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Project Title

Assessing Brownfield Redevelopment Potentials in Hong Kong: A Geographic Information System (GIS) Analysis of Brownfield Sites

評估香港新界棕地發展潛力：基於地理信息系統的棕地研究

Project No. 2021.A1.115.21B

Final Report

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Executive Summary

Abstract

Over the past decades, the New Territories in Hong Kong, predominantly agricultural land, has encountered serious situation where agricultural land turned into sites for non-agricultural activities. In Hong Kong, parcels that are supposed be agricultural land but occupied by industrial uses are considered brownfield, mostly found in the New Territories. First, this study quantifies and visualizes the land use change patterns of brownfields with GIS tool based on historical remote sensing data over the past 20 years to identify the temporal and spatial distribution patterns of different operational types of brownfields, such as logistics, open storage, parking, and construction. Second, based on econometric models, this study identifies key factors that determine the development outcomes of brownfields in the New Territories, with which policymakers will be able to design customized incentive policy based on the varying characteristics of brownfield parcels.

Summary on policy implications and recommendations

How to turn existing brownfields into productive uses compatible to the surrounding environment and how to prevent new brownfields from occurring are some challenges policymakers have faced in Hong Kong. To design effective land policy, it is crucial for policymakers to have a comprehensive understanding of the historical transformation of land uses in rural New Territories and to develop good knowledge about the driving forces behind brownfield development. This project helps achieve the two aforementioned conditions for effective policy. Major findings of this project are:

- Brownfields have undergone a process of expansion-stabilization-contraction, but they tend to be more fragmented and decentralized.
- Warehouse and open storage were more widely scattered, while logistics showed a higher tendency to cluster along commuter rail tracks.
- There is tendency of co-appearance of the logistics and container land uses. Both land use clusters not only appeared stable over time, but also expanded in scale.
- Zoning plans were not as effective as expected to curb unauthorized uses.
- Brownfield parcels are sold at discount prices if its use is not compliant with zoning.

The increased level of patch fragmentation and reduced dominance of large patches suggest that policymakers should be aware of active and sporadic unauthorized uses of smaller-sized brownfield parcels, which are probably hidden and difficult to monitor. Zoning can be a useful tool to curb misuse of land and bring positive impacts; However, simply laying a legislative foundation for land use activities through zoning may not be sufficient to ensure compliance from landowners.

研究摘要

過去數几十年來，香港新界以農地為主的地區遇到了重大的轉變，農業用地轉變成了非農業活動場所。在香港，被工業用途佔用的農地被定義為棕地，這種情況大多存在於新界。首先，本研究使用 GIS 工具，基於過去 20 年的遙感數據對棕地的土地利用變化模式進行量化和可視化，以識別棕地不同運營類型（例如物流、露天倉庫、停車場和建築）的時空分佈格局。其次，基於計量經濟學模型，本研究確定決定新界棕地發展的關鍵因素，決策者將能夠根據棕地地塊的不同特徵制定出有針對性的激勵政策。

對政策的影響和建議摘要

如何將現有的棕地發展為與周圍環境相適應的高效用地，以及如何防止新的棕地的產生，是香港決策者面臨的挑戰。要制定有效的土地政策，決策者必須全面了解新界農村土地利用的歷史演變，充分了解棕地發展背後的阻力和驅動力。該項目為制定有效政策實現上述兩個條件。本課題研究重要發現概括如下：

- 香港棕地歷年來的發展特徵體現在擴張-穩定-收縮趨勢，但是棕地地塊更加碎片化及分散化。
- 倉庫和露天存儲用地分佈更加分散，物流用地的分佈更多聚集於鐵路沿線。
- 物流用地和集裝箱用地呈現出共現傾向。並且，這兩類用地聚集現象不隨時間的推移而改變，反而規模擴大。
- 土地利用規劃（分區計劃）沒有達到預期的有效遏止未經授權土地使用的效果。
- 如果使用不符合土地利用規劃，棕地地塊將以折價出售。

棕地地塊碎片化及大塊棕地數量的減少建議政策制定者應該意識到零星的未經授權的小塊棕地，這些棕地大都分散隱蔽難以監控。土地分區計劃可以成為遏制濫用土地的工具并帶來積極的影響；但是，僅僅簡單地依賴分區計劃立法或許不足以確保土地所有者的合規行為。

1 Introduction

Urbanization has led to the expansive conversion of farmland to non-agricultural human settlements. Over the past decades, the rural New Territories in Hong Kong have experienced significant land use changes where agricultural land has become sites for industrial operations (known as brownfields in Hong Kong). This includes open storage for industrial recyclables and warehouses for repairs, many being unauthorized development. The existence of these industrial activities initially driven by socio-economic factors has persisted, largely due to absent or loose land use regulations. The Hong Kong government thus has successively incorporated increasingly more rural areas into the city's zoning ordinance system, but seemingly has generated limited impact on reducing non-conforming land uses. Brownfields contribute to the problems of land waste, traffic, and pollution. One important issue for Hong Kong's land development is how to manage brownfields more effectively and utilize them more efficiently. It is suggested that brownfields can be a potential source of land supply to help alleviate Hong Kong's land shortage problem (Task Force on Land Supply, 2017).

Focusing on rural areas in Hong Kong, this project aims to examine the temporal and spatial patterns of different operational types of brownfields based on refined land use classification results generated by a support vector machines tool with remote sensing data from 2000 to 2020. This project analyzes the impact of zoning regulations on land use activities in terms of the transition flow, spatial concentration level, morphological characteristics, and transition probability of various land use types. Furthermore, this project attempts to establish relationship between regulatory uncertainty and brownfield prices through the hedonic pricing method. The results show that, despite regulatory control over rural land and strengthened enforcement measures, brownfields continue to grow in a decentralized and fragmented fashion. Our findings suggest that exercising police power through zoning has its limitations on curbing unauthorized development; brownfield parcels are sold at discount prices if its use is not compliant with zoning.

1.1. Intellectual gap in brownfield studies

When dealing with cities undergoing rapid urban expansion, urban planners are often faced with a major challenge: adopting effective means to monitor farmland conversion to urban settlements and to enforce land use regulations for new development. Studies have shown that analyzing the morphological and spatial transformation of a landscape can help expand our understanding of land use land cover changes caused by human activities. The increasing availability of high resolution open-access remote sensing images has capacitated scholars and practitioners to effectively measure urban expansion rate and trace land-use change patterns over time (e.g., Zhu, Liang & Jiang, 2012; Gasparovic, 2020; Das and Angadi, 2021; Feng and Wang, 2022). Much research on remote sensing-based land use/land cover focuses on methodological advances in analyzing urban morphological changes (e.g., Ma, Li & Chen, 2021; Wang et al., 2019; Abdullahi & Pradhan, 2016), while failing to take a step further to explain why such changes have happened. Focusing on different parts of the world, a few studies attempt to link land use dynamics to socioeconomic factors (Puertas et al., 2014), water resource management (Chaudhuri, Singh & Rai, 2017), and planning policies (Padeiro, 2016; Tavares et al., 2012). However, land cover image processing results in these studies are too aggregated (for example, agricultural, vegetation, forestry, and urban land) to offer much information about diverse human activities.

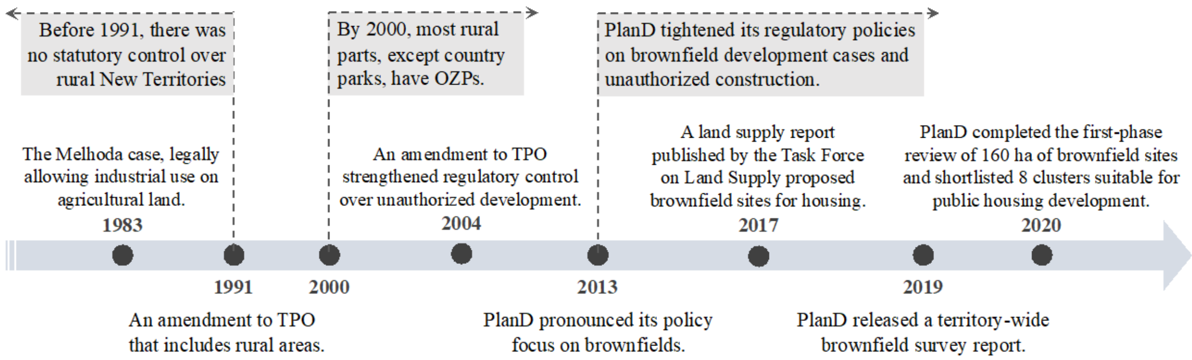
It has been widely believed that rural and urban landscape transformations are a result of economic activities driven by a combined force of industrialization, suburbanization, and automobilization (Angel et al., 2012; Galster et al., 2001). But this economic centric explanation is incomplete because land use policies, such as zoning, have also played an essential role in shaping urban landscapes. Studies of US zoning histories reveal that the public control of private activities involving buildings and land use constantly shapes human environments (Fischel, 2015; Hirt, 2014; Hagoort et al., 2008; Conzen, 1996). Although land use planning, a regulatory process of land resource allocation by local planning authorities to ensure desirable social and environmental outcomes, has been common for urban areas, rural areas are often not subject to land use regulations or such regulations, if any, are weakly enforced. The encroachment of agricultural land by industrial and residential buildings is a common phenomenon in rapidly urbanizing economies, manifested in the frequently reported problems of squatter settlements (Shabane et al., 2011), illegal occupation of farmland (Tang & Chung, 2002; Lichtenberg & Ding, 2008;), and unauthorized construction (Jim, 1996). Solving these problems may call for stricter zoning controls and stronger enforcement measures. However, this is far from a black-and-white issue as local governments should be cautious when exercising its police power to avoid public discontent. In fact, minor zoning violations or certain land use exceptions are often observed and tolerated among community members, even in countries with well-established zoning laws (Fischel, 2015).

With a focus on rural areas, some questions remain unanswered but are explored in this project. During the period of ambiguous means for planning enforcement, how do rural landowners respond to a growing demand for non-agricultural land while maximizing benefits and minimizing penalty risks? Do certain non-conforming land use types tend to cluster spatially? How and why does land use change from one type to another? What would be the extent to which zoning contributes to undesirable land uses? To what extent are land prices affected by the nature of brownfields? Were brownfields sold at discounted prices compared with greenfields? Does the factor of land use compliance have any impact on brownfield sales? Hong Kong is an ideal case study for answering the afore-posed questions because of its large-scale unauthorized development involving agricultural land, which has largely stemmed from a combined force of industrial growth in the city's rural New Territories and loose regulatory planning control over rural land. In Hong Kong, agricultural land occupied by industrial activities such as industrial storage, logistics and parking is considered a "brownfield;" hence, the definition of this term in Hong Kong is not explicitly determined by the presence or potential of contamination in a given area, different from brownfields defined in other cities.

1.2. How did brownfields emerge in Hong Kong

Since the 1980s, the predominantly rural New Territories in Hong Kong have witnessed a growing number of farmlands being abandoned and subsequently used for industrial activities. Although brownfields are often explicitly linked to land contamination in many other countries (Li, 2011), the Planning Department of Hong Kong (hereinafter PlanD) defines brownfields as "primarily agricultural land in the New Territories which has been formed and occupied by industrial, storage, logistics and parking uses." Existing studies on rural New Territories mostly concern the property rights of village houses (Lai and Lorne, 2014; Tang, Wong, & Lee, 2005) and planning control on village house construction (Yu and Hui, 2018; Chau and Lai, 2004), yet only a few examine nonconforming land uses arising from the administration's loss of control over agricultural land use since the early 1980s (Merry, 2020; Jim, 1996; 1997).

Figure 1 depicts the timeline of land use regulations for rural New Territories. Although Hong Kong's Town Planning Ordinance can be traced back to 1939 in colonial times, planning controls over the rural areas had long been beyond the purview of planning legislation. The only restrictions were prescribed in the then Block Crown Lease, which forbade building constructions on agricultural land without government permission. The 1983 Attorney General v. Melhado Investment Ltd case sent a green signal to landowners, legally allowing industrial use on agricultural land. Before the 1990s, there was no zoning for the rural areas. Over time, the decline in agricultural activities and the increased demand from the logistics sector have given landowners the opportunity to convert their land from original agricultural to alternative profitable uses. In the absence of zoning regulations and the weak enforcement of rural land management, there has been an increase in the number and widespread expansion of brownfields used as open storage, parking lots, container logistics, warehouses, landfills and recycling, and open-air vehicle workshops.



Note: Created by the project team. TPO-Town Planning Ordinance. OZP-outline zoning plan. PlanD-Planning Department of Hong Kong.

Figure 1. Timeline of Planning Control Over Brownfields

It was not until 1991 when an amendment to the Town Planning Ordinance was enacted to extend the statutory planning control from urban areas (Hong Kong Island and Kowloon regions) to rural areas (New Territories region). Legislative restrictions on developments in rural areas were imposed through Development Permission Areas (DPAs), later replaced by Outline Zoning Plans (OZP) after three years of DPA enactment, as regulatory land-use bases. The intention of the Amendment was to prevent land use changes without prior planning permission; but pre-existing conditions before the DPA/OZP were allowed to remain. In other words, once a parcel is incorporated in a DPA/OZP plan, any changes made without prior permission or not permitted under the relevant statutory plan would be considered unauthorized development, subject to prosecution by the planning authority. By 2000, except country park, most rural areas of the New Territories had OZPs. Planning enforcement control over rural land was further strengthened in the 2004 Town Planning Ordinance Amendment, which is expected to deter unauthorized construction and any material change of use after the publication of the DPA/OZP.

However, it was found that these heightened development control provisions in the Amendments made little impact on landowners' behavior. The number of unauthorized development cases continued to increase throughout the years: from 692 in 1995, to 961 in 2000, and to 1,301 in 2010 (Town Planning Board, 2011). The most recent data released by PlanD recorded 2,053 suspected unauthorized development cases in 2019. A study by Liber Research Community (2018) reported that the New Territories encompassed 1,521 ha of brownfields in 2017, doubling the size in 1993. The government's action on closer scrutiny can also be reflected in the sheer number of warning letters and enforcement notices issued to property owners or occupiers: between 2009 and 2019, the Central Enforcement and Prosecution Section of PlanD on average issued 3,461 warning letters and 2117 enforcement notices each year, involving a total of 7,017 and 3,898 unauthorized development cases, respectively (PlanD, 2010–2020).

In recent years, the policy focus on brownfields has gone beyond identifying suspected unauthorized development and stopping non-compliance uses toward converting them into better productive uses. In 2013, PlanD pronounced that it would assess the development potentials of all brownfields and expanded the coverage of OZPs guiding enforcement actions against non-compliance. As a result, a total of ten OZPs were enacted in 2013, by far the largest number of new OZPs published within a year after 1995, suggesting the government's determination of land control grip. Since then, brownfields have seized attention from both the government and some civic groups and a series of reports have been published. A 2017 land supply study by the Task Force on Land Supply discussed the feasibility of releasing 540 ha or 41.5% of brownfields for housing to help alleviate the city's long-lasting outcry over land shortage (Task Force on Land Supply, 2017). In 2018, PlanD commissioned Arup to complete an inventory survey of brownfields, which identified 1,414 ha of active brownfield sites and 165 ha of inactive brownfield sites (Arup, 2019). Civic groups, Greenpeace and Liber Research Community (2021), in a joint study criticized the government's underestimation of the scale of brownfields and its inertia pace in turning them into productive uses.

1.3. What deters brownfield redevelopment?

In Hong Kong, policymakers face several challenges to put brownfields into more productive purposes. First, over time the decline of agricultural activities and the increased demand for the logistics sector have given landowners the opportunity to convert agricultural land to alternative uses, which can explain the rising number and scale of brownfields in the New Territories. Mostly privately owned, brownfield parcels may not be utilized in accordance with government approved land use plans (e.g., Outline Zoning Plan). Second, the government does not have the complete *de jure* and *de facto* property rights over land in the New Territories because historical legacy has complicated the situation of rural properties by respecting private ownership (Merry, 2020). Landowners are more inclined to leave brownfields usage status quo than to develop or sell them so as to avoid unnecessary government interference. The ambiguities of property rights remain unsolved today, leading to many unauthorized developments that seem beyond the purview of zoning ordinances (Lai and Lorne, 2014). Therefore, it is vitally important for the land management team to comprehend such a delicate situation.

Another barrier may be related to the physical condition of brownfield parcels. Many brownfield parcels are irregular in shape and small in size, developers find it difficult to consolidate small parcels for large-scale housing development. Also due to remote rural location, these lots may not be included in comprehensive planning, thus not being serviced by basic infrastructure facilities and often mixed with villages, squatters, fallow farmland and fishing ponds. The surrounding area of brownfield parcels is characterized by uncoordinated land use, unpleasant physical environment, and traffic and safety problems.

Brownfield issues had been overlooked by policymakers in Hong Kong until recently. Several initiatives have been carried out by the Planning Department since 2017, resulting in several reports and datasets (Task Force on Land Supply, 2017; Liber Research Community, 2018a; 2018b; ARUP, 2019; PlanD, 2020). A recent survey provides some useful information about current scale and scope of brownfields (ARUP, 2019). Of the 1521 hectares of brownfields identified in 2017, large clusters appear in the northern and northwestern areas of the New Territories, such as Wang Chau, Yuen Long South and Ta Kwu Ling, and numerous smaller parcels scattered throughout. Yuen Long District accommodates 70.5% of the brownfield stock, followed by the North District with 306 hectares or 20.1%.

2 Objectives

- Quantify and visualize the land use changes of brownfields in the New Territories over the past 20 years (2000-2020), with historical remote sensing data.
- Create an index database to analyze the historical changes in industrial operations and related physical characteristics of brownfield sites.
- Categorize land sales transaction records in recent few years into sales of greenfields and different types of brownfields.
- Develop econometrics models to examine the impact of land use nature on sales prices.

- Identify key factors that determine the development outcome of brownfields in the New Territories.
- Design a classification system of brownfield development potentials and identify specific challenges corresponding to each type of brownfields. This typology can guide policymakers toward making more effective and customized brownfield policies based on systematically identified development challenges and potentials.

3 Research Methodology

The main purposes of this research are to (1) examine the dynamics of land use changes related to brownfields with remote sensing data from 2000 to 2020; and (2) identify the determining factors of land development potentials. With an area focus on the New Territories of Hong Kong, spatial metrics are applied to quantitatively demonstrate land development status from greenfield to brownfield and from brownfield to developed land. Transition matrix are used to evaluate brownfield transformation situation. Additionally, a hedonic price model is built to establish the relationship between the marketability and developability of brownfields (i.e., development potentials) and crucial factors, such as parcels' physical features, site locational characteristics, neighborhood socioeconomic factors, and planning rule and legal factors.

3.1 Study area

The New Territories, one of the three geographic regions of Hong Kong, has a total area of 98,251 ha, of which 47.17% is preserved as country parks (46,341 ha) and 0.77% is agricultural area (755 ha). According to the 2011 Census, it encompasses nine out of the 18 districts in Hong Kong, accommodating 3.7 million people or 52% of Hong Kong's population. The region is further divided into four sub-regions: southwest, northwest, southeast, and northeast. Our study focuses on the northwest and northeast sub-regions, where 98% of the city's brownfields are located (Figure 2).

The study area has a land coverage of 585 km^2 and a population of 2.45 million, most of which reside in one of the seven new towns, namely Ma On Shan, Sha Tin, Fanling/Sheung Shui, Tin Shui Wai, Yuen Long, Tuen Mun, and Tai Po. Apart from these seven towns, there are three relatively under-developed districts, called Northeast New Territories (Other Area), Northwest New Territories (Other Area), and Southeast New Territories (Other Area). Currently, approximately half of the study area (297 km^2) is covered by 67 outline zoning plans under the Town Planning Ordinance; while the other half is preserved under the Country Parks Ordinance.

Source: Created by the project team.

Figure 2. Study Area – The New Territories of Hong Kong

At present, Hong Kong's brownfields can be categorized into six types of operations, namely open storage, vehicle parking, construction, containers, logistics, and warehouses (Table 1 and Figure 3). We present the six types in order by the nature of structures from no structure, such as open storage, to relatively stable structure, such as warehouses. Year 2000 was set as the beginning of the study period because most rural areas in the New Territories had been covered by OZP by then. Given that land use characteristics do not change very often, instead of processing satellite images every year, we chose to explore land use patterns from 2000 to 2020 at a four-year interval (i.e., 2000, 2004, 2008, 2012, 2016, and 2020). The land use patterns were then demonstrated and visualized through geographical distribution and land use transition flow by operational types, indicators of spatial concentration levels, spatial metrics, and transition probability matrixes.

Table 1. Brownfield Category

Structure nature	Operation type	Description of land use
No structure	Open storage	Open storage uses relate to activities carried out on a site for which >50% of the site is uncovered and used for storage, repair, dismantling or processing recyclables, other than container-related uses.
	Vehicle parking	Vehicle parking uses refer to surface parking spaces for private or commercial vehicles.
	Construction	Construction uses refer to land undergoing or about to undergo engineering development.
Temporary structure	Containers	Container uses relate to storage of containers, parked container vehicles, and maintenance of containers.
Relatively stable structure	Logistics	Logistics uses offer both modern and general logistics operations. They exist mainly in the form of logistics centers and freight stations, which usually have sheds and logistics trucks.
	Warehouses	Warehouse uses include a variety of workshop activities, such as the maintenance of machines and appliances, usually operated in relatively stable structures.

Source: Created by the project team based on a survey conducted by Arup (2019).

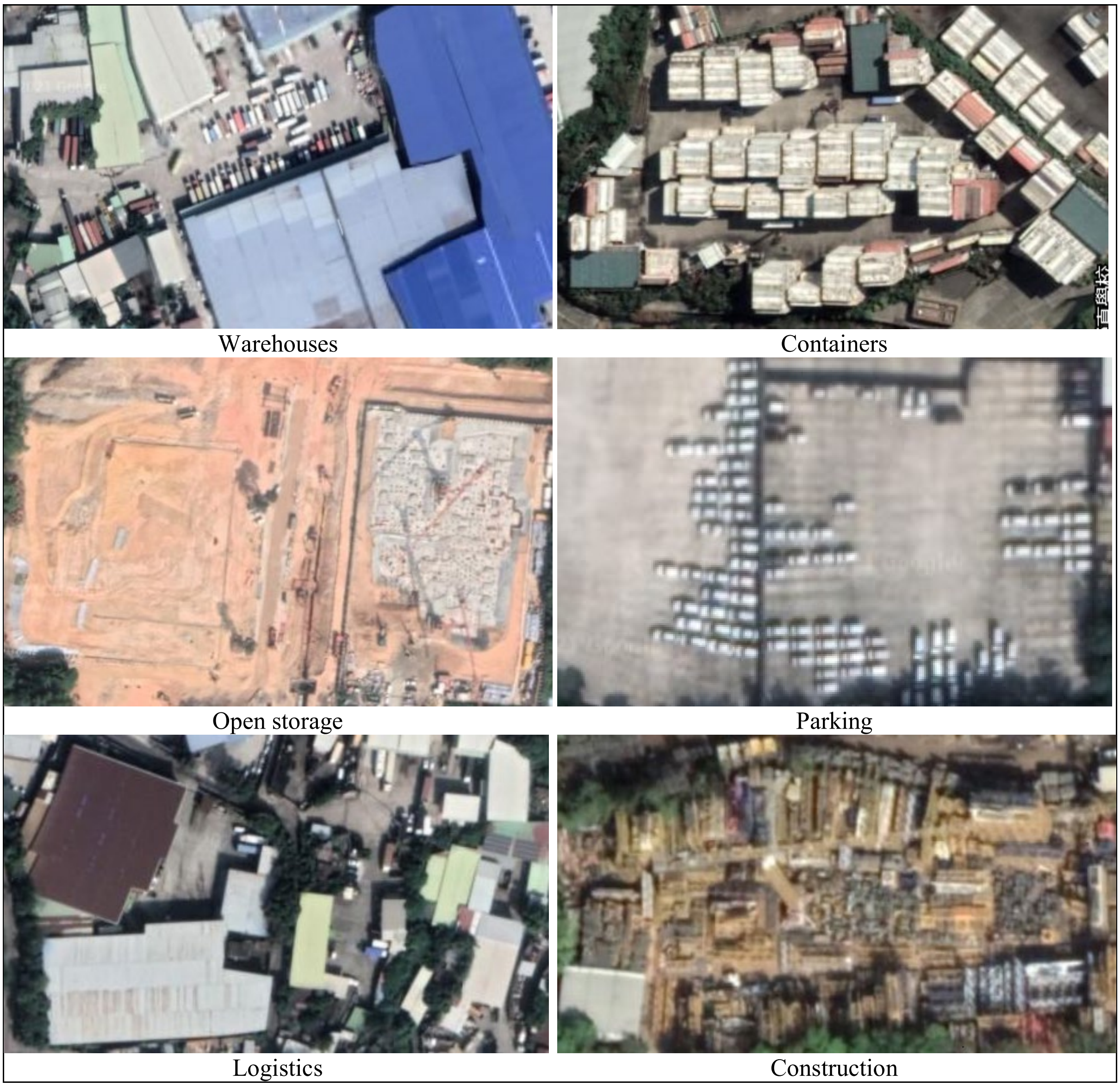


Image source: Google Earth.

Figure 3: Satellite Image Example of Brownfield Uses

3.2 To understand the spatial distribution of brownfields

Figure 4 is the analytical framework for studying the spatial distribution of brownfields and the relationship between land use pattern changes and land use regulations.

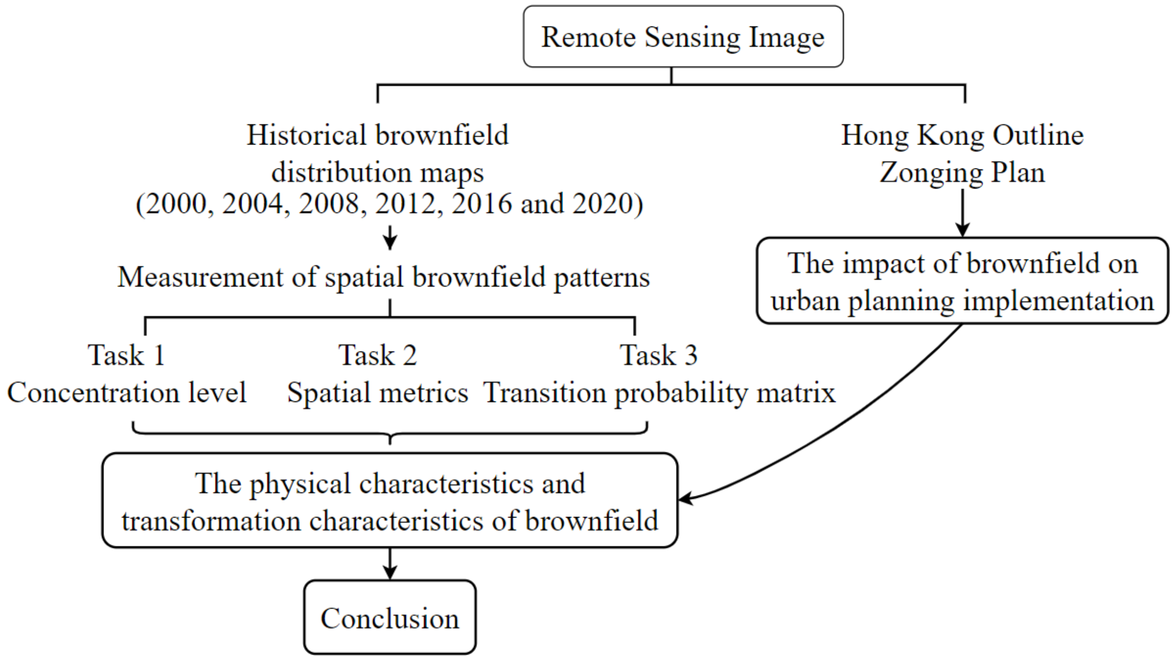


Figure 4: Analytical Framework for Spatial Pattern Analysis

3.2.1 Data processing and data validation

Data required for this study comprises satellite images, geographic data, and text data. Multiple year high-resolution satellite images were obtained from the Google Earth Engine platform, including Landsat 7 data for the years 2000, 2004, 2008, and 2012 and Landsat 8 data for 2016 and 2020. The Google Earth Engine is a remote sensing spatial analysis platform that integrates the steps of acquiring images, selecting samples, training classification, evaluating accuracy, and exporting results. The adoption of these techniques allows researchers to quickly and accurately obtain classification results over multiple years. More specifically, we first selected polygon samples from satellite images with an image processing method proposed by Zanter (2019). These polygon samples then became the inputs for a classification training program with the Support Vector Machine (SVM) method to identify all land use types. The level of classification accuracy was assessed by the Kappa coefficient, ranging from -1 as poor performance to 1 as a perfect level of accuracy. Our results of all land use types (including both brownfields and non-brownfields) showed Kappa coefficients above 0.8 value, which can be considered a close-to-reality estimate (Landis & Koch, 1977).

To further verify the accuracy of the SVM method for detailed brownfield categories, we compared the classification outcomes generated from 2019 Google Earth satellite images with a territory-wide land survey of brownfields completed in 2018 by the Planning Department (Arup, 2019). With several minor adjustments through our own visual recognition, the classification results reached a Kappa coefficient of 0.9, demonstrating an almost perfect match. Thus, we are quite confident that it is reliable to apply the trained classification program to satellite images of any year of interest to generate an accurate spatial database of brownfields in Hong Kong.

3.2.2 Spatial concentration

To measure the spatial concentration level of brownfields over time, we borrowed a measurement approach from segregation studies, which usually intend to indicate the degree to which socially and economically disadvantaged individuals become spatially concentrated (Wang & Goetz, 2021). For this study, two measurements, land patch number and patch size, are included in the formula. A land patch is delineated as a privately owned lot that has a lot number officially assigned by and recorded in the Hong Kong land registry system. On a map, these lots may not be continuous because country parks and public land may not be registered. Thus, we could not apply a conventional method to calculate the area or number of lots for a reference area; to overcome this discontinuity problem, we borrowed a concept from segregation studies. Specifically, the study area was divided into street blocks (SBs) for urban areas and village clusters (VCs) for rural areas, both of which are the smallest census geographical units in Hong Kong. The concentration level in SBs or VCs was presented with two indicators: lot area ratio and lot quantity ratio:

$$PN_i = \frac{Pn_i - \mathrm{Avg}(Pn)}{\mathrm{SD}(Pn)}$$

$$PA_i = \frac{Pa_i - \mathrm{Avg}(Pa)}{\mathrm{SD}(Pa)}$$

where PN_i/PA_i refers to the standardized proportion of the number/area of brownfield lots in SB or VC i to the total number/area of lots in all SBs and VCs. Pn_i is the number of brownfield lots in SB/VC i; Pa_i is the area of brownfield lots in SB/VC i. Avg(Pn) is the average number of brownfield lots of all SB/VCs and SD(Pn) is the standard deviation of number of brownfield lots of all SB/VCs. Avg(Pa) is the average area of brownfield lots of all SB/VCs and SD(Pa) is the standard deviation of area of brownfield lots of all SB/VCs. Three spatial concentration levels can be determined as follows:

- If PN≥1 and PA≥1, the SB/VC displays a high spatial concentration level;
- If (PN≥1 and PA <1) or (PN<1 and PA≥1), the SB/VC displays a medium spatial concentration level; and
- If PN<1 and PA<1, the SB/VC displays a low spatial concentration level.

3.2.3 Morphological characteristics

Spatial metrics can reflect various types of information on a landscape, such as its structural composition and spatial characteristics. The trends of spatial metrics can provide the development status of the regional landscape in the New Territories. The calculation of a series of landscape spatial pattern metrics was conducted with FRAGSTAS (version 4.2)—a widely used spatial pattern analytical program. In this study, we calculated the spatial metrics at the class (i.e., brownfield category) level for each study year. Each spatial metric has a specific formula and ecological significance (Table 2).

Table 2. Spatial metrics

	Index	Definition	Description
Fragmentation of patches	Number of Patches (NoP)	NoP=N_i	NoP>=1. Reflecting the degree of fragmentation.
	Patch Density (PaD)	PaD=$\frac{n_i}{A}$	PaD>0. The number of patches per hectare in the study area. Reflecting the density of patches.
	Mean Patch Size (MPS)	MPS=$\frac{A}{N}$	MPS>0. Average size of patches in the class. Reflecting degree of fragmentation.
Complexity of landscape	Landscape Shape Index (LSI)	LSI=$\frac{0.25E}{\sqrt{A}}$	LSI>=1. Reflecting the shape complexity of the overall class. The closer the LSI is to 1, the more regular the overall shape, and the larger the LSI, the more complex the overall shape.
	Mean Patch Shape Index (MSI)	MSI=$\frac{\sum_{j=1}^{n}(\frac{0.25e_{ij}}{\sqrt{a_{ij}}})}{n_i}$	MSI>=1. Average shape index. Reflecting the complexity of patch shape.
Dominance of patch class	Largest Patch Index (LPI)	LPI=$\frac{\overset{n}{\underset{j=1}{max}}(a_{ij})}{A}(100)$	0<LPI<=100. The larger the LPI, the greater the dominance of the class. Evaluating dominant class in the reference area.

Source: Created by the project team from McGarigal & Marks (1995).

As described in Table 2, for each brownfield type (class), the number of patches (NoP) and mean patch size (MPS) indicate the degree of fragmentation. The combination of both and patch density (PaD) can quantify the fragmentation information. The landscape shape index (LSI) and the mean shape index (MSI) indicate landscape complexity based on the overall class level and patch level, respectively. The largest patch index (LPI), which calculates the proportion of the largest patch area to the entire class area, is a measure of integrity and dominance for each class.

3.2.4 Transition probability matrix

To understand the likelihood of brownfield land use change, we generated the transition probability matrix, which describes the land use status change over time. The mathematical expression is as follows (Guan et al., 2011: 3762):

$$\text{Prob} = (P_{ij}) = \begin{vmatrix} p_{11} & p_{12} \cdots & p_{1n} \\ p_{21} & p_{22} \cdots & p_{2n} \\ \cdots & & \\ p_{n1} & p_{n2} \cdots & p_{nn} \end{vmatrix}$$

where the number of land use types is *n*; P_{ij} is the transition probability from type *i* to type *j*, and

$$0 <= P_{ij} <= 1;$$

$$\sum_{i=1}^{n} p_{ij} = 1$$

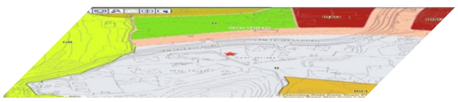
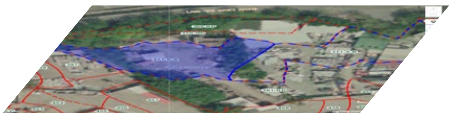
The transitional probability matrix is presented by brownfield types and four-year periods (five periods), which are created from the six data collection time points: 2000, 2004, 2008, 2012, 2016, and 2020. Results from the ArcGIS Union tool generated four changes in land use status: newly appeared brownfields, disappeared brownfields, brownfields that experienced type change, and brownfields having no change. Thus, the matrix indicates the transformation between different types of brownfield operations and non-brownfields.

For this study, five transition matrices were generated, each indicating the probability of one land use type changing to another (including the six brownfield types and non-brownfield) over a four-year period. Within each matrix, the diagonal values indicate the probabilities of no change, and the off-diagonal values indicate the probability of change. The sum of each matrix is 100%.

3.3 To build hedonic pricing models

Dealing with more recent image and statistical data, another part of this project overlays brownfields information from various aspects with GIS tool and hedonic models to identify the determining factors of brownfields development potential. Based on remote sensing classification, visual interpretation, and on-site investigation, this task first identifies the location and use types of brownfields in the New Territories in 2019. ArcGIS and FRAGSTATS (Spatial Pattern Analysis Program for Categorical Maps) are used to calculate the indexes of brownfields distribution in 2019. Spatial metrics of 2019 are integrated with all 2019 land sales records and other data, including lot information, zoning, locational amenities, and census (Table 3). Factors that determine development potentials are presented from various perspectives: (1) the morphological characteristics of the parcel itself; (2) the accessibility of the neighborhood where the parcel is located; (3) the socioeconomic situation of the neighborhood; (4) the clarity of the property rights of the parcel; and (5) the demand for housing development.

Table 3. Factors that Determine Development Potentials

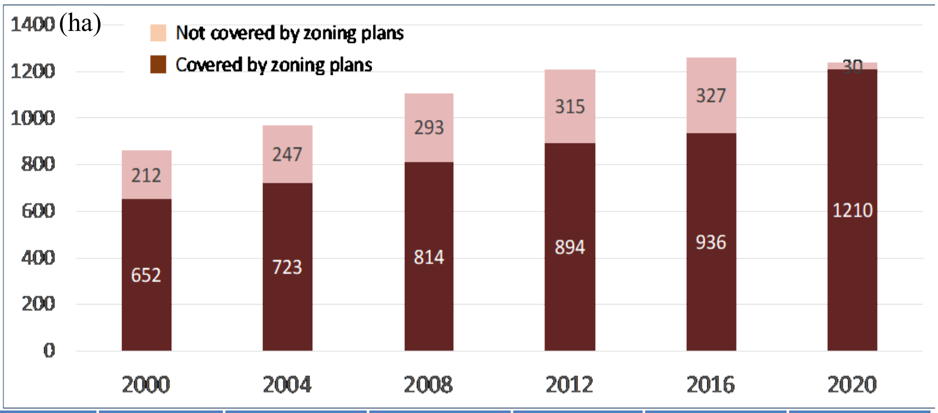
Data layer	Data description	Data source
	Land transaction records Geo-coded land sales	Land Registry
	Socio-economic factors: population, income etc. Population density, income level, business activities at Tertiary Planning Unit level.	Hong Kong Census
	Locational features: transportation, school, town center Measured by distance to CBD, subway station, nearest town center, school district etc.	MTR, Planning Department (PlanD)
	Planning regulation: Outline Zoning Plan, land use regulation Measure the conformity of land uses in accordance to zoning	PlanD
	Lot information: lot morphological features, such as those indices calculated in Table 1.	Lands Department
	Landsat or drone images Classified by different types of brownfields and greenfields	Google; United States Geological Survey

A series of hedonic price models (Chang and Li, 2021; Lieske et al., 2021) are built to test the correlationship between land sales prices and all other key factors listed in Table 3. In the model $P_i = \beta_0 + \sum_{k=1}^{k} \beta_k x_k + \varepsilon$, P_i is the land price, x_k include a vector of factors, and β_k are their associated coefficients. Two hypotheses are tested:

H1: Compared to greenfields, brownfields are sold at discounted prices after controlling other factors.
H2: Of all the land parcels sold in 2019 in the New Territories, brownfield uses that are in non-compliance with OZP zoning were sold at discounted prices than those that are in compliance with zoning after controlling other factors.

4 Research Findings

Over the 20 years in the study area, the total brownfield area increased from 864 ha to 1,245 ha. Note that not all areas in the New Territories have been covered by outline zoning plans. As shown in Figure 5, around a quarter of brownfield areas were not subject to any OZP regulations before 2016. Our 2020 result shows a significant improvement in regulatory coverage that almost all brownfields (97.6%) were subject to OZP regulation. The overall brownfield growth was over 100 ha every four years until 2012, slowing down to 54 ha by 2016. From 2016 to 2020, there was a slight decrease in the total area. Regarding brownfield types, most were operated for open storage, logistics, and warehouses. Brownfields used for vehicle parking and construction took up the smallest shares—combined, they accounted for less than 10%. Although warehouse area continuously increased throughout the study period, the sizes of other land use types fluctuated in different patterns. Open storage expanded from 218 ha in 2000 to 357 ha in 2016, but dropped to 307 ha in 2020. After a slight dip in 2004, logistics brownfields rose to 406 ha in 2016, accounting for nearly 1/3 of that year's total brownfield area. Container brownfields underwent a substantial drop in 2016, diminishing by 60% compared with the 2012 numbers, but then rose again by 70% four years later.



	2000	2004	2008	2012	2016	2020
# of zoning plans	39	42	42	44	62	67
Total (ha)	864	970	1107	1209	1264	1240
% not covered by zoning	25%	25%	26%	26%	26%	2.4%

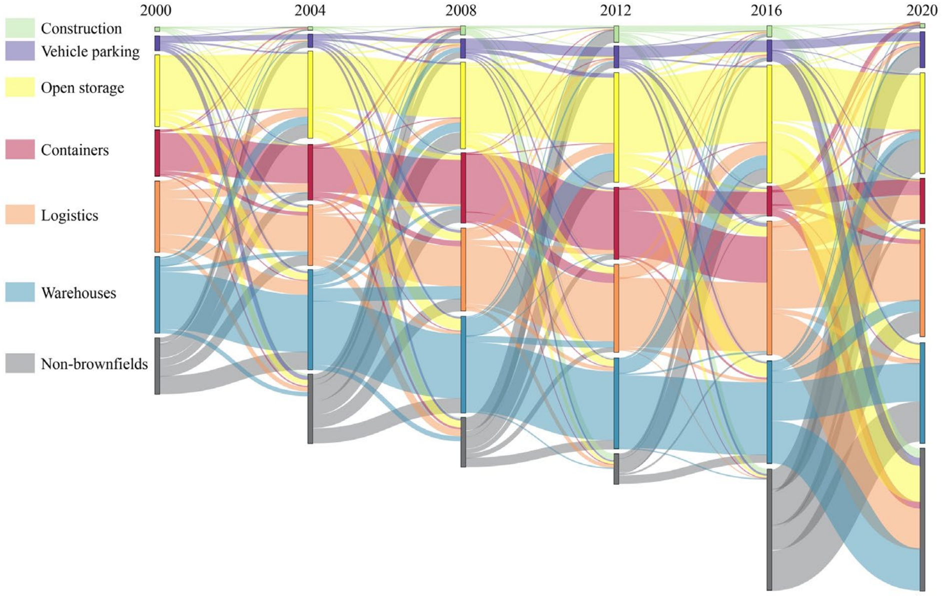
Note: Created by the project team.

Figure 5: Brownfields and Zoning Plans

4.1 Brownfield transition and distribution

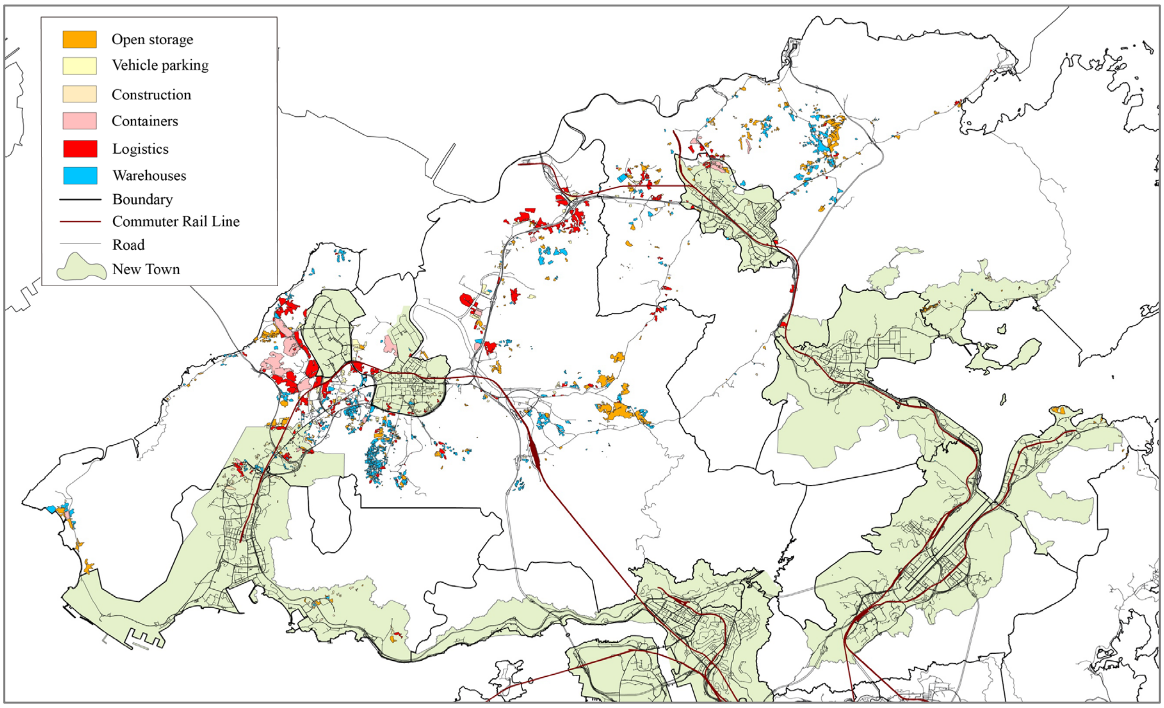
The transition flow of land use types changing from one category to another is visualized by a Sankey diagram with the vertical bars representing the total area of each brownfield type in respective year (Figure 6). The transition flows during each period indicate the volume and direction among various brownfield categories and non-brownfields. Figure 6 presents three interesting observations. First, there was a steady increase in all brownfield types from 2000 to 2012. Second, container use experienced a sudden drop in 2016, a large portion of which was absorbed by logistics operation. Third, from 2016 to 2020, although the total brownfield area remained stable, active exchanges between brownfields and non-brownfields occurred, suggesting that many industrial uses returned to original non-brownfield status and many previously non-brownfield land was occupied by industrial operations. This makes us wonder that: in recent years, perhaps land use control measures on brownfields are effective to existing brownfields, but not so much to sites that are not identified as brownfields.

The geographical distribution of brownfields by operation types shows that they tend to appear along commuter rail lines and on the edge of new towns (Figure 7). Throughout the entire study period, the combined areas for logistics and warehouses accounted for approximately 50% of the total brownfields, followed by open storage (25%). The three dominant types (open storage, logistics, and warehouses) displayed distinctive distributional patterns. As shown in Figure 7, warehouses and open storage were more widely scattered in the study area, while logistics showed a higher tendency to cluster along commuter rail lines. Another interesting pattern is the co-appearance of the logistics and container land uses (the dark and light red colors in Figure 7). We found that brownfield lots with relatively stable structures (e.g., logistics and warehouses) were more stable in land use than empty lots for construction or parking—hence, the latter were more susceptible to change. Open storage brownfields, however, showed a high level of stability, which was likely attributable to OZP’s acknowledgment of open storage as one zone category.



Note: Y-axis is unit-less and it indicates the volume of land use in hectares.

Figure 6: Transition Flow of Land Use Types, 2000–2020



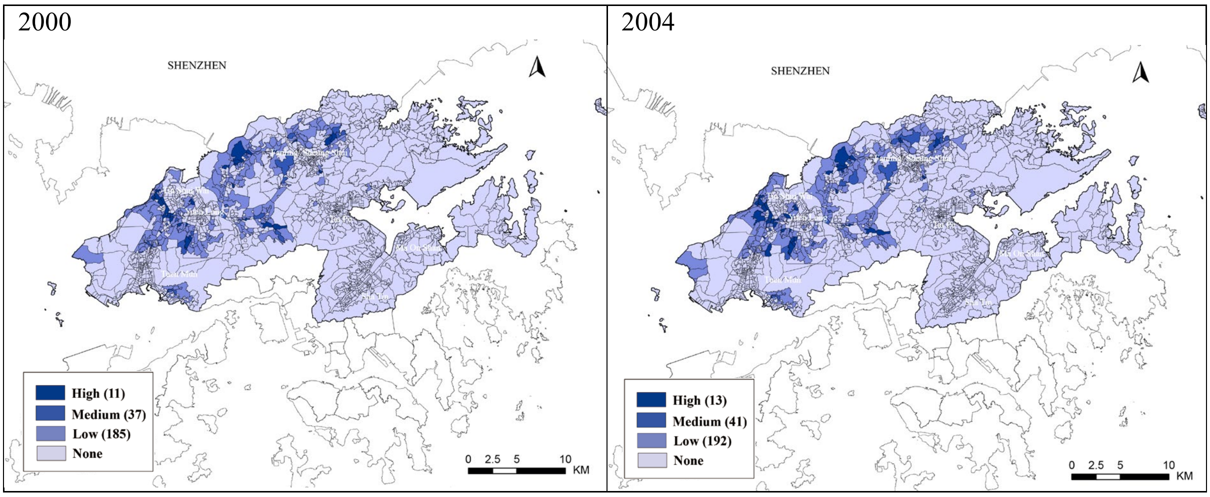
Source: Created by the project team.

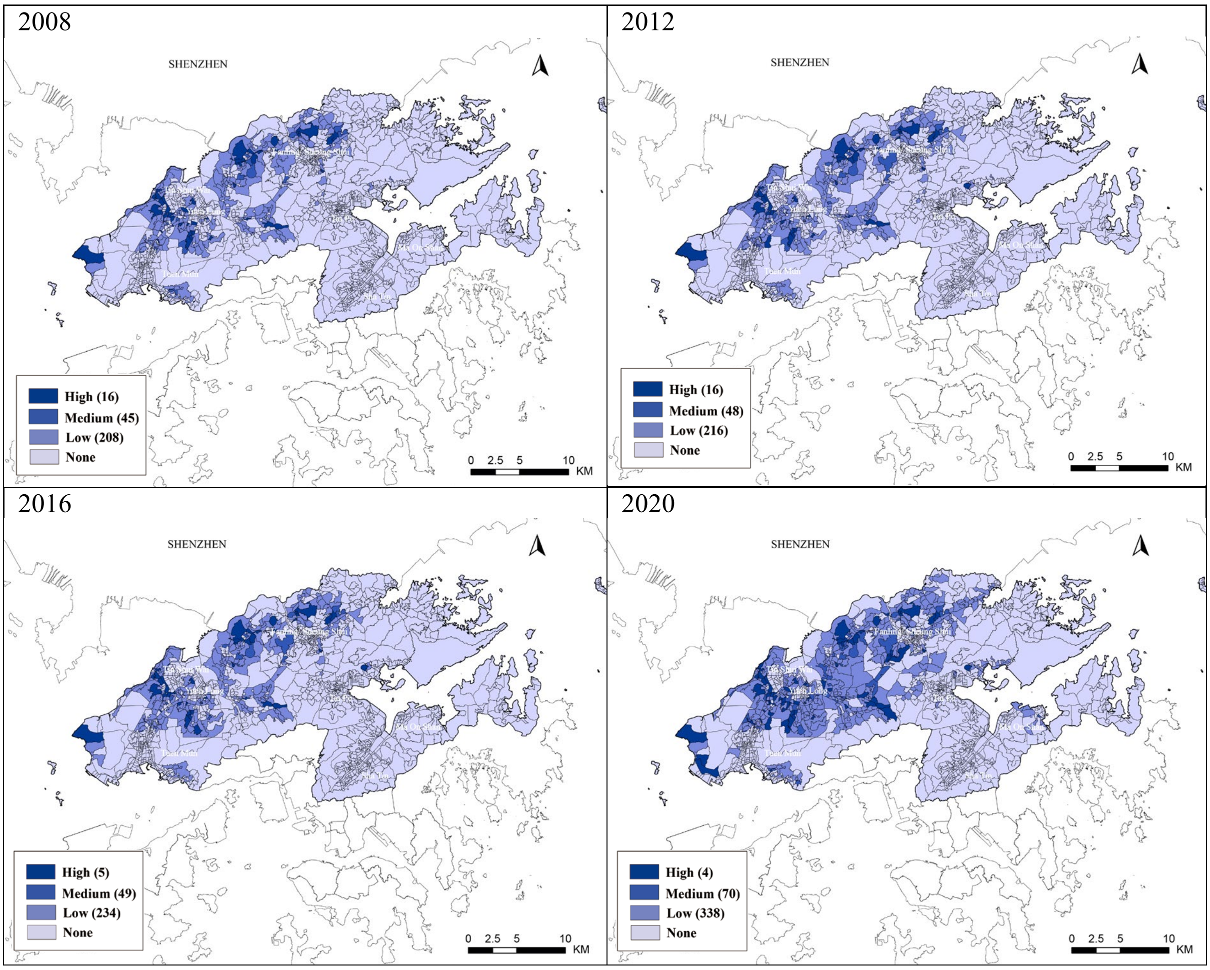
Figure 7: Distribution of Brownfields by Operation Type, 2020

4.1.1 Concentration level

The six spatial concentration level maps (Figure 8) show that brownfields mainly appeared in the Northwest New Territories, and that they clustered around new town districts, such as Tin Shui Wai, Yuen Long and Fanling/Sheung Shui. The distribution of brownfields was uneven, showing high-density centers (in dark blue) surrounded by lower-density geographic units (in light blue). Before 2016, the overall distribution remained relatively stable; after 2016, brownfields spread spatially, a phenomenon suggesting the replacement of large-scale brownfields by newly appeared fragmented industrial lots in recent years.

Interestingly, the geographic scale of brownfields expanded during the study period; however, areas with high spatial concentration levels have reduced, suggesting that the spatial distribution of brownfields developed in an expanded and decentralized manner after 2012. The number of SB/VC tracts with at least one brownfield lot increased from 233 in 2000 to 412 in 2020 (Figure 8). Regarding SB/VC tracts with high concentrated levels, the numbers fluctuated during the study period: they first increased from 11 in 2000 to 16 in 2012; decreased to five in 2016; and then to four in 2020. This reduction in high-concentration tracts may be explained by government's zoning actions beginning in 2013: between 2013 and 2020, a total of 23 new OZPs were enacted in the study area, with eight in 2013 and five in 2014. However, these OZPs may have contributed to the reduction of high concentration tracts, but less so to single brownfield sites. The numbers of tracts with medium concentration levels grew steadily, going from 37 in 2000 to 49 in 2016 and then jumping to 70 in 2020. The majority of affected tracts fell within the low concentration range, rising from 185 in 2000 to 338 in 2020, again suggesting the sprawling tendency of land use involving brownfield operations.





Note: Numbers in parenthesis are number of street block/village cluster tracts. High concentration (PN>=1, PA>=1); Medium concentration (PN>=1, PA<1 or PN<1, PA>=1); Low concentration (PN<1, PA<1); None (no brownfields).

Figure 8: Concentration Level

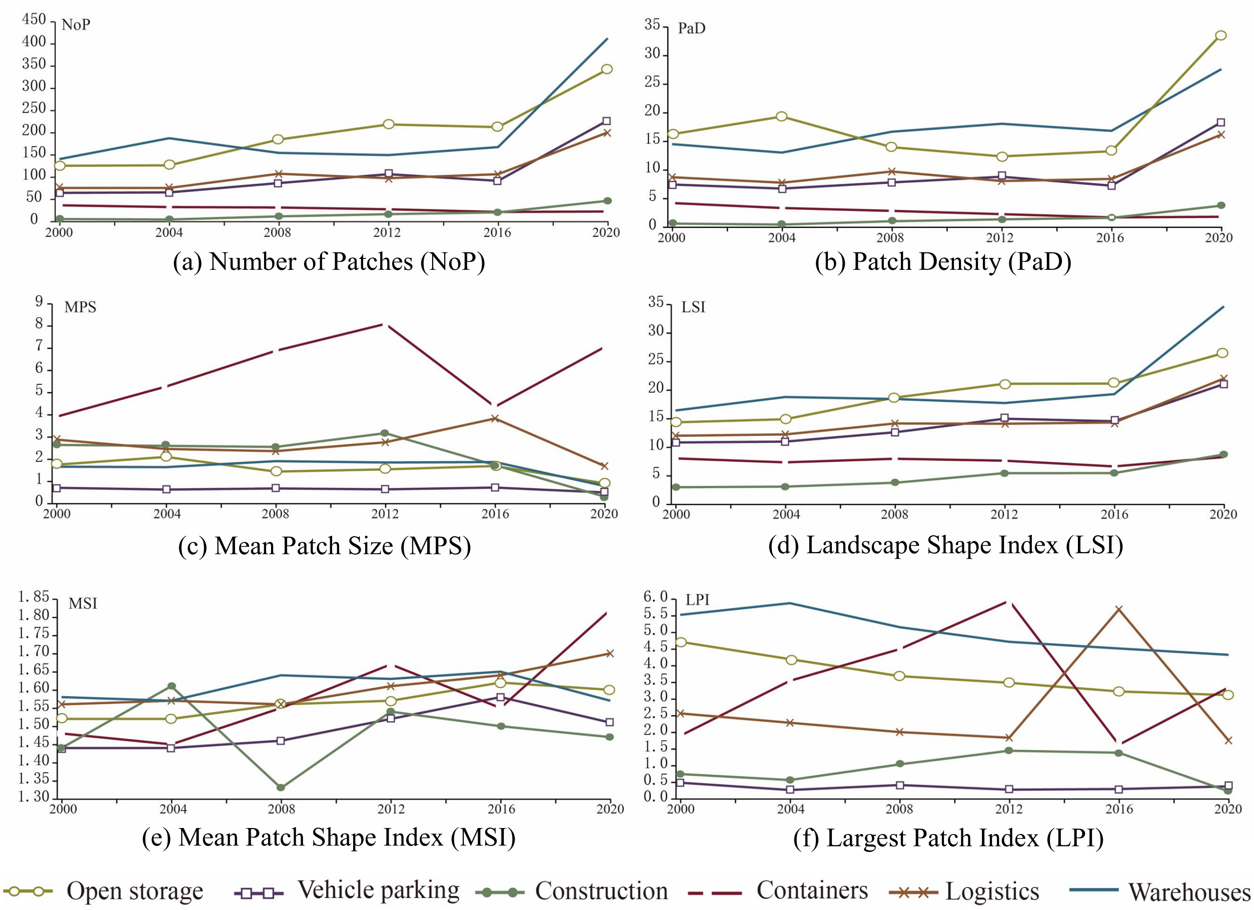
4.1.2 Morphological characteristics

Spatial metrics are indicators of the physical characteristics of brownfield parcels by operational type. We compared the changes in the spatial metrics of brownfields over time by two dimensions: within-category and cross-category.

The number of patches and patch density remained relatively stable for all brownfield types until 2016 (Figures 9a and b). Compared to other types, container land parcels were often more than twice larger, as indicated by mean patch size measurement (Figure 9c). Open storage and warehouses showed high patch counts and densities and low mean patch sizes, indicating that both brownfield types were large in number, but small in size. Moreover, these two types were commonly found at the fringe of new towns. Vehicle parking lots showed a moderate number of patches and the smallest mean patch size index, implying the scattered and pocket-sized nature of parking lots.

Regarding landscape complexity, it was observed that the majority of brownfield parcels were irregular in shape, regardless of land use types (Figure 9d). In particular, the degree of shape irregularity increased in 2020 for all brownfield types. Brownfields for open storage, vehicle parking, logistics and warehouses showed relatively consistent landscape complexity over time; while the average shape complexity of container and construction parcels varied substantially (Figure 9e).

Figure 9f presents the degree of dominance of certain brownfield types. The presence of warehouses and open storage appeared to overshadow other land use types with two exceptions where containers and logistics took over in 2012 and 2016, respectively.



(a) Number of Patches (NoP) (b) Patch Density (PaD)

(c) Mean Patch Size (MPS) (d) Landscape Shape Index (LSI)

(e) Mean Patch Shape Index (MSI) (f) Largest Patch Index (LPI)

Figure 9. Spatial Metrics of Brownfields

4.1.3 Transition probability analysis

The five transformation probability matrices offer a refined picture of land use type change tendency for every four years (Table 4). The value of each cell in the matrix presents the probability of the land use change from the row-side to the column-side type. The row sum of non-brownfields indicates the probabilities of newly appeared brownfields, which refer to land parcels that were originally non-brownfields and four years later used for brownfield operations. The column sum of non-brownfields indicates the probabilities of disappeared brownfields, referring to parcels that accommodated brownfield operations in a specific year and later turned to alternative non-brownfield uses.

Several interesting land use change patterns caught our attention. First, after comparing all four-year periods, we found that the transition tendency between brownfields and non-brownfields were the highest from 2016-2020, suggesting active land use changes during that period. In contrast, from 2008-2016, there were probabilities of 3-4% for a brownfield to transition to a non-brownfield, indicating a relatively stable land use status of brownfield operations.

Second, among the six brownfield types, container parcels were often the least likely to turn into non-brownfields; while open storage parcels were highly likely to become non-brownfields. This brownfields-to-non-brownfields transition probability may imply the developmental potentials, in that open storage parcels may have a higher chance of being redeveloped than container ones. Meanwhile, in case there is interest in understanding what types of brownfield operations are more likely to occupy non-brownfield land, the non-brownfields-to-brownfields transition probabilities revealed relatively large percentage figures for non-brownfields converting into open storage and warehouse brownfields.

Third, given that the diagonal percentages in Table 3 (marked in bold) indicate the likelihood of unchanged land uses over a four-year period, above 10% values are consistently found for open storage and logistics, which suggest that both operations were more likely to maintain their status quo than others. Warehouse brownfields also showed high stability, except for the 2016-2020 period. Similarly, container operation mostly remained unchanged before 2012.

Table 4. Transformation Probability Matrix

	Non-brownfields	Open storage	Vehicle parking	Construction	Containers	Logistics	Warehouses	*Row sum*
				2000 – 2004				
Non-brownfields		3.95%	1.45	0.46	2.34	2.99	5.35	*16.54*
Open storage	1.52	**16.02**	0.25	0	0	1.27	1.99	*21.05*
Vehicle parking	1.21	0.46	**1.57**	0	0	0.55	0.56	*4.35*
Construction	0.62	0.10	0.05	**0**	0	0.12	0.38	*1.27*
Containers	0.39	0.24	0.07	0.41	**11.14**	1.12	0.20	*13.57*
Logistics	1.30	2.29	0.18	0	2.60	**10.37**	4.08	*20.82*
Warehouses	1.26	2.37	0.31	0.13	0.17	1.33	**16.81**	*22.38*
Column sum	*6.30*	*25.43*	*3.88*	*1.00*	*16.25*	*17.75*	*29.37*	*100%*
				2004 – 2008				
Non-brownfields		4.24%	1.57	1.37	3.49	3.31	3.89	*17.87*
Open storage	1.97	**13.70**	0.44	0	1.25	1.98	2.98	*22.32*
Vehicle parking	0.53	0.52	**1.06**	0.10	0.06	0.71	0.44	*3.42*
Construction	0.26	0	0	**0**	0.46	0.10	0.06	*0.88*
Containers	0.54	0.15	0	0.61	**11.45**	1.45	0.04	*14.24*
Logistics	1.79	1.19	0.69	0.27	0.51	**10.32**	0.78	*15.55*
Warehouses	1.28	2.47	1.21	0	0.79	3.41	**16.55**	*25.71*
Column sum	*6.37*	*22.27*	*4.97*	*2.35*	*18.01*	*21.28*	*24.74*	*100%*
				2008 – 2012				
Non-brownfields		2.89%	1.44	3.14	1.12	1.14	2.25	*11.98*
Open storage	0.68	**15.81**	0.56	0.27	0.25	1.63	1.73	*20.93*
Vehicle parking	0.36	1.01	**2.36**	0	0.44	0.35	0.11	*4.63*
Construction	1.51	0	0.03	**0.58**	0	0.01	0.09	*2.22*
Containers	0.04	0.14	0.06	0	**14.19**	2.42	0.09	*16.94*
Logistics	0.86	2.27	0.48	0	1.36	**14.09**	0.95	*20.01*
Warehouses	0.31	4.34	0.38	0.02	0	1.56	**16.66**	*23.27*
Column sum	*3.76*	*26.46*	*5.31*	*4.01*	*17.36*	*21.20*	*21.88*	*100%*
				2012 – 2016				
Non-brownfields		3.28%	0.70	0.51	0.24	0.40	1.96	*7.09*
Open storage	0.56	**17.47**	0.65	0.49	0.71	2.40	3.23	*25.51*
Vehicle parking	0.46	0.37	**2.72**	0.08	0.20	0.90	0.40	*5.13*
Construction	1.35	0.20	0	**1.43**	0.39	0.34	0.19	*3.90*
Containers	0.14	0.03	0.21	0	**5.22**	10.70	0.45	*16.75*
Logistics	0.12	2.93	0.42	0	0.25	**15.99**	0.75	*20.46*
Warehouses	0.30	3.16	0.26	0.13	0	0.42	**16.88**	*21.15*
Column sum	*2.93*	*27.44*	*4.96*	*2.64*	*7.01*	*31.15*	*23.86*	*100%*
				2016 – 2020				
Non-brownfields		6.14%	3.74	0.56	0.56	4.10	7.44	*22.54*
Open storage	6.64	**10.20**	0.30	0.05	0.28	1.56	2.84	*21.87*
Vehicle parking	1.50	0.10	**1.61**	0.03	0	0.44	0.29	*3.97*
Construction	1.70	0.18	0.08	**0**	0	0.09	0.06	*2.11*
Containers	1.29	0.29	0.03	0.17	**2.93**	0.87	0	*5.58*
Logistics	7.57	0.29	0.67	0	4.59	**10.79**	0.95	*24.86*
Warehouses	7.88	1.49	0.25	0.03	0.03	2.22	**7.16**	*19.06*
Column sum	*26.58*	*18.69*	*6.68*	*0.84*	*8.39*	*20.07*	*18.74*	*100%*

Note: For each matrix, percentages may not add up to 100% due to rounding.

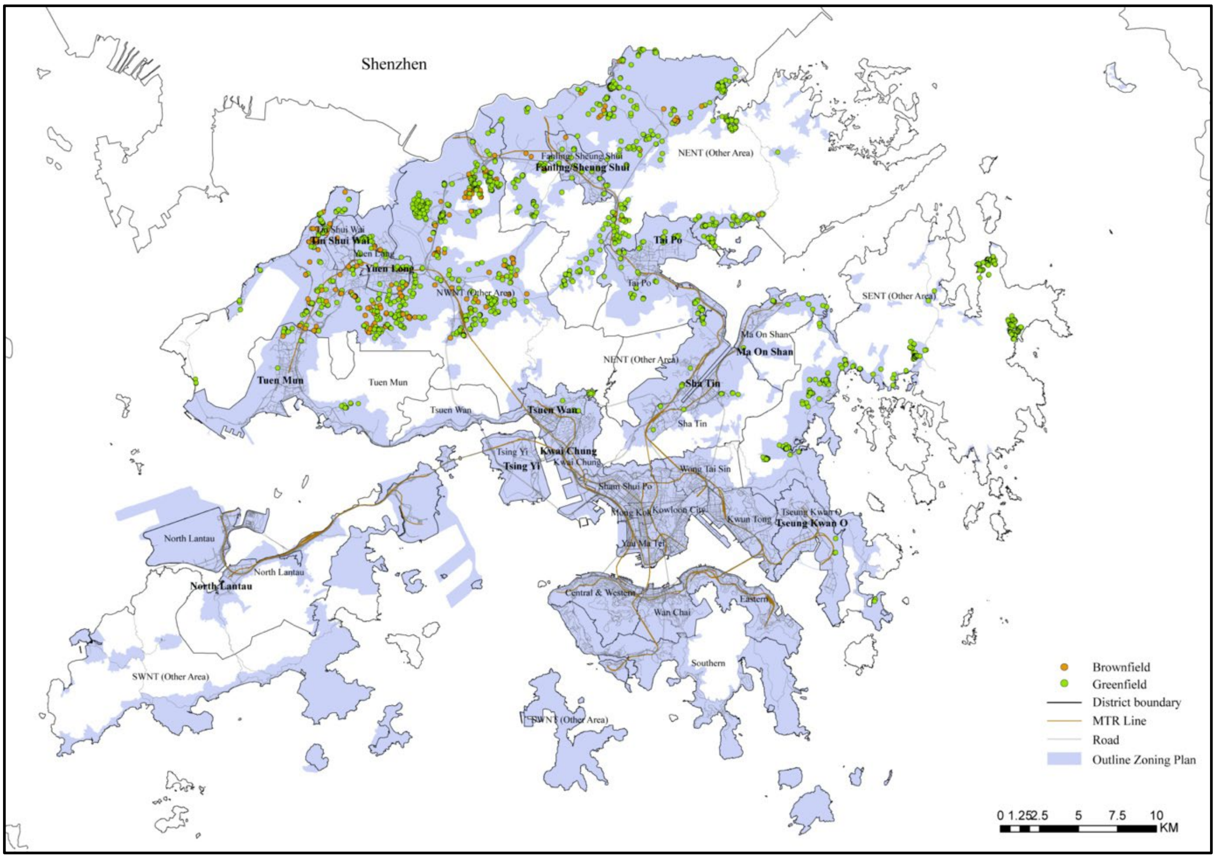
4.2 Econometric analysis

We collected land sales transaction in 2019 and processed satellite image of 2019. We consider a parcel as brownfield if it is used for one of the industrial activities; otherwise, the parcel is defined as greenfield. Therefore, greenfield parcels include not only agricultural land, but also village type development land. As shown in Table 5 and Figure 10, there were

2100 parcels sold in the New Territories in 2019. Among them, 15.4% are brownfields and 4% not covered by any outline zoning plans.

Table 5: Summary of greenfields and brownfields sales in the New Territories, 2019

	OZP area	Non-OZP area	Sum
No. of greenfield parcels	1,701	76	1,777
No. of brownfield parcels	315	8	323
Sum	2,016	84	2,100



Source: Created by the project team based on 2019 data from the Planning Department and Lands Department of Hong Kong.

Figure 10: Spatial Distribution of Greenfields and Brownfields Sales in the New Territories

4.2.1 Descriptive statistics

Table 6 is the descriptive statistics of the variables tested in the regression models. After conducting a series of regression testing with different combination of the variables, we dropped a few of them and chose the deciding factors to be included for further analysis.

Table 6: Descriptive statistics of the full sample

	Description	Units	Min	Max	Mean	Std dev.

Dependent variable	Land price	HK$/m^2	10	575,721	24,528	1,157
Independent variables						
Site characteristics	Lot area	Sq.m	4	51,550	833	3,792
	Landscape shape index (LSI)	Index	1	3.57	1.25	0.006
	Brownfield categories	Dummy	0	1	0.84	0.008
Neighborhood characteristics	Regional population	person	1,115	286,232	12,376	24,668
	Regional monthly income	HKD	12,000	20,000	15,500	1,518
	Regional household	Number	386	93,966	4,994	194
Location characteristics	Distance to commercial area	Meters	69	15,758	4,956	80
	Distance to school	Meters	19	9,732	1,869	48
	Distance to hospital	Meters	120	12,226	3,116	60
	Distance to housing estate	Meters	0	14,130	4,047	72
	Distance to bus station	Meters	0	4,739	719	20
	Distance to MTR station	Meters	99	13,908	4,034	70
Policy factor of interest	In violation of the Outline Zoning Plan? (1=Yes; 0=No)	Dummy	0	1	0.957	0.203

4.2.2 Were brownfields sold at discounted prices, compared to greenfield sales?

The first question examined is whether brownfields are sold cheaper than greenfields after controlling other factors, by running the full sample of 2100 sales records, which cover both brownfields and greenfields. As shown in Table 7, results of the four models meet our expectation. For site-specific characteristics, parcel size is positively related to land prices and LSI is negatively related to prices. Because LSI measures the complexity of the parcel, with closer to 1 indicating a more regular shape and larger LSI figures meaning more complex shape, the negative coefficients for all models suggest that irregular shaped parcels are sold at lower price than the regularly shaped. Locational factors presented expected relationship with prices, suggesting the closer to bus station, hospital or MTR station the higher the land price. Regarding neighborhood characteristics, the models include population, income, and the number of households. Out of our expectation, on average, parcels in higher population density region were sold at a lower price than parcels in regions with smaller population. Income and the number of households are positively related. Finally getting to the factor of interest—brownfields. The positive coefficient on the Greenfield variable suggests that greenfields on average were sold at higher prices than brownfields, and the result is statistically significant at 1% level.

Table 7: Regression results of brownfield vs. greenfield sales

	Model 1	Model 2	Model 3	Model 4
Site Characteristics				
Area	.830***(0.197)	1.039***(0.176)	.924***(0.175)	.907***(0.175)
LSI	-1.172***(0.195)	-1.320***(0.175)	-1.181***(0.174)	-1.147***(0.174)
Location				
ln(NEAR_BusStation)		-.373***(0.040)	-.377***(0.039)	-.381***(0.039)
ln(NEAR_Hospital)		-.157**(0.065)	-.173**(0.068)	-.149**(0.068)
ln(NEAR_MTRStation)		-.753***(0.062)	-.543***(0.071)	-.575***(0.071)
Neighborhood				
ln(Total Population)			-1.822***(0.522)	-2.053***(0.522)
ln(Median monthly income)			2.009***(0.384)	1.961***(0.382)
ln(Domestic households)			2.043***(0.527)	2.268***(0.527)
Factor of interest				
Greenfield (=1)				.487***(0.105)
R square	.077	.271	.288	.296
Observation	2100	2100	2100	2100

Note: LSI is land shape index. Robust standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1

4.2.3 Were non-compliant brownfields sold at lower prices than compliant ones?

With a focus on parcel sales of brownfields only, this section explores whether non-compliant industrial use land exhibits a discounted value due to its violation of zoning regulations. Thus the data in the hedonic models includes 312 sales records. To create the compliance variable, we overlayed outline zoning plan maps over the brownfield GIS map the team created. We assume that the lot's land use is in compliance with zoning if the lot falls in one of the zoned land use types: village type development, industrial (Group D), major road and junction, comprehensive development area, open space, open storage, undetermined, other specified uses, and unplanned. The lot would be recorded as non-compliance if it locates in other zoning types, such as agriculture, residential, green belt, government institution or community, commercial (2), recreation, and coastal protection area.

As shown in Table 8, when focusing on brownfields, factors related to site characteristics become statistically insignificant, suggesting that land prices are not affected by site-specific features, such as size and lot shape. The results involving locational factors and neighborhood characteristics are mostly consistent with the results from the full sample regressions in previous section, with the exception of distance to hospital and MTR station factors. For brownfields, distance to the nearest MTR station and to the nearest hospital became non-deciding factors for land prices. The positive coefficient on variable compliance (i.e., the factor interest) indicates that higher land prices are associated with land uses in compliance with outline zoning plans.

Table 8: Regression results of sales of compliant vs. non-compliant land use parcels

	Model 1	Model 2	Model 3	Model 4
Site Characteristics				
Area	-0.310(0.328)	-.193(0.311)	-.376(0.175)	-.389(0.298)
LSI	.418(0.314)	.180(0.298)	.361(0.285)	.364 (0.284)
Location				
ln(NEAR_BusStation)		-.275***(0.069)	-.369***(0.068)	-.354***(0.069)
ln(NEAR_Hospital)		-.441**(0.171)	-.114(0.190)	-.162(0.190)
ln(NEAR_MTRStation)		-.158(0.140)	.130(0.141)	.187(0.144)
Neighborhood				
ln(Total Population)			-6.155***(1.358)	-6.230***(1.352)
ln(Median monthly income)			1.893***(0.707)	1.938***(0.705)
ln(Domestic households)			6.468***(1.370)	6.575***(1.366)
Factor of interest				
Compliance				.114**(0.060)
R square	.031	.150	.248	.257
Observation	312	312	312	312

Note: Robust standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1

5 Policy Implications and Recommendations

There appears to be a consensus among planning practitioners, scholars, and the public that brownfield operations in the New Territories of Hong Kong are a result of the combined force of socio-economic factors, such as population growth and industrial restructuring, as well as loose regulations for rural areas. However, this notion cannot fully explain the dynamic transitions among operational types and non-brownfields even after regulatory planning rules came into force. Much of the New Territories is covered by outline zoning plans (OZPs) mostly passed after the enactment of the 1991 Town Planning Ordinance. By 2000, our study area was covered by 39 OZP plans; and by 2020, it was covered by 67 OZPs. The Planning Ordinance stipulates that any intensification of or change from present uses would require planning permission once an OZP comes into force. However, because land uses that existed before the passage of a DPA/OZP are allowed to remain, it is common to find many non-conforming land uses (aka grandfathered uses). The government appeared to have a dormant period before 2012 as only five new OZPs were passed within 12 years. It then took a leap of determination in passing 18 OZPs between 2012 and 2016 and five between 2016 and 2020, suggesting strengthened monitoring and regulation measures over rural land uses during these two periods.

As shown in Table 9, except 2020, around a quarter of brownfield areas were not subject to any OZP regulations; it was not until 2020 when almost all brownfields (98%) were covered by OZPs. Table 4 also summarizes the distribution of all brownfields in terms of hectares under Hong Kong's major zoning categories, some being authorized and some not. The most recent distribution data (the 2020 column) shows that brownfield lots appeared in large volume under categories of rural zones, such as Agricultural and Village Type Development, and urban (others) zones, such as Other Specified Uses and Open Space, as well as Green Belt, Major Road and Junction, and Residential. This data, though unable to distinguish authorized from un-authorized uses, provides some hints on the large scale of non-conforming uses if OZP-designated land uses were strictly enforced.

Table 9: Brownfields Area Located in OZP-designated Land-Use Zones

	2000	2004	2008	2012	2016	2020
Accumulative number of OZPs passed by respective year in study area	39	42	42	44	62	67
Total brownfields (ha)	863.9	970.2	1107.2	1209.4	1263.6	1240.1
Area not covered by OZP	211.4	247.5	293.4	315.1	327.4	30.0
Area covered by OZP	652.4	722.7	813.8	894.2	936.2	1210.1
Brownfields covered by OZP-designated major zoning categories (in hectares)						
Rural						
Agriculture	40.7	63.3	77.1	84.3	101.0	114.1
Village Type Development	107.5	102.3	110.6	133.8	136.8	130.3
Urban (built-up)						
Residential	93.3	96.5	95.2	115.4	119.4	146.9
Industrial & Rural-based Industrial	20.2	19.2	18.1	21.0	24.2	29.7
Comprehensive Development Area	12.1	13.1	17.5	23.3	29.6	41.4
Commercial	-	-	-	-	-	0.3
Urban (others)						
Government, Institution or Community	18.7	21.2	26.2	28.4	26.7	47.9
Other Specified Uses	47.8	50.6	46.0	48.0	49.4	106.3
Open Space	16.8	17.2	24.1	25.1	21.1	120.4
Conservation and recreation						
Conservation Area & Coastal Protection Area	30.9	29.5	31.2	34.2	37.7	47.7
Green Belt	123.1	149.2	159.0	156.9	161.2	126.2
Recreation	8.4	10.4	17.8	19.8	26.3	25.6
Miscellaneous						
Major Road and Junction	74.0	82.7	106.9	112.0	110.6	167.5
Drainage and River Channel & Nullah	4.5	2.3	2.5	5.8	1.8	2.5
Undetermined	7.6	10.8	15.8	17.5	17.8	32.9
Open Storage	47.0	54.4	65.9	68.6	72.6	70.4

Source: Calculated and created by the project team.

One would expect that landowners would be discouraged from alternating their land use to minimize government scrutiny after the passage of OZPs. Our findings suggest otherwise. Brownfield lots have continued growing over the past two decades, quantitatively confirming the assertion of previous studies that unauthorized developments involving industrial operations are common in rural New Territories (Merry, 2020; Chau and Lai, 2004). Our finding also suggests that OZPs appeared to exert little force on rural landowners, evidenced by the rising volume of brownfields from 2000 to 2016 and their high concentration around new towns.

Our results did show some positive impacts of the strengthened regulations for the period 2012-2016, during which the probability of a brownfield parcel becoming non-brownfield was low, fewer non-brownfield lots were converted for industrial operations, and there was a sharp drop in the number of high concentration tracts. Since 2012, brownfield distribution has begun to show a high level of fragmentation, being characterized by more medium- and low-concentration clusters and fewer highly concentrated clusters. These triangulated findings suggest that OZP appears effective in regulating large scale brownfield sites, but less so in curbing industrial operations involving sporadic small sites.

Some may applaud the effectiveness of land use regulations regarding the slight reduction of 24 ha brownfields from 2016 to 2020. However, our results suggest that this optimism is a disguise. Evidence from the land use transition figure (Figure 6) shows that many new brownfield lots appeared despite a slight decrease in brownfield area during that period. Another piece of evidence points to the larger number of SB/VC tracts having at least one brownfield lot, suggesting an increased level of patch fragmentation and a reduced dominance of large patches (Figure 9). Therefore, policymakers should be aware of active and sporadic unauthorized uses of smaller-sized brownfield parcels, which are probably hidden and difficult to monitor.

Additionally, this project identifies key factors that have significant impacts on land sales outcome. Factors under consideration include the physical features of brownfield sites, site locational characteristics, socio-economic variables, and the legal status of land uses. Sales of brownfields reflect market-driven factors. In general, private sales of land lots in the New Territories follow similar market rules that having been identified in existing studies—price discount exists for brownfields and location and socio-economic factors matter. However, when focusing on sales of brownfields only, some locational factors (e.g., distance to MTR station) become less important in determining prices; instead, whether the brownfield uses conform to zoning rules affects prices. These findings imply the importance of zoning in stimulating the private land market in the New Territories.

6 Conclusion

This project reveals a total of 1,240 hectares of brownfields in the New Territories in 2020. These brownfields have brought to the surround neighborhoods environmental problems such as noise and air pollution, land and water contamination, and traffic interruption. It would be beneficial to convert these sites into more productive, environmental-friendly uses. However, because the majority of these sites are privately owned, the government would need to find ways to incentivize landowners' participation. Yet approaches such as the land sharing pilot scheme launched in May 2020 were not as effective as expected (Cheng, 2020). The challenge policymakers are facing is to gain a comprehensive understanding of the scale and scope of brownfields over time and to design land policies that are effective in guiding appropriate development of brownfields.

This project explored the association between rural land use regulations and the spatial and temporal dynamics of land use changes of brownfields over the past 20 years in rural Hong Kong. More specifically, we measured land use characteristics of brownfields in terms of land-use transfer matrixes, spatial metrics, and concentration levels, from much-refined land use classification data processed from the Google Earth Engine remote sensing data with the support vector machine (SVM) classification method. By deciphering the policy factors behind land use changes, we argue that such transformations of brownfields from one operational type to another are more than a reflection of social and economic transitions, but a result of the effectiveness of land use controls.

Brownfields in Hong Kong have experienced multiple changes from abandoned agricultural land to industrial uses for open storage, logistics, and warehouses. Considering the recent government policy agenda on assessing the development potentials of brownfields in Hong Kong, we believe it is instrumental that policymakers should possess a comprehensive understanding of the transformations of brownfields over time and across different land use types. In this study, using the concept of land use land cover changes, we analyzed brownfield changes from 2000 to 2020. Based on remote sensing images from multiple years (2000, 2004, 2008, 2012, 2016, and 2020), we adopted the machine learning SVM classification and visualization methods to demonstrate the distributional patterns of brownfields in the New Territories of Hong Kong. Furthermore, by combining analyses of landscape metrics and transition probability matrices with examination of spatial concentration levels, we evaluated the evolution of brownfields from spatio-temporal aspects. We found that brownfields have undergone a process of expansion-stabilization-contraction, but tend to be more fragmented and decentralized.

Land use regulations, especially zoning, have been popular tools to control activities on private properties. Incorporating rural areas that are under the pressure of urbanization into the city's regulatory planning system appears to be a natural process. However, simply laying a legislative foundation for land use activities through zoning may not be sufficient to ensure compliance from landowners. Results from Hong Kong's rural land transformation patterns imply the limitations of zoning in curbing non-conforming land use activities. On the one hand, advances in remote sensing technology empower planners to monitor land use changes and take enforcement actions against unauthorized developments. On the other hand, planners should be aware that rigid controls and implementation are not the sole solution. In a society where demands and desires are constantly changing, periodic amendments of zoning or zoning exceptions are necessary to keep up with the changing world. Land policymakers thus face up to the challenge of how to keep the balance between regulatory flexibility and enforcement fairness. As the Hong Kong government is moving from simply prosecuting wrongdoings toward assessing the development potential of brownfields, some alternative flexible tools may be required, such as incentive zoning or land swap. Ultimately, the goal is more than catching and prosecuting non-complying activities, but engaging landowners in desirable land uses voluntarily.

7 Public Dissemination of Research Findings

The findings of the project have been presented at two international conferences:
(1) "Planning Control over Rural Land Development: Zoning Enforcement in Hong Kong" presented at the 5th World Planning Schools Congress and 16th Asian Planning Schools Association Congress (online), Bali, Indonesia (Aug 29-Sept 2, 2022), and
(2) "The Impact of Zoning on Brownfield Development Potential: Land Sale Evidence from Hong Kong" presented at the 62nd Annual Conference of Association of Collegiate Schools of Planning (ACSP), Toronto, Canada (Nov 3-6, 2022).

The first component of this project has been published in *Land Use Policy*, a top-tier peer-reviewed journal in the field of environmental studies. The citation of the paper is: Liang, Jingmin, Jiayu Chen, De Tong, and Xin Li (corresponding author). 2022. "Planning control over rural land transformation in Hong Kong: A remote sensing analysis of spatio-temporal land use change patterns." *Land Use Policy*. DOI: 10.1016/j.landusepol.2022.106159. The second component of this project about econometric analysis is to be submitted to a peer-reviewed journal for publication.

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