology of settlement types in Mexico City (Kerins et al., 2021) by training a CNN on satellite data (Sentinel-2) based on the Atlas of Urban Expansion (Lincoln Institute of Land Policy, 2016), but categories of settlement were not linked to distinct social processes (e.g., informal settlements are labeled in this classification as "atomistic" settlements with irregular spatial layouts). Here we address the three aforementioned challenges of i) understanding informal urban mechanisms and payoffs, ii) distinguishing processes by spatial patterns, and iii) evaluating some of their social and environmental outcomes in the case of Mexico City. We extend previous work that examined informal urban institutional types and mechanisms in Mexico City (Tellman et al 2021) by linking each institutional type to a spatial pattern on the landscape. In this case, we explore both the potential and the constraints in analysis posed by available datasets, and from this exploration, propose a way forward for research.

Spatial Patterns of Four Informal Urban Land Institutions for Low- and Middle-Income Housing in Mexico City

The Mexico City Metropolitan Area is one of the largest megacities in the world, with nearly 30 million people, and has the highest percentage of urban expansion through informal growth (an estimated 65%) in Latin America (Connolly, 2009). Informal urban growth for low and middle income housing persists because of inadequate public housing efforts, a formal housing market inaccessible to the poor, and economic and political gains to politicians, developers, and intermediaries (informal actors who provide access to services like water or electricity) profiting from informal settlement expansion (Tellman et al., 2021). This kind of urban expansion involves an ordered social and institutional process with four distinct types: i) so-called “ant” urbanization (direct sale of one plot to one settler), ii) illegal subdivision (one actor who buys and sells many plots of land), iii) land invasion (a group of settlers illegally squatting on land, usually facilitated by a political group), and, iv) via social or public housing (city or federal subsidized housing for low or middle income populations) (Tellman et al., 2021). The last type is not typically considered informal in the literature (Berglund, 2019; Lambert, 2021). Evidence from Mexico City, however, demonstrates that this development is often deeply embedded in social transactions that deviate from stated legal norms and procedures.

The four types of informality are identifiable by common types of land transactions of each and the economic and political payoffs to the actors involved (Fig. 1, see Tellman et al., 2021 for more details). Economic returns include cash earned through bribes and side payments, sale of land or urban services, kickbacks paid by developers to politicians to change zoning or evade regulation, and increased municipal budgets from an expanded tax base. Political returns include opportunities for politicians to advance in their party or win office by gathering loyal clienteles of voters and citizens to participate in mass mobilization. Urban consolidation expands in space and accelerates in time as returns in political and economic capital increase (Fig. 1).

The hypothesized spatial pattern of each informal urban type, from initial construction to consolidation, is depicted in Figure 2, with an empirical case example from Google Earth Satellite imagery provided in Figure 3. Cases were identified via GPS points taken in the field, which were uploaded into Google Earth. Screen shots were taken using the Google Earth timelapse feature, but place names are intentionally anonymous due to the sensitive nature of the topic (e.g., potentially making communities vulnerable to eviction). An explanation of the hypothesized pattern and empirical example for each urbanization type follows.

Ant urbanization generates a small amount of economic capital to landowners selling their plot on the informal market and to government officials bribed by informal settlers to prevent foreclosure. Politicians engage ant urbanization areas to influence the distribution of services, provide construction materials, or encourage consolidation to garner votes. Ant urbanization appears near the urban fringe on existing agricultural or conservation lands. It is produced by one-off land sales in Southern Mexico City on land zoned as “conservation.” Urban growth is not permitted outside areas zoned urban in local government land-use plans (which began in 1997), but some agricultural activity is allowed. Farmers with land rights who no longer wish to farm or need cash may sell plots (typically 250m^2 in size) informally to settlers seeking to build a home. Ant urbanization produces a slowly developing, dispersed settlement pattern (Fig. 2). Growth may accelerate or consolidate when intermediaries install urban services, making the land more valuable and increasing demand. Ant urbanization is typified by one community (Fig. 3) that took 15 years to develop and is still slowly growing. In addition to the spatial pattern, ancillary data of land zones that identifies areas not permitted for urban growth are required to identify this urbanization type.

Subdivision generates larger economic returns than ant urbanization, because the process is concentrated in one actor who sells dozens to thousands of lots. This actor purchases agricultural land from a member of an agrarian community with communally-held property (*ejidos* in Mexico) and who holds individual land-use rights to farm a small portion of the *ejido* (~ 1 ha). It is either outright illegal to sell this land or expensive to do so legally because of high transaction costs. As such, an *ejido* member illegally sells the land to an entrepreneur known as a "land flipper." The land flipper buys many *ejido* plots, which are subdivided and re-sold to settlers. The political returns are often higher than ant urbanization due to larger numbers of settlers (and potential votes to be gained). Subdivision occurs on rectangular agricultural plots (Fig 2), and the urbanization pattern is more rapid and spatially consolidated than ant urbanization. One such community reached its development in about 10 years (Fig. 3). Subdivision and ant urbanization together represent at least 10% of all urbanization in the Mexico City Metro Area, occupying at least 3,200 ha in Mexico City's conservation land. In addition to its characteristic spatial pattern, ancillary data on land tenure is required to identify areas of collective title where subdivision typically occurs.

Land invasion generates larger political returns, because settlers "pay" for rights to land and services via political participation with the group engineering the invasion. The economic returns can be higher than subdivision, depending on the size of the invasion. Land invasion generates the most rapid and consolidated urban pattern. These communities construct many homes rapidly in interstitial urban areas (empty lots, or public spaces such as garbage dumps) or open lands immediately adjacent to the urban fringe (Fig. 2). Urban plots are built next to one another with little undeveloped space, and the community (~100-1,000 homes) is completed within a few months (Fig. 3). Although often receiving significant media attention, this process represents the smallest proportion of informal growth (in terms of spatial extent) in Mexico City. The two most common invasion groups in Mexico City, Antorcha Campesina and the Pancho Villas, have together urbanized 600 ha of land, representing 2% of the city's growth since 2000. In addition to its distinctive pattern, media reports can be used to identify approximate neighborhoods where an invasion process may have taken place.

Social housing generates the highest economic returns, concentrated in one developer. Such housing refers to large, new construction funded by INFONAVIT (National Housing Fund for Workers) on the urban fringe of the metropolitan area, not to the renovation of existing buildings in Mexico City's urban core related to the INVI program (The National Institute of Housing). Developers may purchase cheap agricultural land far from the urban fringe and convince the accompanied municipalities to rezone the land as urban through bribes, offering to aid in zoning plans in under-resourced municipalities, or demonstrating the potential of increased tax returns. Municipalities are required to install urban services, the government facilitates the sale of these homes via a social housing program, and the developer captures the capital gains. Social housing areas are large, and develop within two to four years (Fig. 2). This pattern represents at least 11,000 ha of urban growth, around 30% of new urban land in the Mexico City area from 2000-2010. Social housing has slightly smaller rates of consolidation compared to land invasion (Fig. 2), but the area urbanized is much larger. Ancillary data on permits for social housing construction could be used to identify the names and municipality of construction, but specific data on the polygons associated with these permits are not publicly available. Sometimes, the name of the developer appears in Google Earth, which can help identify a social housing complex.

Outstanding challenges in Mexico City

Previous work has addressed the first challenge of systematically examining the mechanisms, rules, and payoffs associated with types of informal urban expansion (Tellman et al., 2021), however, the remaining two identified challenges (distinguishing spatial patterns across the metropolis and estimating social and environmental impacts of patterns) have only been partially addressed. While Google Earth offers exemplary visual trajectories of informal settlement types and spatial patterns, classifying these patterns across the city requires an annual time series of >15 years at <5m spatial resolution. Attempts to identify ant urbanization patterns with a time series of urban land cover with Landsat (at 30m resolution) (Goldblatt et al., 2018) failed because dispersed single family homes fell into mixed pixels covered with forest on the urban fringe. Likewise, in other urbanizing cities, such as Wuhan China, informal urbanization from migrant farmers can only be resolved with high resolution commercial imagery (<3m spatial resolution) (Dolley et al., 2020).

While the social consequences of different types of urban informality have been documented (Tellman et al., 2021), understanding how the spatial patterns of each degrade (or retain) environmental services has not been examined. In addition to socio-environmental consequences associated with informal land-use patterns, the underlying institutions that produce these patterns may have social costs. For example, politicians may withhold urban services such as electricity, water, or public housing in exchange for votes or political support (Castro, 2006; de Alba, 2016; Hilgers, 2008), or intermediaries may set up informal electricity or water grids and charge residents substantial fees for access (Tellman et al., 2021; Venkatachalam, 2015). Below we offer a research agenda to address remaining challenges in Mexico City, with lessons for efforts to capture such patterns in other urbanizing regions.

Identifying informal land change patterns in urban areas requires higher resolution time series of >15 years

Mapping informal settlements requires high resolution (<10 m) satellite data in an annual time series of enough length to detect settlement evolution (Kuffer et al., 2016). Public satellite data available to map annual urban expansion (MODIS and Landsat, or 250m and 30 m^2 respectively), in this case, from 2000-2015, are not at a resolution sufficient to capture growth patterns, such as ant urbanization in which a typical abode has a roof of no more than $60m^2$. Plausible options for high-resolution time series data for urban classification include commercial optical data from Planetscope (3-5m, from 2017, and Rapideye, from 2009), the recently publicly available (as of August 2020) SPOT archive (2.5-6m for Spot 2, 6 and 7 from 2002-2016), or publicly available Sentinel-2 data (10m resolution, available starting 2015).

High-resolution urban time series data would facilitate pattern analysis to address several key questions to understand informal urban land systems and aid their governance: Do formal versus informal urban development produce distinct and identifiable patterns? Can distinct types of informal growth be differentiated across a metropolitan area? If so, do these differentiated patterns indicate distinct environmental and social consequences? Answers to these question through the use of high-resolution data could aid impact evaluation of policies such as land titling and regularization, eviction, payments for environmental services, and other interventions designed to curb urban growth.

The paucity of such data for Mexico City impeded empirical testing of the hypothesized spatial-temporal patterns presented. The average land invasion in Mexico City from 2000-2016 was 1.9 ha, which is equivalent to only 20 Landsat pixels. Subdivisions and ant urbanization are even more dispersed and are unlikely to be distinguishable from land invasions at such a low spatial resolution. Google Earth Imagery tiles can be visualized, but are not available for download for quality empirical analysis, as in the data can only be captured using screen shots in low resolution. Efforts to map informal growth at 5m in Mexico City for one point in time have been successful (Rodriguez Lopez et al., 2017), but no time series are available. Time series of at least 15 years are required to differentiate, for example, a consolidated ant urbanization community from a subdivision (Fig.3). Other studies that have examined patterns in land system architecture rely on 1m resolution images (Li et al., 2017). While we were unable to take advantage of the data for the analysis here, the availability of Sentinel-2 data, r opening of the SPOT archive, or advances in deep learning to classify Google Earth Imagery for informal per-urban development (see Dolley et al., 2020) could help identify distinct informal urban land patterns in Mexico City and elsewhere in the future.

Disaggregating urban informality links institutions to landscape patterns and social and environmental consequences

Not all urbanization is driven by the same mechanisms or produces the same patterns. At first glance, heterogeneity in informal urban pattern appears seemingly chaotic, and has overwhelmed attempts to model the pattern of urban growth in the Global South robustly (Pontius et al., 2008). In Mexico City, we identified explicit and distinct sets of actors and rules characterizing different types of informal urbanization, each with its unique spatial footprint, demonstrating the potential links between processes and patterns for one metropolitan area. The general approach of linking urban social process to spatial pattern could be applied to other cities, always starting with the specific informal settlement typology and spatial pattern. For example, analyses of Caracas would include vertical slums (Schmaeler, 2016), whereas analysis of Wuhan would include peri-urban migrant farmers(Dolley et al., 2020), while analysis for Nairobi would describe communities of individual “shacks” versus denser tenements, each with a distinct spatial pattern (Mwau & Sverdlik, 2020). On this basis, we posit that codifying and translating rule sets into urban growth models could improve their accuracy. To improve urban growth models, however, a series of such studies should be made across the Global South to enable meta-analyses (e.g (Kuras et al., 2020; Narayanan et al., 2017; Seto et al., 2011; Teo et al., 2021; Tuholske et al., 2021). The outcomes may point to common patterns associated with the general type of processes involved or by regional context. Connecting institutional and social patterns to spatial footprints, as demonstrated here for Mexico City, provides a framework that could be replicated in other cases and lead to informal urban pattern meta-analyses. Understanding the spatial patterns of informality could lead to more robust modeling approaches and assessment of consequences for the environment.

Informal urbanization is a social-ecological process that produces diverse but potentially consistent patterns for their projections with measurable environmental outcomes, and with future advancements, perhaps predictable outcomes. Each pattern is driven by institutional arrangements that produce a distinct land system architecture with implications for both social outcomes and environmental services (Turner , 2017). Social outcomes of urban informal types can be assessed by their ability to provide land and housing, the location and quality of housing and services, and the economic and social cost (e.g. exclusion, violence, or control) to residents. For example, for residents in Mexico City, participating in invasions is the cheapest way to obtain land for a home, but such participation then requires political participation in protests and electoral allegiance (Tellman et al., 2021).

Stocks and flows of environmental services in and for cities (also known as urban ecosystem or environmental services (Tan et al., 2020)) are largely dependent on spatial land-use patterns (Andersson et al., 2015). In Mexico City, for example, land system architecture of small areas of slow, distributed ant urbanization on conservation land versus the large areas of rapid, consolidated social housing on agricultural land could have different consequences for hydrologic ecosystem services, such as water filtration, aquifer recharge, and flood mitigation. Yet, public discourse in Mexico City assumes ant urbanization and invasion as the primary cause of reducing environmental services and increasing water scarcity and flood risk (Eakin et al., 2019; Lerner et al., 2018). This assumption leaves other types of informal urbanization and their spatial and environmental consequences unexamined. Disaggregating informal urbanization based on institutional arrangements and landscape patterns could provide a new avenue to analyze tradeoffs based on environmental costs of informal growth in Mexico City and elsewhere. Open source modeling software such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) can be used to translate land-use patterns into quantified biophysical and economic value of a large suite of urban environmental services (Hamel et al., 2021). Open source web-tools leverage deep learning algorithms to classify Google Earth imagery and quantify tradeoffs in informal housing and agriculture with urban food security, and other sustainable development goals (Dolley et al., 2020). Trade-offs between environmental services for identified typologies of urban growth could be examined in three ways: i) comparing past changes in urban land-cover patterns using extant maps or remote sensing (e.g., (Xiang et al., 2022)) across urban informality types; ii) using land-use models to project future patterns of urban growth scenarios assuming different percentages or types of urban informality and quantifying the resulting services, or iii) stakeholder scenario mapping of potential urban land-use plans and quantified trade-offs of social benefits and environmental services (Dolley et al., 2020) . Methods exist to examine tradeoffs in future land change projections and their environmental services (Lang & Song, 2019), but have not been applied to distinct types of urban development. A better understanding of environmental service impacts generated by distinct types of informal growth could aid urban planning efforts to improve urban sustainability. Yet differentiated environmental service assessments are predicated on the ability to identify the process, spatial pattern, and local of informal settlement types, which is currently a challenge for the land change community.

Conclusion

Overall, land system science has yet to fully engage with the range and nuances of institutional contexts that shape informal or illicit transactions. These transactions may result in unique landscape signatures, urban or non-urban in kind. Linking institutional rules and social relations to the distinct spatial footprints they engender requires bringing together disparate knowledge communities which have focused almost exclusively on either informal urban processes or urban land cover patterns. Linking spatial patterns to social process represents an exciting frontier for land systems scientists, and a necessary step to understanding urbanization in the Global South. Identifying, projecting, and evaluating informal urban expansion patterns requires meta-analyses of socio-institutional informal development across cities, developing higher spatial and temporal resolution time series data, and methods to assess socio-environmental consequences that avoid further marginalizing vulnerable communities.

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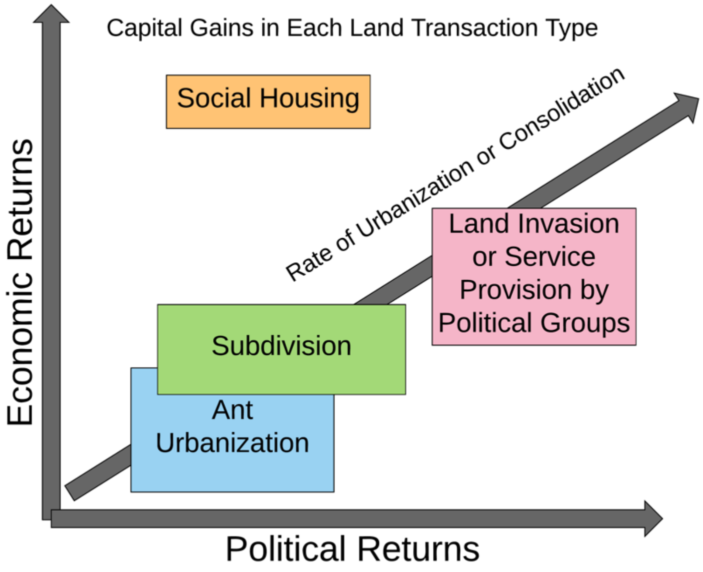
Figures:

1.



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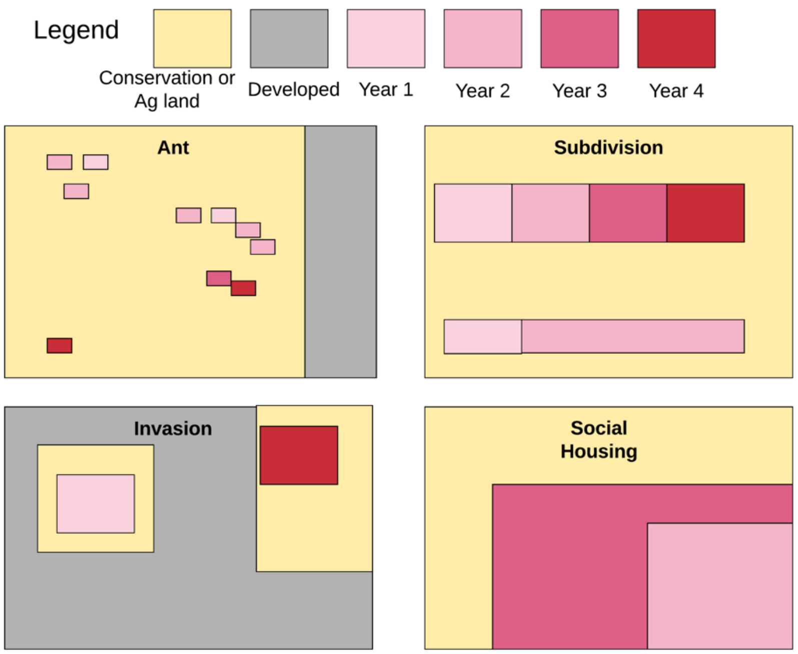
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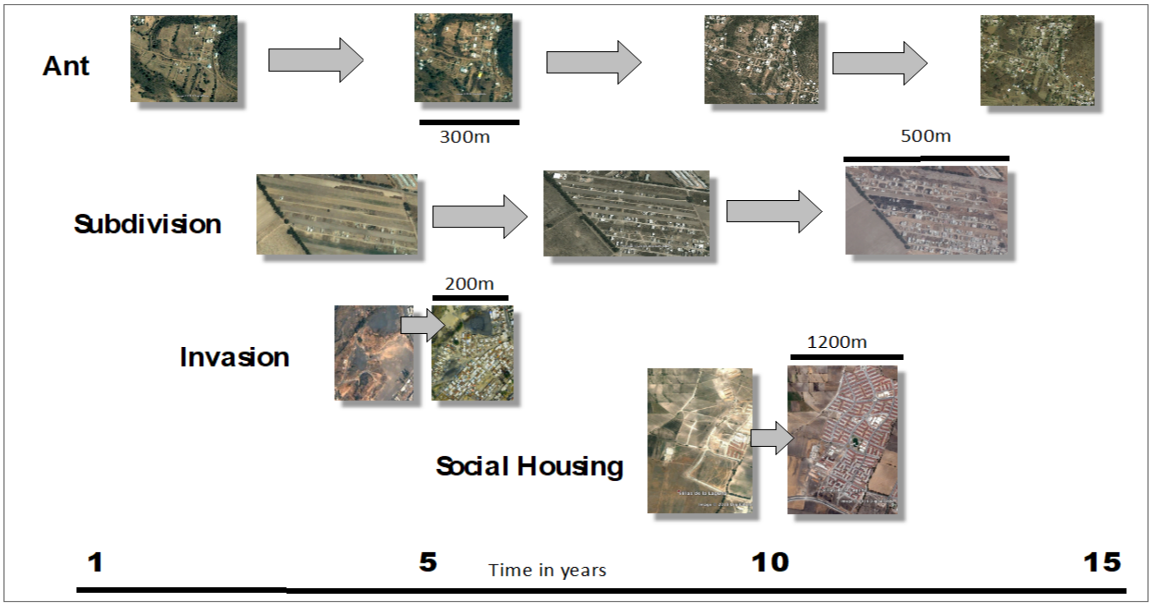

Figure 1. Economic and political capital returns in each informal land transaction type in the Mexico City metropolis, and a hypothesized vector of how rate of change is orthogonally and positively correlated, adapted from Tellman et al 2021. Social housing refers to large housing complexes funded by INFONAVIT on the fringe of the metropolitan area.

Figure 2. Hypothesized spatial patterns of informal urban development, illustrated from textual interview analysis (Tellman et al., 2021). Yellow represents existing undeveloped land (in Mexico City, often conservation land or ejido agricultural land, except for invasions that may "infill" empty lots or public spaces such as garbage dumps in the urban core), grey is existing urban land cover. New informal urban settlement is displayed in pink to red, with shades representing year of development.

Figure 3. Empirical examples of each informal urbanization type by hypothesized spatial pattern and speed of development, starting from the first image date, when initial signs of urban land cover change take place (e.g. visible homes, roads, or other impervious surface) to the final image date, when consolidation has finished and thereafter no additional visible roads and homes were added.