DEVELOPMENT OF A HISTORICAL URBAN LAND USE WEB APPLICATION FOR THE CITY OF HONG KONG

by

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To my family, for their continuous support

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Abbreviations

DTM	Digital Terrain Model
GIS	Geographic information system
GISci	Geographic Information Science
GIST	Geographic information science and technology
HK	Hong Kong
HULU	Historic urban land use
OZP	Outline Zoning Plan
PlanD	Planning Department
SAR	Special Administrative Region
TPB	Town Planning Board
TPU	Tertiary Planning Unit

Abstract

Hong Kong is a dynamic city located on the southern coast of mainland China. A once unassuming island of fishing villages became an economical trading hub as a British crown colony following the Opium Wars. Hong Kong's geology limited the natural area of developable land, and as the population of the colony increased over the decades, land reclamation projects were commissioned to account for exponential emigration. Over the course of its century-long history, the urban topography of Hong Kong has transformed significantly, and is expected to continue to evolve as the city maintains its status as an international business hub. This thesis explores the development of an open Historical Geographic Information System (HGIS) web application that portrays interactive digital versions of historic land use maps of Hong Kong. Historic maps of Tertiary Planning Units in Hong Kong's Central district from the late 1960s to the late 1980s are the maps used in this application's first iteration. This project incorporates georeferencing and spatial data creation techniques and methodologies for digitizing historical data and configuring app building software. The Hong Kong Historic Urban Land Use Web App successfully delivers the historic data in a user-friendly web-based application that allows users to investigate the land use differences and download the complete dataset for their individual purposes. The project also serves as a model for the development of similar web-based applications for exploring historical spatial data.

Chapter 1 Introduction

Hong Kong is a unique and dynamic city located near the Pearl River Delta off China's southern coast. The city is rich with history interwoven with its complex geography. Shaped by its position as an important former British colony, the city has undergone periods of rapid population growth and urbanization to become a global financial hub. A key feature of Hong Kong's geography is the land reclamation projects that have altered the original coastlines of Hong Kong Island and the Kowloon peninsula. Consequently, land reclamation profoundly impacted Hong Kong's land use and urban development.

This thesis project creates an interactive web map application that shares spatial data of historical land use and land zoning of Hong Kong's Central and neighboring districts. Prior to this, these maps were only available in print form and could only be accessed through designated record offices. This application utilizes a web geographic information system (GIS) to provide downloadable open datasets of these historical maps as well as allow users to search and query the data based on land use, town planning unit, and date. This chapter provides more background on Hong Kong's history, land reclamation and its relation to the land use (as fifty-two percent of the spatial data captured sits on reclaimed land), and an overview of the project goals, users, and development process.

1.1 Hong Kong Background

The Hong Kong Historical Urban Land Use Web App provides historic Hong Kong GIS data in a digital format. To better understand the context of this application, this section provides background information on Hong Kong's history.

1.1.1 Colonial History of Hong Kong

Originally a cluster of small fishing villages, Hong Kong eventually became an important free port for traders of the British Empire. Early in the 19th century, the British Empire was dependent on tea imports from China to meet its local demand. During this period, Imperial China only accepted payments of silver. The British Empire could not sustain this exchange and began to illegally import opium into China (Civatis n.d.).

The first Opium War started in 1839 when the Qing dynasty declared opposition to the opium trade. After China's defeat, the island of Hong Kong was ceded to the British under the Treaty of Nanking in 1842. The Second Opium War followed, and it led to further Chinese cessions. The 1860 Convention of Beijing granted the British control of the Kowloon Peninsula and Victoria Harbor. In a final convention over territory in 1898, the full extent of British Hong Kong also included the New Territories and Lantau Island, which were given a lease term of 99 years, set to expire on June 30, 1997 (Szcepanski 2020).

The Chinese Revolution in 1911 brought the establishment of the Republic of China in 1912, and Hong Kong became a political refuge for exiles, prompting an initial growth in population. During World War II, Hong Kong briefly fell under Japanese control, but the British took it back after the Japanese surrender in 1945. The Chinese Civil War brought an influx of refugees from the mainland, both rich and poor. This base of labor and capital set the foundation for Hong Kong's growth towards an international manufacturing and financial hub (Schenk 2023). The decades following saw an increasing influx of immigrants from southern China and fueled rapid economic and population growth. By the end of the 1980s, Hong Kong had become one of the most prosperous places in Asia.

At the approach of the end of the British lease on the New Territories, China and Britain signed a Joint Declaration on December 19, 1984, to pronounce Hong Kong a Special

Administrative Region (SAR) of China. The agreement of this declaration brought forth the, “one country, two systems” policy, which would allow Hong Kong to retain its existing legal system and capitalist economy for 50 years following the handover (Civatis n.d.). On July 1, 1997, Hong Kong officially became Hong Kong SAR, marking the historic handover.

1.1.2 Hong Kong Geography

The Hong Kong SAR is located at the southern coast of China at the mouth of the Pearl River. The territory encompasses the two major islands of Hong Kong and Lantau, a portion of China’s mainland (the Kowloon Peninsula and New Territories), as well as a collection of 230 smaller islands and the waterways that interconnect them. The total area of the territory is 2755 square kilometers, roughly 1104 square kilometers (40% of total area) of which is comprised of land. Figure 1 shows the official territory of the Hong Kong SAR.

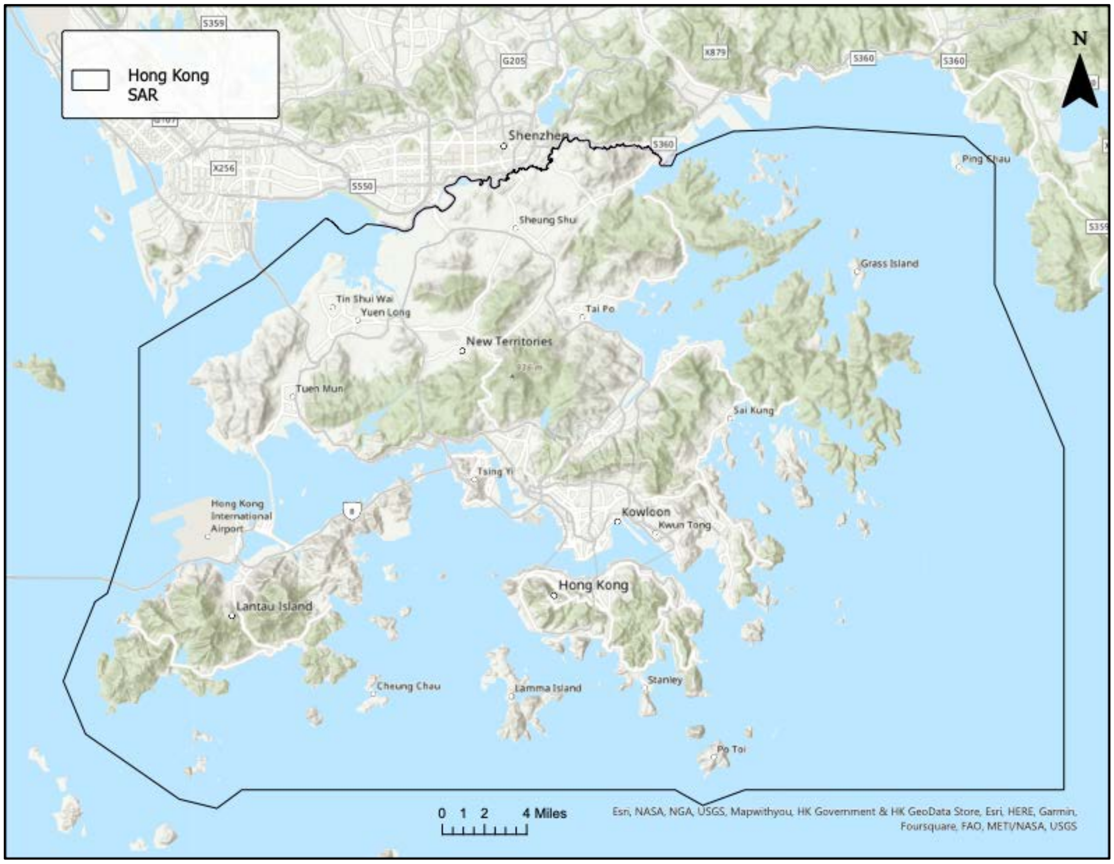

Figure 1. Map of Hong Kong SAR

The area's topography is considered rugged, constituting steep mountains and deep valleys. The highest point is Tai Mo Shan located in the New Territories with an elevation of 957m (CEDD 2019). Figure 2 shows modern aerial imagery of Hong Kong Island, the Kowloon peninsula, and neighboring islands.

Figure 2. Aerial imagery of Hong Kong Island

The geology of Hong Kong is an important aspect of understanding the full picture of its urban development. Most of Hong Kong is igneous rock, specifically granitic and volcanic rocks. Igneous rock accounts for 85% of Hong Kong's land surface while sedimentary rock accounts for 15% (Shaw 2010). Igneous rock is extremely hard and dense, making it difficult to excavate or drill through, they are considered unfavorable for engineering purposes (Blat 2006). Because 84% of the total area of Hong Kong is sloped (Ye 1998), developing and building on land poses a unique issue. Hong Kong's hills are generally slopped at 30-45 degrees (Gregory 1964), only adding to the engineering difficulty.

1.1.3 Hong Kong Economic Growth and Land Reclamation

There is a high demand for land space in economic development. The coastal region of China is one of the most densely populated places in the world and it is a main component of the fast-growing national economy. In 2011, China's coastal provinces and cities contributed to 60.8% of the national GDP, while they hosted 43.5% of the country's population in only 13% of its territory (Liu and Liu 2008). The combination of a large population and a rapid-growing economy has led coastal administrations to promote urbanization and expand. China imposes a minimum area of land that all regions should maintain for food production and the strictness of this policy means that developing on arable land is not possible. In response to this, local governments have turned to land reclamation as a replacement for the arable land that would have been used for urban or industrial development (Liu and Liu 2008).

In contrast to other world cities, the developed area of Hong Kong is only 25% of the entire territory, highlighting how much the region is hamstrung by its topography. Hong Kong has undergone a series of land reclamation projects in an effort to accommodate the expanding population and work around the area's naturally difficult geology. Land reclamation is the process of creating new land by filling in existing bodies of water. In total, the land reclamation programs have added 70 square kilometers to the city's area. The first land reclamation project occurred in 1851 in the western part of Hong Kong Island after a fire destroyed over 400 homes and the British rulers decided to combine the rubble and soil and deposit it in the harbor to create a new roadway. Between then and the early part of the 20th century, most land reclamation projects occurred on the northern coast of Hong Kong and were welcomed as a way to alleviate health and safety concerns of overcrowded neighborhoods. As of 2018, the sections of reclaimed land comprised about 6% of the total area of Hong Kong and 25% of its developed land (Ng 2022).

1.2 Land Use and Urban Development in Hong Kong

Land use is a vital component of urban planning because it determines how land is allocated and developed in cities. Good land use planning ensures that the urban environment is functional, efficient, and sustainable. Land use should also align to support the economic, environmental, and social goals of the city. Because land in Hong Kong is an extremely scarce resource, effective land use planning is paramount for managing the city's growing populations and the demands of its multifaceted economy.

The "Hong Kong 2030+" planning vision is a policy initiative the Hong Kong Government has implemented to manage the city's land resources and guide land use planning and development (Planning Department 2021). In this plan, the government aims to promote more sustainable land use practices such as development of green spaces and promotion of developments with low-carbon footprints.

1.2.1 Urban Planning for Density

Cities like Hong Kong and Singapore successfully incorporated the high-rise, high density Multiple Intensive Land Use (MILU) concept in the late 20th century (Zhang 2000). MILU involves increasing the density of land use by combining residential, commercial, and other activities in urban areas that are supported by public transportation infrastructure. Hong Kong only has 17,600 hectares of buildable land to house 6.7 million people, resulting in a high-density range of 2500-3000 people/ha (Lau 2005). The population of Hong Kong is projected to increase steadily over the next 30 years with an average rate of 0.7% per annum (Wang et al. 2015). There is a basic housing demand for the growing population. The average living space in Hong Kong is less than 14 square meters per capita (Wong 2011). Leading up to 2030, the total housing demand is 924,000 units (Wang 2015). Additional land is also needed to serve economic activities and transportation infrastructure.

Because Hong Kong is one of the most densely populated urban areas in the world, focusing on vertical expansion has been the key solution to managing limited land and resources. Urban designers and managers have shown great interest in Hong Kong's approach to vertical land use, recognizing its potential to maintain a thriving living and work culture (Lau 2005).

Developing effective land use policies requires consideration of local characteristics. In cities with high population density, compact, mixed, and efficient land use patterns are preferred. In contrast, in less dense cities, urban layouts that prioritize convenient living for citizens are prioritized over purely efficient use of land (Wang et al. 2015). As a typical high-density city at the crossroads of fast population growth and limited land resources, Hong Kong's high-rise approach was the logical choice. Sustainable development and land use is still a crucial part of Hong Kong's urban plan.

1.2.2 Planning Department in HK

There are two entities responsible for the urban planning and development of Hong Kong, The Town Planning Board (TPB), and the Planning Department (PlanD). The Town Planning Board is a statutory body of the Hong Kong Government that is tasked with developing urban plans. Members are appointed by the Chief Executive including professionals from sectors such as architecture, engineering, and surveying. It is established under the Town Planning Ordinance with the main goal of promoting health, safety, convenience, and general welfare of the community through the preparation of layout plans for areas of Hong Kong. Its functions including considering planning applications, making amendments recommendations on development plans, and listening to public's representation on planning matters (Town Planning Board n.d.).

The Planning Department and is the organization that decides how land in Hong Kong can be used. It is responsible for implementing the land use planning policies and decisions set by the TPB. The objective of the Planning Department is to foster a better live and work environment for residents of Hong Kong. The Planning Department is responsible for the preparation of different types of plans to guide the proper use and development of land. The plans can range from developmental strategies at the territorial level to statutory and departmental plans at the district (Planning Department 2018).

An Outline Zoning Plan (OZP) is a statutory plan prepared by the Town Planning Board under the Town Planning Ordinance. Essentially it is a plan that portrays the land-use zonings and major road systems of individual planning areas. Land within the maps are divided into different zones marked with their land uses, such as commercial, industrial, or residential. A zone can also be divided into subtypes; for example, residential could have several subtypes depending on the proximity to the coastline. Each plan is accompanied by a Schedule of Notes which specifies the uses have always been permitted and those that would require permission from the Town Planning Board (Planning Department 2018).

The key relationship between the TPB and the Planning Department is that the TPB sets the policy framework for planning decisions, while the Planning Department implements those decisions and provides technical expertise.

1.3 Open Data Overview

The simple definition of open data is data that "can be freely used, re-used, and redistributed by anyone – subject only, at most, to the requirement to attribute and sharealike" (Open Data Handbook n.d.). The open data movement is also being used by governments to release their data to make it available for the public to use. This open data can then be used by citizens to develop new applications and services. It also increases governmental transparency and promotes more accountability of responsible decision making.

Hong Kong promotes its open data initiative with its website data.gov.hk. Data.gov.hk is coordinated by the Office of the Government Chief Information Officer with the participation of other government departments to disseminate different types of information for the public sector. The objective of the data.gov.hk portal is to increase community value by providing demographic, economic, geographical, meteorological, and historical data to the public to be used in commercial and non-commercial purposes (data.gov.hk n.d.)

1.4 Application Overview

The goal of the Hong Kong Historical Urban Land Use Web App is to provide an accessible database where historic land use data of Hong Kong can be easily downloaded and used for other spatial science work. Currently land use maps and records for Hong Kong are only accessible by visiting the Government Records or Planning Department offices in person and searching based on Town Planning Unit or Outline Zoning Plan. This greatly limits the work that can be done surrounding historic land use in Hong Kong. The main utility of this application is creating a centralized database of these historic data to be accessed anywhere over the internet.

1.4.1 Target Users

This application is designed to cater to spatial scientists, historians, journalists, and urban planners that are interested in studying the difference in land use over time in Hong Kong. It is intended to be a way to quickly visualize what the possible differences are and then take that data for further use if desired. Even though the primary target users are researchers, it is designed simply enough to be used by anyone who has a general interest in the subject.

An example of a target user could be an urban planner who is considering a design of a new section of reclaimed land. The planner could use the platform to see if there is a pattern of how land use has been transforming near the area of the newly reclaimed land. For example, if there is a pattern that a neighboring area has been evolving from business and commercially dominated to more residential, then the planner may have a better idea of how to proportion the new reclaimed land to suit the growing demand of a specific land use.

Another example of a target user could be the Planning Department and the Government Records office. These departments want to disseminate the records they have available to the public but must follow the formalities of their departments. This application could act as a public preview to the source maps and provide the general public easy access to data that is on their shelves.

1.4.2 Study Area

The initial version of this project focuses on a few districts on the north and northwestern coastline region of Hong Kong Island. The districts include Kennedy Town, Sai Yin Pun, Sheung Wan, and Central. The early colonial city of Victoria covered this extent and therefore is the area of the island that has the longest land use history. The official units of study area are the

Tertiary Planning Units (TPU) 114, 122, and 123. Figure 3 depicts the boundary of the three TPUs as they are currently.

Figure 3. Boundary of TPUs 114, 122, and 123 demarks study area

1.4.3 Data Overview

The key data for this application are historic maps of TPUs. The Tertiary Planning Unit is a geographical reference system demarcated by the Planning Department of Hong Kong for the entire territory. TPUs provide a common geographical system for the compilation of statistical data. For example, the Census & Statistics Department of Hong Kong would prepare and manage data of the population census based on the TPU. Also, data requirements of the different users can be met by converting data recorded on the basis of TPU in the users' geographical information system for their planning and operational purposes (Planning Department 2018). TPUs are delineated upon the consideration of various factors including the nature of the geographical features of the area (such as roads, railway lines, coastlines, contours, and waterways), lot boundaries, and zoning boundaries in the Outline Zoning Plans. TPU boundaries would be revised from time to time to reflect the latest urban developments including urban renewal, urban sprawl, and reclamation.

1.4.4 Data Accessibility

The current accessibility of the historic TPU maps is limited to in-person search at the Government Records Office in Kowloon. The public has access to view these maps on site and can purchase copies or digital scans on a per piece basis. Unfortunately, there is no way to preview the maps remotely or online. One of the project's aims is to increase the accessibility of this spatial data in an open online data source so that it can be viewed and used from anywhere at any time by anyone.

1.4.5 Methodology Overview

The main component of this project involves digitizing historic land use maps to create a new database. Land use maps are first scanned into a JPEG or PNG format and then brought into ArcGIS Pro and georeferenced to fit the imported map onto the base map in the correct coordinate system. Once correctly georeferenced, a new feature class of polygons is made by hand tracing over the imported historical map. The layers are then published in ArcGIS Online as web maps and are used as the main component of the web app. The web app was built and configured with widgets using ArcGIS Web App Builder.

1.5 Thesis Structure

The following sections describe the related works, methodology, results, and discussion surrounding the project. In Chapter 2, a literature review is conducted on the topics of Historical GIS (HGIS) and Open Data, and it concludes with other examples of similar projects. Chapter 3 covers the methodologies used to complete the project. It goes over the requirements and the goals of the project, the process of acquiring and processing the data, and how the project was published publicly. Chapter 4 reports the results of the methodologies used and examines then in more detail. The thesis concludes with Chapter 5, which discusses the project's strengths, insights gained from using the application, as well as challenges as ideas for continued development.

Chapter 2 Related Work

This chapter provides a review of studies related to HGIS, Open Data, and Open GIS. The first section discusses the importance of HGIS in scholarship and how the combination of geographic information science (GISci) and history can provide insights for both disciplines. Section 2.1.2 provides examples of HGIS research and its influence. The next sections discuss open data and open-source GIS. A core concept of this project is about providing an upgraded open dataset that can be used in iterative and collaborative work. The chapter concludes with discussing the opportunities and challenges of open data and open-source GIS and provides examples.

2.1 Historical GIS (HGIS)

Historical GIS is the combination of the disciplines of history and GISci, wherein GIS tools and methodologies are used to explore elements of history. Section 2.1.1 discusses the importance of HGIS in scholarship and how historians have used GIS. Section 2.1.2 covers examples of HGIS research and reviews other HGIS projects.

2.1.1 Importance of HGIS in Scholarship

The use of GIS technologies in historical research started in the late 1990s and eventually developed into what is now known as Historical GIS, or HGIS. As Knowles (2008, 3) states, “[a]lmost every historical document contains some kind of geographical information.” It therefore makes sense that more and more historians are using GIS technologies and techniques to uncover spatial relationships, reconstruct places and natural environments of the past, and extract more value derived from historical sources (Cillis et al. 2021). In the decades since its advent, HGIS has experienced a rise in interest for historical research.

Lawson (2022) identifies four major characteristics emerging in HGIS. Firstly, all historical research often has significant geographical elements. Second, a lot of the evidence in research is actually geographical information. Thirdly, Structuring and organizing the evidence into databases that record location and time is the basis for analyzing it further. And fourth, the results are often shown in the form of maps. Mapping is an integral part of GIS, but it is essentially a database technology, and it is the treatment of historical data as information to be inputted into a database that makes HGIS (Gregory 2007).

HGIS, and indeed all GIS, are able to provide information about what is featured in the database, and more importantly, where it is located. HGIS allows for the overlaying of different kinds of data that can help orient the historian to identify patterns. Bodenhamer (2008) says that GIS is intrinsically integrative where multiple information sources are layered on a map with the same spatial units.

There is a slight difference between HGIS and narrative history insofar that traditional historians are essentially interpretive storytellers that try to provide an explanation of events of the past. But HGIS uses maps and spatial data to illustrate the patterns but not provide an explanation (Schlichting 2008).

An intention of HGIS is to provide a way to create new insights of geographies of the past. These new insights can advance historical scholarship by challenging existing historical narratives and enable researchers to attempt to answer unresolved questions or ask new ones. A prime example of this is when in 2006, Knowles explored the Battle of Gettysburg in a new way by creating a detailed Digital Terrain Model (DTM) of the area and performed a viewshed analysis to discover what an observer would have been able to see from any location on the field. This new insight allows historians to identify what officers could have seen throughout the battle and how that could have had an influence on key decisions (Gregory 2007). This shows that the application of GISci by formulating a spatial question and using of GIS technologies to address it, can lead to an advance in historical understandings.

There are some clear advantages of HGIS in scholarship. One advantage described by Gregory (2007) is that because spatial data tells us where the data are located, data that could be seemingly incompatible can be integrated together based on where on the Earth's surface the data are located. Similarly, MacDonald and Black (1998) argue that the use of GIS in history is useful in providing context by bringing a wide variety of data types together, such as textual, numerical, and visual, all in the correct location in space and time. These advantages of GIS in historical research are strengthened by the fact that historical data can be visualized with maps, animations, and virtual landscapes.

Another major advantage of HGIS is the dissemination of information. Conventionally, historical research is confined to academic journals and textbooks, but HGIS allows for easy dissemination of complex historical data via the internet. The combination of assembling a wide variety of historical information, linking it to a common geography and publishing it on the internet allows the research to reach a wider audience beyond academics. The simplest way to disseminate an HGIS project is to publish the data on a web map that allows user to zoom, pan, turn layers on and off and make queries, such is the goal of this project.

HGIS could be considered an ideal tool for maintaining a collective memory of environments of the past. Because of the integration with computational systems, HGIS programs can highlight inconsistency and incompleteness of data, thereby encouraging researchers to keep a high data-quality standard (Siebert 2000). Using GIS for historical research also makes it easier for the researcher to record metadata, further centralizing related information of the integrative data.

Naturally, there are some disadvantages when using GIS for historical research. A common issue in any GIS research is that data acquisition and input is very costly and time consuming, this is only more exaggerated when dealing with huge amounts of data that span a long period of history (Siebert 2000).

An example of the challenges and limitations of HGIS is described by Berman (2014), which addresses the challenges of measuring the space of administrative geographies in historical China when using HGIS. Berman argues that aligning conceptions of bearings and distance between the past and the present is essential when reconstructing historical geographies, but often the accuracy of this information cannot be verified, which then can lead to false conclusions when running calculations in a GIS. To address this, Berman proposes using network models to represent established relationships between known points instead of using bounded jurisdiction models, which are more conventionally used in GIS. Berman says that when dealing with ancient sources, limiting the types of administrative units is preferred. Instead of reconstructing estimated boundaries implementing a network model to show the administrative hierarchy of a specific time using known point locations and administrative relationships is a better use of time (Berman 2014).

2.1.2 Examples of HGIS Research

Visualizing patterns of historical data with HGIS can have an impact on historical debates. Such is the case with Geoff Cunfer's HIGS "On the Great Plains: Agriculture and Environment, which contributes to the debates about what caused the Dust Bowl of the 1930s (Cunfer 2005). In this project, Cunfer explores the change of 400 counties in the Great Plains region from the 1870s to the late 20th century using agricultural census data. This allowed Cunfer to examine crop diversity, irrigation patterns, cultivation and grazing areas and agricultural mechanization. This was visually presented in choropleth maps.

There are a few HGIS projects that are good examples of information dissemination. Schaefer's online GIS of nineteenth century England (Schaefer 2004) and the North American Religion Atlas by Lancaster (2002) are prime examples. The International Dunhuang Project (2006) from the British Library uses point data superimposed over raster scans of maps. The project has created a database of over 100,000 documents, manuscripts, and other relevant materials from between the 5th and 11th centuries that were excavated on the Silk Road near Dunhuang, China. The database includes coordinates of the location of each artifact. This online GIS allows users to query the database through a map-based interface (Klemme 2014). The Sydney TimeMap Project shows the development of Sydney from early European colonization to the present day (Wilson 2001).

HGIS can also be used as a tool for deeper research, such as monitoring, preserving, and planning forest landscapes. Clillis, Statuto, and Picuno (2021) present a method to monitor the dynamics and management strategies in a case study in the Mediterranean region. In the study, they explain that the territory is transforming at a rapid pace due to socioeconomic and climate reasons, which is pushing the ecosystem to be unbalanced. Their goal was to evaluate the temporal dynamics surrounding this. They used a methodology based on HGIS that allows different types of geodata to be integrated together. Using historical cartography and remotely sensed data, they assessed where and how much the forest landscape had changed. Their results show that the forest area is returning to how it was recorded in the first half of the 1800s with a progressive increase since 1950 due to artificial reforestation and the re-naturalization of forests due to a decrease in agricultural activities.

HGIS has even been used for health-related studies. Oxford et al. (2001) look at the correlation between poverty and mortality rates in London from the late 19th century to the 1990s. Charles Booth originally conducted a massive survey of the social and economic conditions of residents of London in the late 19th century and constructed large, detailed maps of the social class of London on a street-by-street level. The result was a clear geography of poverty and affluence of the period. Using GIS, Oxford et al. combined Booth's data with more contemporary ward boundaries and other census data from the 1990s and created an index and compared the geographies of poverty and mortality rates (Oxford et al. 2001). The study discovered that the geography of poverty and affluence from the late 19th century was similar to that of the late 20th century, showing that the spatial patterns of poverty in London have not changed in a hundred years. Another interesting discovery of the study was finding that causes of death for people over 65 years old was more closely related to the geography of poverty from the 19th century than in the contemporary period (Oxford et al. 2001).

HGIS has been used to analyze rural landscapes. Statuto et al. identifies land use changes in a rural area in the Basilicata Region of southern Italy by using territorial analysis with GIS. Historical maps from 1829 to 2013 were imported and DTMs were used to make 3D reconstructions of the landscape from different time periods (Statuto et al. 2017). This is another example where it is imperative to digitize historical cartography to do proper analysis of rural land changes and understand how land transformations are connected to both human and natural events. In the 1820s, the study area was mainly dominated by woods and grazing was the main agricultural activity. By 1876, the landscape was modified to increase agricultural land and the wooded areas were cleared for economic opportunities. The area that was once a semi-natural zone transformed into a full agricultural area from 1876 to 1955 due to the increase in the population's economic needs. The human activities that caused this transformation are now better understood with this HGIS analysis (Statuto et al. 2017).

Historic population change can be studied in HGIS. McLeman et al. looks at the historical impact of droughts had on population change on the Canadian Prairies during the 1930s and how there is a complex intersection of climate, agriculture, and population change (McLeman et al. 2011). GIS was used to map "hotspots" where there was severe heat and lack of precipitation let to a decline in population in rural areas. The model used digitized census data combined with historical climate data at 10 kilometer grid cell scale and showed that drought conditions, decreased prices of commodities and economic recession led to the displacement of hundreds of thousands of people. The authors suggest that a focus on historical data can provide a better understanding of how populations have adapted to extreme climate conditions and how that can provide feedback for future strategies (McLeman et al. 2011).

2.1.3 Examples of HK HGIS

Land reclamation is major part of Hong Kong's urban development history. Approximately 6% of Hong Kong's total area is reclaimed land and the government says that this accommodates 27% of the city's population and as much as 70% of all commercial activities (Vetter 2018). Land reclamation in Hong Kong began as far back as 1841 and over the course of its colonial history and beyond, more projects have been added to create the final coastline it has today. In 2014, Ngo et al. developed a web map to visualize the expansion of Hong Kong's coastline by land reclamation. Prior to the Hong Kong Coastline Web Map, maps of Hong Kong's reclaimed land boundaries were scarce and became quickly obsolete as new projects continued. A map reading group of volunteers spent a year researching historic maps, photos, and articles to create illustrations of the land reclamation projects throughout Hong Kong's history. These illustrations were digitized and converted to spatial data using Google Maps Engine and then transferred to CartoDB for customization (Ngo et al. 2014). The interactive web map allows users to visualize the location and progression of land reclamation through time. Pop-up windows can be opened to provide more information about the data. A slider tool allows users to animate the land reclamation development as well as narrow the search to specific time frames. The map also includes geo-tagged historic photos.

Another Hong Kong centered web GIS project is HKMaps.hk. HKMaps.hk was developed by Tymon Mellor, an engineer that has worked on many infrastructure projects in Hong Kong. HKMaps.hk is a simple web map app that has a map viewer with and OpenStreetMap basemap. The viewer has zooming and panning functionality and a few basic widgets. The main widget opens a list of historical maps that when selected, display over the basemap. A transparency slider widget allows the user to increase the transparency of the overlaid historical map to see how it compares with the current map. Other data can be selected and layered onto the web app such as coastline line data, aerial imagery, and point data of military and mining sites. HKMaps.hk also includes a tab with a list and preview of all the maps available in the web app, as well as more information and links to the source.

2.2 Open Data and Open Source GIS

A foundation of this project is to provide an open database of the land use maps sourced from the Hong Kong Government records office. This section discusses open data and open-source GIS. Section 2.2.1 covers the definitions of open data while section 2.2.2 covers the origins of the open data movement. Section 2.2.3 describe how open data related to GIS and geospatial data. Section 2.2.4 covers the opportunities and challenges surrounding open data while section 2.2.5 provides examples of open data projects.

2.2.1 What is Open Data?

The definition of open data is data which is not restricted by copyright laws and is user accessible, meaning it is available using platforms or tools that are free and easily accessed by the public. The Open Knowledge Foundation (2023) defines open data as “data that can be freely used, shared, and built-on by anyone, anywhere, for any purpose.”

Licenses are used in the field of open data for organizations to set parameters on how the data may be used or accessed. This usually includes legal information regarding the data and how it can be used. Common licenses such as Creative Commons exist while government agencies and organizations have developed custom licenses that explain the parameters of how the data may be re-distributed or used. Open data can be organized at the country, state, organization, or topic level (World Bank 2021).

The ideal for open data is that it is useable, and for this to occur, data should have complete metadata. Two indicators that open data is accessible and being successfully used are when open data leads to innovations within a particular field and open data is incorporated into existing or new projects or products. The hope is that as open data’s value is seen and recognized and utilized within new business, products, and projects and this reinforces the demand for open data and therefore promotes more open data to be created (World Bank 2021).

Open data stems from the concept of open science, which refers to science conducted in a collaborative environment with a focus on research communication. Both open science and open data consist of principles of transparency, reuse, participation, accountability, and practices of using open publications, sharing data, and citizen science. (Charalabidis et al. 2018).

Wilkinson et al. (2016) created the acronym FAIR, which stands for findable, accessible, interoperable, reusable. They (2016, 4) argue that "FAIRness is a prerequisite for proper data management and data stewardship" and "good data management and stewardship is not a goal it itself, but rather a pre-condition supporting knowledge discovery and innovation".

2.2.2 Origins of Open Data

Simon Chignard, an expert of data governance, describes the open data movement as a techno-political idea that has rapidly spread around the globe. He underpins this statement with the definition of open data being data that must be free technically (accessible using free tools), legally (little to no copyright barriers), and economically (free without paywalls).

Chignard mentions that this idea is not something new and that the scholar Robert Merton was already advocating that all science research should be publicly accessible in 1942 (Chignard 2013). The Nobel Prize of Economics in 2009 was awarded to Elinor Orstrom, who unveiled how a "common good" was technically possible. Orstrom showed that not only does open data allow multi-user access (meaning nobody's work is impeded by the work of another) but also that the open data idea can actually lead to innovation or further research being added to the common good (Ostrom 1990).

Open data was first used in an environmental government publication in 1995 to collect and utilize data to compile a more complete and global image of the state of the biosphere and oceans (Chignard 2013).

2.2.3 Open GIS

Open data and open-source software have been making a significant impact in GISci. Over the past few decades, GIS has witnessed significant growth encompassing various proprietary and open-source software. Free and Open-Source Software for Geospatial (aka

FOSS4G) is a recurring global event held since 2006, encouraging and promoting open-source software development (Maurya et al. 2015). GISci has seen an increase in desktop, mobile, and web applications and the open-source movement has played a critical role in this growth. The criteria for open-source software is that it must have be free to redistribute, contain the source code, include derived works, protected the integrity of the author's source code, does not discriminate against any persons or groups, does not discriminate against any field of endeavor, the license must not be specific to a products and the license must not restrict other software (Maurya et al. 2015).

Open-source web GIS has been used for monitoring urban land use planning. Development of a Web GIS application framework using open-source software to provide open data services for policymaking and urban land use planning. The application was developed using a comprehensive geodatabase model and user interface using open-source tools such as QGIS, MapSever, and P mapper. The system is designed to create a complete digital map service with information on urban land use policy, suitable for public consumption and a decision support system for stakeholders (Sejati et al. 2020). This web GIS framework was applied to Balkipapan City, in East Borneo, Indonesia. The expectation of the system is to serve as a model for land-use monitoring based on the principles of information disclosure towards smart city and smart governance. The framework was developed to mainly monitor urban land use planning in developing countries and includes a user interface with menus for accessing data such as infrastructure planning, search, and reporting. Balikpapan's Web GIS menus uphold the principles of open data, not only enabling operators but also the public to report on infrastructure development and land use. The display data is sourced from both the government appointed operators and the public, this is to stay in line with the principles of smart governance which include data transparency and participatory data. The authors state that the implementation of such a framework can have a positive impact on public trust in the government. The use of this web GIS is a step towards bridging the communication gaps between the public and government (Sejati et al. 2020).

Open-source is also used in database building. Open-source databases and their spatial extensions provide robust and reliable solutions for managing spatial data (Chen 2008). As the demand for spatial data handling increases, open-source databases are likely to see more development and adoption. Currently, MySQL is the most extensive open-source database software and is available on operating systems such as Linux, Mac, and Windows. PostgreSQL is highly scalable, is SQL compliant and has a strong reputation for reliability, data integrity, and correctness. PostgreSQL has a spatial extension called PostGIS, which conforms with OGC and ISO SQL/MM standards. This makes it possible to use PostgreSQL for modern spatial application development. (Chen 2008).

Open-source geospatial software is regularly used by governments, business, professionals, and academics and the communities of open-source geospatial software and open geospatial data highly intersect. The Open Geospatial Consortium is closely linked with open geospatial standards and ensures geospatial interoperability (Minghini et al. 2021). The relationship between open-source geospatial software and open geospatial data is likely to get even closer.

2.2.4 Open Geospatial Data

There are three types of open geospatial data: collaboratively contributed data, authoritative data, and open scientific data. Collaboratively contributed data is when volunteers collect and maintain geospatial data, usually by crowdsourcing. Authoritative data is collected and shared by governments and other public administrations to promote the freedom of access to information. Scientific data is shared to help with the verification of research findings and to integrate results (Coetzee 2020).

Collaboratively contributed open geospatial data are distinguished between user generated content, crowdsourcing, and citizen and community science. Open Street Map (OSM) is the most widely known example of an open geospatial dataset that is maintained and expanded by its community of contributors. Raifer et al. presents the OpenStreetMap History Database (OSHDB), which is a framework for spatio-temporal analysis of OSM history data. This allows for spatio-temporal analyses of OSM data on a global scale, a user-friendly way to create large scale visualizations (Raifer et al. 2019). But there is still an issue with the data quality of OSM, it may vary in accuracy, completeness and precision since the enthusiasts that contribute might have different GIS knowledge and skills (Coetzee 2020).

Authoritative data is when governments collect and maintain geospatial vector data such as administrative boundaries, building footprints, street centerlines, etc for governance and management purposes. The idea is that open and shared authoritative data could lead to more efficient and effective decisions for government. A specific example of this is the European Amended Public Sector Information Reuse Directive, which aims to make public government data available for reuse with fewer legal restrictions. The sharing of open public data can increase entrepreneurship and innovation. Spatial data infrastructure (SDI) facilitates the sharing of spatial data among the different stakeholders in the community, and an open SDI is not just about providing open data, but also organizing the infrastructure around it to encourage the participation of others outside the government (Coetzee 2020).

Open scientific data allows for scientific claims to be verified, confirmed, or rejected in an open way. The need for open scientific data has been recognized for over fifty years by the International Council for Science. The promotion of FAIR principles aims to improve the sustainable use of digital resources such as data. Scientific journals such as *Nature* and *Scientific Data* endorse the notion of science as an open enterprise and will only publish articles with supplementary material that meet FAIR standards (Coetzee 2020).

2.2.5 Opportunities and Challenges

The open GIS concept includes 8 dimensions: data, software, hardware, standards, research, publication, funding, and education. Open GIS offers 4 opportunities for the GIS community: technology-driven opportunities, application-led opportunities, crowd powered opportunities, and education focused opportunities (Sui 2014).

Despite it becoming increasingly important in shaping future research and educational agendas, there are academic, legal, social/political, and environmental impediments for the practice of open GIS (Sui 2014).

The future of the open-source communities is uncertain. Open data can be difficult to ensure quality, and openness makes the data and software more vulnerable to abuse and manipulation. Both open-source projects and open datasets are examples of shared resources that are maintained by the community, so there are questions around how contributing volunteers can be retained (Coetzee et al. 2020).

Although greater transparency and accountability, improved data sharing, increased citizen access to government decision-making is a positive effect of open data, there are also some downsides. Open data that fails to address privacy concerns may lead to negative and harmful outcomes, such as the emotional, financial, and physical targeting of individuals

(Johnson et al. 2017). There is a danger when governments provide open data to support economic development because they might be supporting a model that promotes private sector services instead of using open data for citizen-facing services. Private sector companies may use open data to gain commercial advantages, such as bidding to supply public sector services. Private sector companies may also repackage, process, and analyze government data for the government or private sector. Taxes paid by citizens to fund the provision of open government data are affected by the indirect costs of not having reliable access to the data. At the same time, private sector companies profit by offering a private service back to the public for a fee. Therefore, the government needs to be cautious of using open data to support economic development that promotes private sector services instead of citizen-facing services (Johnson et al. 2017).

There is a cost to geospatial open data. The indirect costs are citizen participation challenges, uneven provision across geography and user types, subsidy of private sector activities, and corporate influence on government. These indirect costs may stunt the effectiveness of open data in increasing transparency and citizen engagement in government. Johnson et al. suggests that governments need to manage the indirect costs of open data while maximizing its positive effects. It must balance competing values such as privacy and transparency and develop outreach programs to educate the public on how to access, use, and interpret open data.

Open geospatial software and open data will influence each other in the future. The increase in the use of spatially enabled services and shifting towards software that can process spatially-enabled data (Coetzee et al. 2020). Because of the increasing volumes of free and open geospatial data, there is a need for computing platforms that can extract useful information from the data in an efficient way. Cloud computing platforms are changing the way geospatial data are processed, analyzed, and visualized (Coetzee et al. 2020).

2.2.6 Urban and Land Use Open Data/GIS

GRASS GIS is a muti-purpose open-source GIS. Geographical Resources Analysis Support System (GRASS) is a key open-source GIS that has been under development for over 28 years. It is a mutli-purpose GIS that can be used for geospatial data production, analysis, and mapping. The development of GRASS is community based, the developers are distributed globally, communicating through online source code repositories, mailing lists, and a wiki (Neteler et al. 2012). The latest release of GRASS has more than 400 modules and natively runs on all popular operating systems, giving basic and advanced functionality to users of all kinds. GRASS offers many spatial modeling algorithms, 3D visualization, image processing routines, and integrates well with other open source and proprietary software packages that have GIS applications. GRASS has been applied in the field of public health, epidemiology, and infectious diseases (Neteler et al. 2012).

There is increasing importance of metadata in the GIS community, especially in the academic context. It is becoming more complex to create and maintain metadata. There is preliminary work on an approach to overcome these issues using the Free and Open Source (FOSS) GIS products quantum GIS 1.8.0 and PostreSQL 9.2 with Post GIS 2.0. The authors describe how metadata creation can be automated. It couples metadata and data, and ensures that the metadata is updated automatically when the data changes. The motivation is to automate metadata creation that can save time and effort, improve metadata quality and consistency, and contribute to interoperability among multiple GIS (Ellul et al. 2013).

There is a study that linked open geospatial data for predicting urban semantics and land use classification in Europe. OSM/Linked geodata was used to extract features related to land use, land cover, and infrastructure (Re Calegari et al. 2015). The study found that linked open geospatial data can be used to support sustainable urbanization and planning activities is less costly than manual work.

There is potential of using linked open geospatial data in extracting actionable knowledge about the urban environment to support sustainable urbanization processes and offer innovative solutions to smart city problems (Steiniger 2009). The article presents set of experiments that use geo-information about points of interest as input in a classification model of land use over wide urban areas in Europe. The experiments were replicated in different European cities to ensure replicability. This emphasizes the importance of monitoring changes in land use to support a sustainable urbanization process. The experiment aimed to develop a classification model for land use in four European cities, Milan, Barcelona, Munich, and Brussels. The article discusses the use of linked open geospatial data in predicting urban land use, with the aim of supporting or updating expensive spatial data sources. The authors suggest that combining complementary geospatial information from OpenStreetMap with other sources like phone activity data, could lead to better solutions (Steiniger 2009).

Chapter 3 Methodology

This chapter reviews the requirements of the project and the methodologies for completing it. This chapter begins with a review of the project's requirements and objectives, which are the guideposts of the application's development. The following sections cover the steps necessary to develop the application. Section 3.2 covers the software choices needed to execute the methodologies and deploy the final version. Next, section 3.3 discusses the data used in creating the new database. Finally, section 3.4 covers the process of building the historical database and application.

3.1 Requirements and Objectives

The objective of this application was to create a platform that allowed users to visualize historic land use data in the central district of Hong Kong and to provide access to this data. This section outlines the requirements that were necessary to fulfil this objective. A goal of the application is to display the land use survey data of the tertiary planning units (TPUs) and allow users to see the different land use types across years. By using a digital map, users can see multiple survey map data at the same time and pull this data for their own use. To accomplish these objectives, the necessary requirements are explained below.

3.1.1 Accessibility

The accessibility requirements for this application prioritize easy access. The application must be available to users via a desktop or mobile device. There should be no additional program downloads or account setup for most of the functionality, therefore users will only need a default web browser to access the application. Lastly, the application will require no training to use, making the application accessible to anyone regardless of GIS background.

3.1.2 Functionality and Intended Users

This application is designed to provide specific functionality to meet the needs of various intended users. Firstly, the app must have the capability to visualize the georeferenced land use types of the TPUs. Users should be able to explore the data by panning and zooming using a mouse or trackpad. The application should also allow users to toggle layers for different TPUs and years, enabling them to selectively view the desired information. Additionally, users should have the ability to import and visualize other data alongside the land use data, enhancing the analytical capabilities of the app. There should be search and query functionality to facilitate the identification of specific land use types. Lastly, the application should support data export functionality, allowing users to utilize the data in other software programs for further analysis.

The intended user base for this application is diverse, catering to a range of disciplines and interests. The primary intended user is an academic researcher who is interested in exploring the spatial history of Hong Kong. The app and accompanying dataset can serve as a valuable resource for analyzing the transformation of land use in Hong Kong from its colonial era to its current status as a part of China. GIS professionals and academics specializing in the field can also find this application and associated thesis helpful as a reference for developing similar historical GIS projects.

Furthermore, key users of the application could include the Hong Kong Public Records Office and the Hong Kong Planning Department. The Public Records Office houses the original paper maps of the TPU land use surveys that have been digitized for this project. Researchers interested in accessing these maps currently need to physically visit the office, making the research process time-consuming. The website of the Public Records Office catalogues the maps, but without preview images, making it difficult to ascertain the contents of each map without a full download. The availability of a readily accessible website application like this one would significantly reduce the time and effort required to study these land use maps.

Finally, the application also aims to serve the general public and non-professionals who have an interest in Hong Kong's history. History enthusiasts and curious individuals would find value in an application that provides access to historical data, offering insights and perspectives that might not be readily available otherwise.

3.1.3 Software Requirements

Since this application is an early version that will continue to be developed over time, the software requirements must reflect this. There are four main things when considering which software to use to develop the application. First, it must be capable of producing web maps. Second, it must allow for free sharing and access for the user. Next, it must include tools to interact with the presented data. And lastly, it must allow for continued development for future iterations.

3.2 Software Choice

For better integration of the software requirements, a software platform that could handle each part of the requirements was preferred. Esri is an American GIS software company that is best known for its ArcGIS products. ArcGIS products are considered the gold standard of GIS software and most notably include ArcGIS Pro and ArcGIS Online. ArcGIS products are capable of spatial analysis, mapping, data collection and management, imagery and remote sensing, and 3D GIS (Esri). Esri's ArcGIS products are used by governments and universities worldwide. The Esri product suite fulfills the map digitizing requirements with ArcGIS Pro, the publishing requirements with ArcGIS Online, and the customization requirements with ArcGIS Web AppBuilder.

ArcGIS Pro is the software heavily used at the Spatial Sciences at USC. It is Esri's professional desktop GIS application and has full-functionality for building maps and visualizing data. For the first part of this project, ArcGIS Pro was the appropriate software to bring in scanned images of the historical TPU maps and convert them to digital polygons.

ArcGIS Online is a cloud-based mapping and analysis program. It is not as robust as ArcGIS Pro but it is preferred for its sharing capabilities. With ArcGIS Online, content can be shared inside and out of an organization and is a good choice for collaborative projects. For this project, sharing the polygon layers built in ArcGIS Pro to ArcGIS Online was a necessary step towards building the web map application.

ArcGIS Web AppBuilder is application available to run via ArcGIS Online. It is an application that allows users to build unique and dynamic experiences without having to write any code. This is the preferred publishing software for the project as it is already seamlessly integrated with the other Esri software.

3.3 Data

The data used in this project are historical land use maps of TPUs. Tertiary Planning Units are a geographical reference system that subdivide Hong Kong's territories into units smaller than districts. The six maps used to create spatial data are from TPU 114, 122, and 123. These TPUs were chosen as they are clustered together in neighboring districts. There are two maps from different years for each TPU as is shown in Table 1. Maps created before 1980 used the Hong Kong 1963 Grid coordinate system, while maps created after used the Hong Kong 1980 Grid. A description of each historical TPU map is given in sections following.

Table 1. Land use survey map data

Dataset	District	Source	Date	Scale	Coordinate System
TPU114_1972	Sheung Wan	HK GRS	Nov 1972	1:2400	HK 1963 Grid
TPU114_1982	Sheung Wan	HK GRS	April 1982	N/A	HK 1980 Grid
TPU122_1967	Central	HK GRS	Aug 1967	1:2400	HK 1963 Grid
TPU122_1985	Central	HK GRS	Aug 1985	1:2500	HK 1980 Grid
TPU123_1967	Central Area	HK GRS	Aug 1967	1:2400	HK 1963 Grid
TPU123_1985	Central Area	HK GRS	May 1985	1:2500	HK 1980 Grid

3.3.1 Map of TPU 114 (1972)

TPU 114 is located in the middle of the Sheung Wan neighborhood, on the northwestern part of Hong Kong Island. Sheung Wan is the neighborhood directly west of the main Central District. Part of TPU 114 sits along the coastline with the harbor. The map of TPU 114 from November 1972 shown in Figure 4 is at a scale of 1:2400. The original map has faded to a yellowish color and shows wear and tear around the edges. This map depicts TPU 114 at a time when it met with the coastline, showing protruding ferry piers.

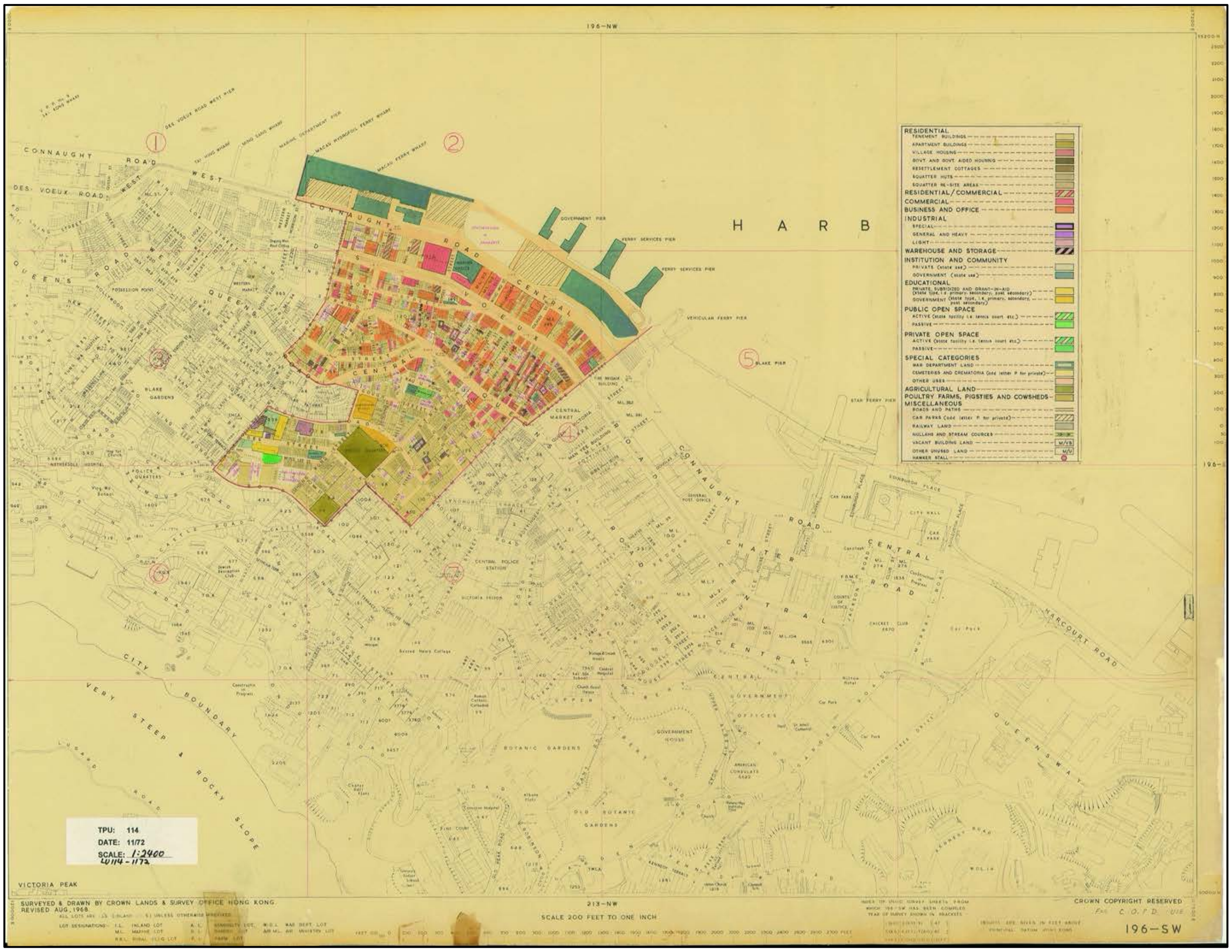

Figure 4. Original map of TPU 114, year 1972

3.3.2 Map of TPU 114 (1982)

The map of TPU 114 from April 1982 as shown in Figure 5, does not have a specified scale. The extent of the map is smaller than the 1972 version. The map is less faded and shows streets and building plots more clearly. The survey data of this map does not include the coastline area and ferry ports as it did in the 1972 version.

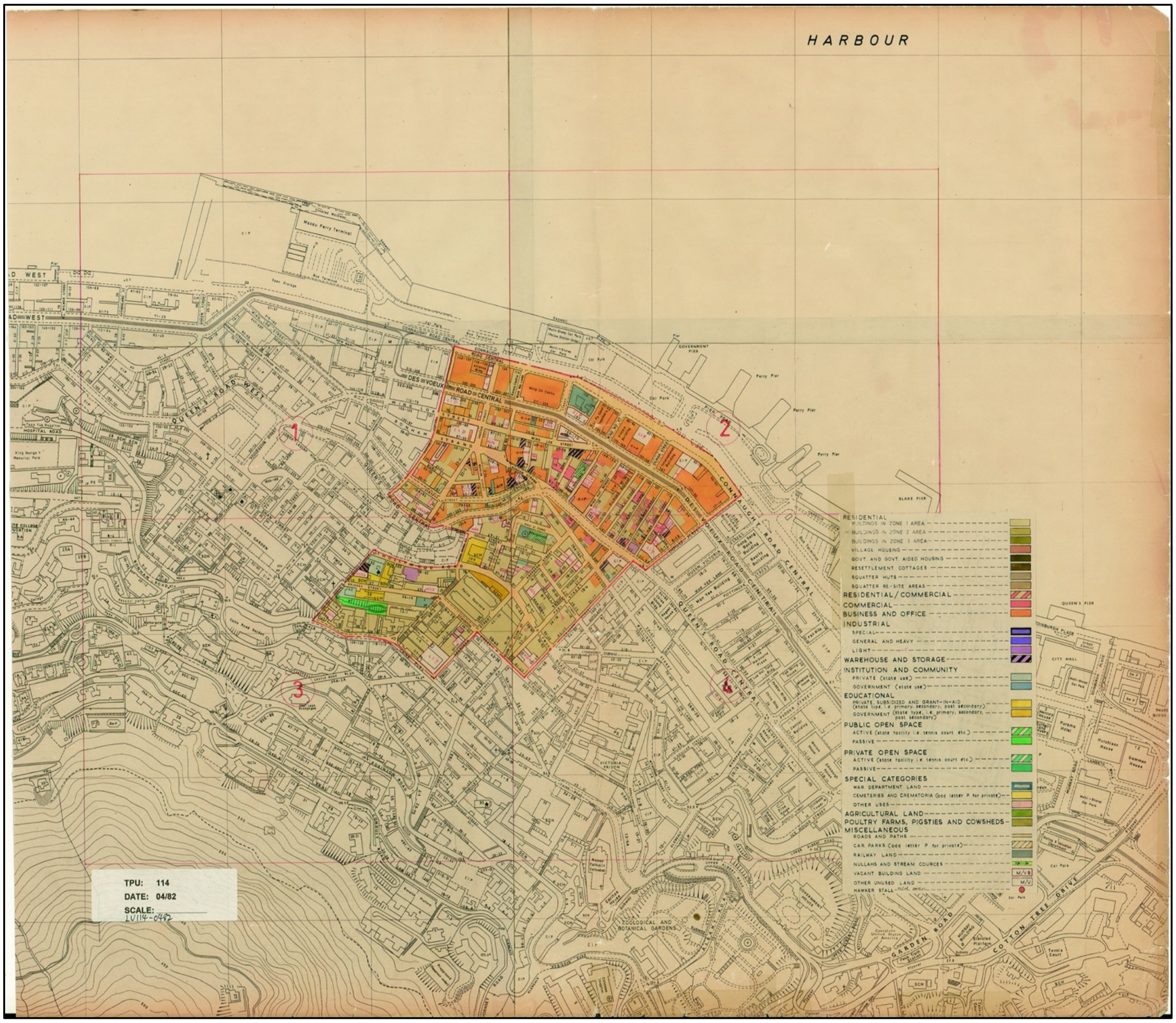

Figure 5. Original map of TPU 114, year 1982

3.3.3 Map of TPU 122 (1967)

TPU 122 borders TPU 114 to the east and is smaller. It is further inland away from the harbor and closer to Mount Austin. This TPU mainly revolves around the parcel that was the Central Police Station. The original map for TPU 122 from August 1967 as depicted in Figure 6 is at a scale of 1:2400 and shows signs of fading within the legend.

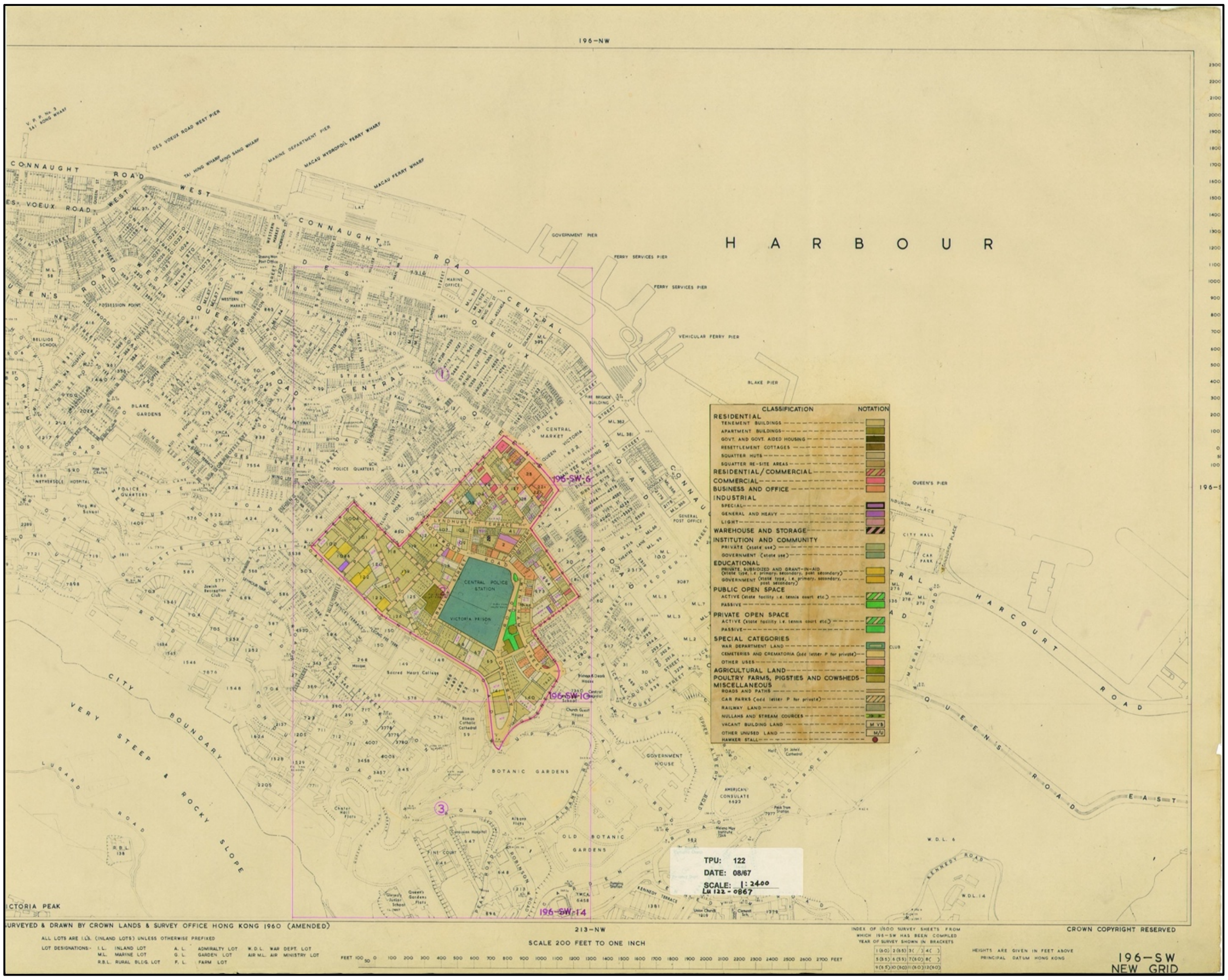

Figure 6. Original map of TPU 122, year 1967

3.3.4 Map of TPU 122 (1985)

The map for TPU 122 from August 1985 is at a scale of 1:2500. Figure 7 shows that the extent of the map is different from the 1967 version, it includes more depiction of Mount Austin in the southwest and less of the northern coastline.

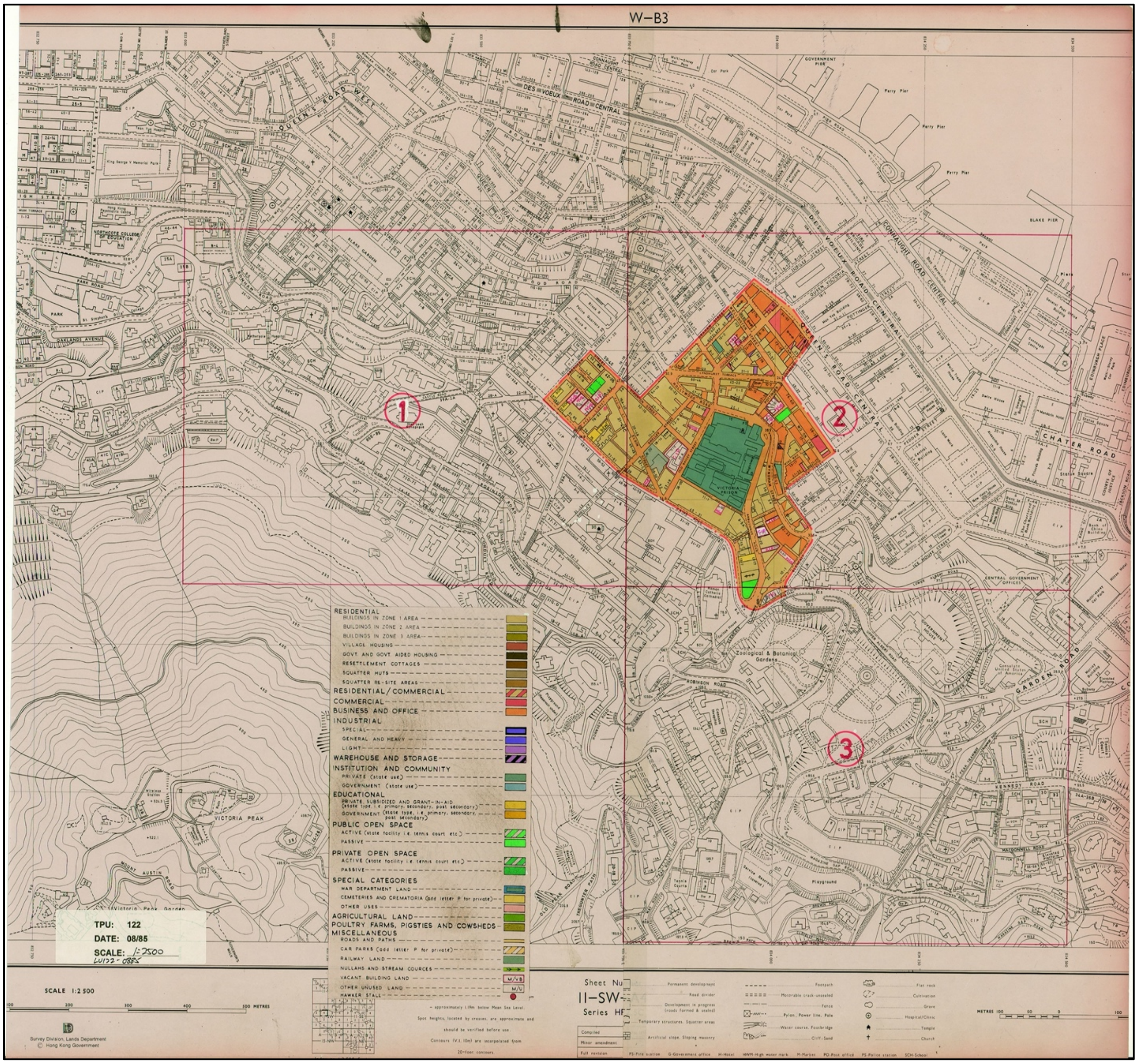

Figure 7. Original map of TPU 122, year 1985

3.3.5 Map of TPU 123 (1967)

TPU 123 is in the middle of the Central district and shares a border with TPU 122 to the west. TPU 123 includes the Government House, which was the office and residence of the Governor when it was a colony and for the Chief Executive after. This TPU once sat along the harbor before more land was reclaimed. The map for TPU 123 from August 1967 is also in a scale of 1:2400. It highlights the land use from Government House down towards the coastline, as is shown in Figure 8. As one of the older maps of the series used in this project, the paper is yellow from age.

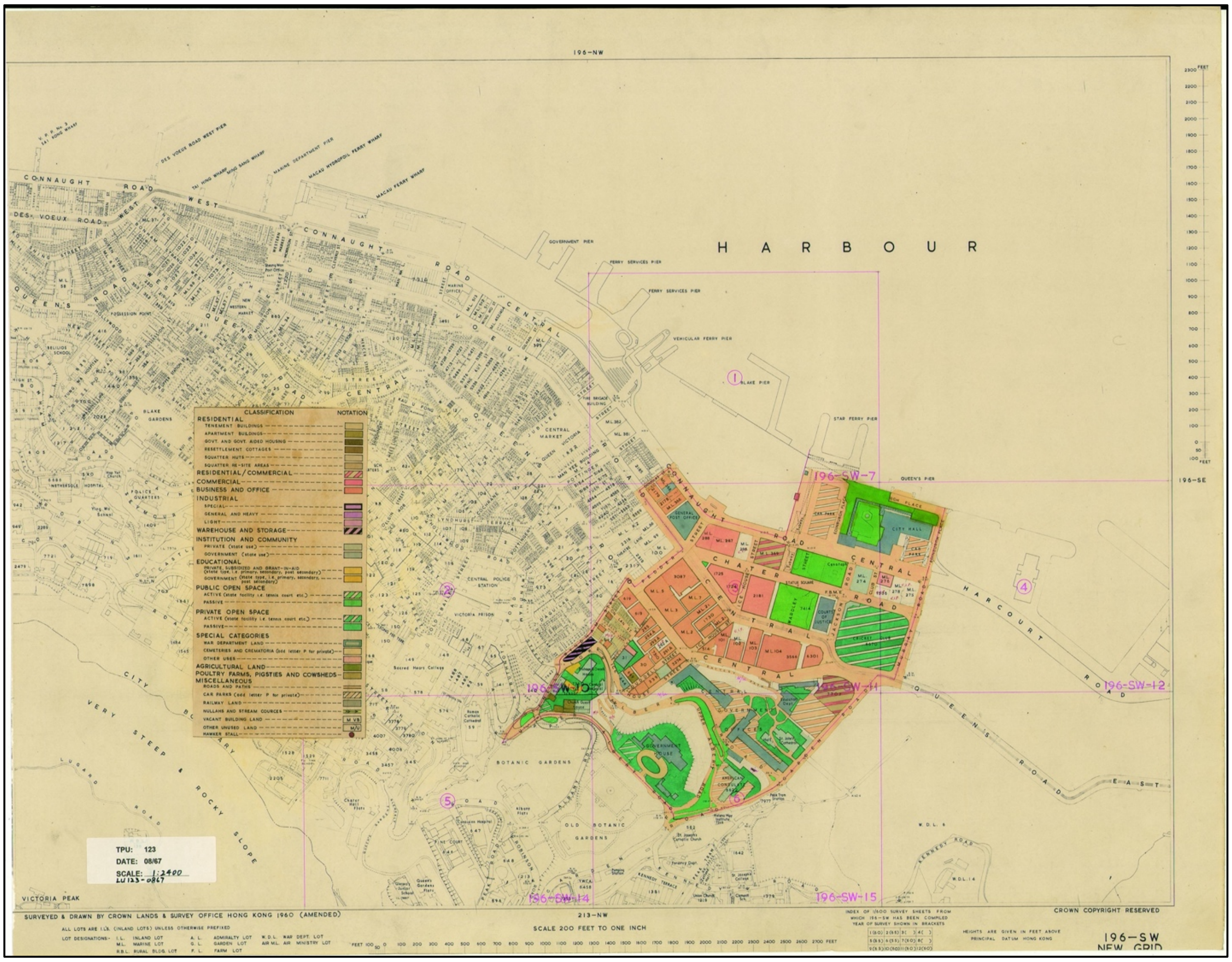

Figure 8. Original map of TPU 123, year 1967

3.3.6 Map of TPU 123 (1985)

The map for TPU 123 from May 1985 is at a scale of 1:2500. Scales of all maps used in the project are referenced in **Error! Reference source not found.**. As seen in Figure 9, the 1985 map of TPU 123 shows less extent and includes land use data of the ferry pier, which was visible in the 1967 map but not categorized.

Figure 9. Original map of TPU 123, year 1985

3.4 Building the Historical Database

The construction of the historical database was the most time intensive component of this project. Ultimately, the utility of the application and the data it contains relies on the accuracy of transforming the historical maps into digital data. Section 3.4.1 describes the georeferencing process that aligned the historic maps to a coordinate system, and section 3.4.2 covers the steps taken to create a digital layer of each map's data.

3.4.1 Georeferencing

In many GIS and HGIS projects, the building of the database is considered to be the most time-consuming stage, and such was the case in this project. To capture vector data from the historic maps, the process of digitizing was initiated. Captured data from a map or another source like aerial imagery is considered as secondary data capture because the source is at least one stage removed from the real world (Gregory 2007). With paper maps, they first needed to be converted to a digital image by using a high-resolution scanner. Since the TPU maps had already been digitized by the Government Records Office, they were ready to be brought into ArcGIS Pro for further processing. The maps were imported as PNG files to keep high resolution.

Georeferencing is a fundamental GIS technique which converts the raw coordinates of the image into a real-world coordinate system. When the layer has real-world coordinates, it means it can be used to calculate distances, areas, and angles in real-world units of measurement. Also, the layer can then be integrated with other layers that have real-world coordinate systems (Gregory 2007). Georeferencing is done by adding control points to the layer. In technical terms, it refers to the alignment of spatial data on a geographic grid (Skopyk 2021). The Hong Kong 1980 Grid was chosen as the as the geographic grid for this project. The Hong Kong 1980 Grid is a projected coordinate system widely used in Hong Kong for describing position of land boundaries, map features, buildings, and town planning zones (Kwok 2012).

When bringing a map image into ArcGIS Pro, it will not automatically display in the area of interest on the map; it has no spatial reference. To begin the process of digitization, the correct coordinate system of the basemap needed to be specified. To match the coordinate system of the historical paper maps, the Hong Kong 1980 Grid coordinate system was selected. Each map then needed to be brought into the approximate extent before it could be further georeferenced. To do this, the background reference map in ArcGIS Pro was roughly zoomed in on the location of central Hong Kong. The map image layer was set to display.

Once the map image was displayed in the correct approximate extent, control points could be added. Typically, four or more control points are used and positioned in the corners of the map sheet. Control points were added by activating the Georeferencing ribbon in ArcGIS Pro and selecting Add Control Points. First, a point on the digitized historical map was selected, then another point was selected on the map in the GIS to rectify where the original point should have been. It is important to understand the map and the study area when choosing appropriate control points. In the case of the TPU maps, they had all been produced between 1967 and 1985 and many of the building lots had changed. To select control points that were consistent between the historical map and the modern background map, major street intersections were chosen as well as corners of the Government House parcel. After the input of each control point, ArcGIS Pro automatically bends, stretches, and rotates the pixels in the map image to fit the geographic grid.

When the georeferencing transformation happens, a mathematical equation is assigning XY coordinates to every pixel of the map image. In ArcGIS Pro, there are several transformation options, and each has a unique advantage. The zero polynomial simply shifts data, first order polynomial optimizes for global accuracy, and the 2nd and 3rd order polynomial provide local but not always general accuracy (Skopyk 2021). For this project, first order polynomial was chosen. Once the georeferencing was completed with control points, it was saved as a new raster layer and each layer was set to the Hong Kong 1980 Grid coordinate system.

3.4.2 Digitizing Historical Maps/Creation of Spatial Data

With the maps accurately georeferenced, the process of digitizing each map could begin. Digitizing the map effectively means to create spatial data of the content within the map. A new file geodatabase was created in ArcGIS Pro and from there a new feature class was created for each georectified TPU map. When creating each new feature class, the two new text fields were added to the attribute table for Type and Subtype; the original maps had general land use types and then more specific types under the general category. The feature class was set to the same Hong Kong 1980 Grid. The new feature class created a new layer in the project, which was then selected and in the Edit tab, the Create function was chosen to open the Create Features pane. From the pane, the option of creating polygon features was chosen. Using this tool, each polygon on the original map was traced by hand. After each polygon was drawn, attribute values were typed in for the zoning type and subtype.

3.5 Web App Development

After the spatial data had been created, the next phase of the project was the development of the web app. Using chosen software, workflows were followed to make the spatial data publishable and layout designs were selected. Section 3.5.1 discusses the publishing of the web layers. Section 3.5.2 covers how the web map was designed. Section 3.5.3 describes the building of the web app and lastly, section 3.5.4 covers how the web app was launched and published.

3.5.1 Publishing Web Layers

Once the maps had been digitized in ArcGIS Pro, the next step was to publish the layers so they can be used in web map. To do this, each layer first needed to be adjusted to be in the WGS 1984 Web Mercator (auxiliary sphere). This was done by changing the coordinate system in the layers' properties. The layers were then selected and chosen to Share As Web Layer. After configuration and an analysis of potential publishing errors, each layer was then published to ArcGIS Online and listed under Content.

When sharing as a web layer, a layer type must be selected from either feature type, tile type, or vector tile type. Web feature layers support vector feature querying, visualization and editing. This is the option most suitable when visualizing data on top of a basemap. A web tyle layer uses predawn map images (called tiles) for fast map visualization. This layer type is best for basemaps. Vector tile layers are vector tiles and style resources that adapted for customized display. These are best for basemaps or operational layers. Since the HK HULU app prioritizes showing the data on top of a basemap, feature layer types were chosen when publishing the web layers.

3.5.2 Designing the Web Map

A new web map was created in ArcGIS Online to consolidate all the digitized polygon layers from ArcGIS Pro. In order to focus attention on the digitized polygon layers, an appropriate basemap needed to be chosen that would adhere to cartographic best practices. The Light Grey Canvas basemap was selected as it offered enough detail to view the polygon layers in context but simple enough that it did not distract the viewer from the important information.

To complement the choice of basemap, the symbology for the layers needed to be colorful but not busy. A problem occurred when originally setting the symbology in ArcGIS Pro.

When the layers were symbolized using the unique values choice in the symbology pane, the colors were unique based on attributes Type and Subtype. However, when this was applied to other layers, the unique values colors did not match the ones of the previous layer. This was because not all layers had the same combination of Types and Subtypes included in their attributes. To solve this, a new field in the attribute table was created titled Type_Subtype so each combination of Type and Subtype would be its own unique value. The unique value symbology was set to this new field. There were 25 unique combinations. To complete the symbology and make sure that the same colors would be used in each layer, 25 unique RGB values were generated by best matching the color scheme from the source maps and applied to each Type_Subtype in all layers. The Warehouse and Storage and Misc(Car Park) categories were symbolized with hatching on the source maps but that functionality was not compatible with ArcGIS Web App Builder so a solid color that best represented the category was chosen. The details of RGB values and HEX code for each Type_Subtype are shown in **Error! Reference source not found.**.

Table 2. RGB values for land use categories

Type/Subtype	R	G	B	HEX #	Color
Business and Office	255	170	0	FFAA00	
CIP	245	245	220	F5F5DC	
Commercial	241	70	106	F1466A	
Educational	240	230	0	F4E600	
Educational (Government)	248	220	15	F8DC0F	
Educational (Private)	248	237	18	F8ED12	
Industrial (General and Heavy)	160	100	180	A064B4	
Industrial (Light)	213	165	219	D4A5DB	
Institution and Community (Government)	108	177	158	6CB19E	
Institution and Community (Private)	138	252	185	8AFCB9	
Misc (Car Park)	255	180	100	FFB464	
Misc (Other Unused Land)	240	240	230	F0F0E6	
Misc (Vacant Building Land)	248	248	245	F8F8F5	
Private Open Space (Active)	170	255	150	AAFF96	
Private Open Space (Passive)	106	241	119	6AF177	
Public Open Space (Active)	160	255	100	A0FF64	
Public Open Space (Passive)	129	241	82	81F152	
Residential (Apartment Buildings)	183	166	110	B7A66E	
Residential (Govt. & Govt. Aided Housing)	70	45	29	462D1D	
Residential (Tenement Buildings)	204	191	139	CCBF8B	
Residential (Zone 1)	219	205	153	DBCD99	
Residential/Commercial	255	120	150	FF7896	
Special Categories (Other Uses)	230	187	187	E6BBBB	
TBD	128	128	128	808080	
Warehouse and Storage	130	70	150	824696	

3.5.3 Designing the Web App

The Web App is the final published version of the project application. Because it was built using ArcGIS WebApp Builder, it did not require any code to design the specific elements of the application. However, design choices were made regarding layout and widgets were chosen and configured to execute the required functionality of the application.

3.5.3.1 Layout Design Choices

First, the Theme of the app had to be selected. A Theme in WebApp Builder is an out-of-the-box layout template that gives the app it's look and feel. Themes are organized by panels, styles, and preconfigured widgets. It is important to select a Theme with the end-user experience in mind. There are several Themes to choose from when working with ArcGIS WebApp Builder, Themes include: Billboard, Box, Dart, Dashboard, Foldable, Jewelry Box, Lanchpad, Plateau, Pocket, and Tab. All of the Themes are pre-designed for a few general purposes. The Billboard theme is the most basic which is for apps with very simple tasks. Other themes such as the Dashboard theme is more focused on showing all widgets open at the launch of the app. The Pocket theme is designed for apps that are intended to be embedded in other websites.

The Hong Kong Historical Urban Land Use application is a map-centric app. The main focus on the application is the layers of spatial data that had been digitized from historical maps. The Dart theme was chosen as it provides a wide view of the map. The application is also meant to be engaged with, allowing users to view different layers and perform other actions to gain more insights from the data. Even as a map-centric application, the app also needed to support a host of widgets that give users easy access to tools to analyze the data further. The Dart theme has a ribbon that runs along the bottom of the screen where the widgets were brought in neatly so all functionality was available without disturbing the attention of the map. The Dart theme also allows for widgets to be opened in smaller windows on the screen that can all be opened at the same time and moved around the page, giving the user flexibility without over complicating potential workflows.

3.5.3.2 Widget Choices

Widgets are tools that control the functionality of an app in ArcGIS WebApp Builder. The Hong Kong Historical Urban Land Use application is meant to be interacted with, and the spatial data available for further analysis and processing. There are many different widgets available when creating a project and each Theme comes with a few pre-configured widgets. The Dart theme automatically loads with map zoom buttons, a legend widget, and layers widget. The legend widget is necessary to identify the land use types in each layer. The layer widget allows the user to select which layers are visible; this is very important since the first version of this app includes land use data of the same TPUs from different years, so the layers overlay each other.

The next widget added was the Filter widget. This was chosen so that users can change how the map is displayed based on the attributes they are interested in. The Filter widget allows for custom filter choices, an important part of the user experience. Next, the Screening widget was added. The Screening widget allows the user to identify an area of interest and analyze specific layers. In the widget, users can identify the area of interest by searching for a place name, drawing an area, or uploading a shapefile. The Screening widget is a fundamental tool because it allows for the area of interest to be downloaded in CSV, File Geodatabase, and shapefile formats.

The Query widget allows for users to retrieve information from the source data. When configuring the Query widget, the six TPU data sources from the web map were set as the queries. This allows the user to query each layer and retrieve its information. Queried results have the option to be exported to CSV, JSON, and GeoJSON files. The next widget chosen was the Select widget. The Select widget is a similar tool to the Screening and Query widgets but the user can easily use the mouse to highlight or click on the features of the map they are interested in. Once highlighted then the user has the option to export the selection to CSV, JSON or GeoJSON form. A key difference between the Select widget and the Screening widget is that the Select widget does not allow for the download of shapefiles. The Swipe Layer widget was added as an extra tool. This widget allows users to swipe to see the difference between one layer and another. Since this application portrays the change of data from the same locations over time, it is a convenient feature to have a quick visual comparison at the historical land use change.

The next widget added was the Add Data widget. The Hong Kong Historic Urban Land Use app strives to provide the most amount of functionality for an array of users. It is important that users can use the app to gain further insights for their own specific purposes. The Add Data widget allows users to bring other data into the web app. Users can search data from ArcGIS Online (if they have access), or they can input a URL, or even upload a file in shapefile, CSV, KML, GPX, and GeoJSON formats.

While not technically a widget, the Attribute Table function was enabled in the app to allow users to have a more traditional GIS experience. The Attribute Table is a separate tab at the very bottom of the page, not along the ribbon with all the other widgets.

The About widget opens a pop-up window with information about the application and provides tips on how to use the widgets. Also, a link is provided to a GitHub page where the full dataset is available in shapefile format.

Finally, the Share widget was added. This widget is to make it easy for users to share it with their contacts/audience by providing a link or embedding it on a website.

3.5.4 Publishing the Web App

The final process to the project was publishing a finalized web app. Since the web app pulls the map from the ArcGIS Online, it was first necessary to adjust the settings to make sure that all the layers could be visible publicly under the Share options. This process had to also be repeated for web map and web application. Lastly, the web app was published by selecting the launch button in ArcGIS WebApp Builder.

Chapter 4 Results

This chapter displays and discusses the results of the methodologies described in the previous chapter. The combined result is a working, publicly accessible web application that supports the functionality of exploring the data layers within it. The application is accessible via the URL: https://arcg.is/1GHWPW0. The chosen built-in widgets allow for filtering, querying, an downloading data. There is also functionality to bring in additional outside data into the application. This chapter opens with a full description of the spatial data created and then explores the results of the web map, followed by the final web mapping application.

4.1 Root Mean Square of Control Points

Georeferencing can be error prone. If the paper map is folded or creased or not placed perfectly flat in the digital scanner, or if the control points are inaccurate, the resulting map layer can be distorted. The cause of the distortion is called the root mean square (RMS) error. An RMS error is the difference between where the from control point ended up in comparison to actual specified location (ArcGIS Pro Help n.d.)

The connection between RMS errors and the coordinate system is a crucial one. The coordinate system provides the reference framework needed to take accurate measurement of the errors. Because the coordinate system establishes a consistent frame of reference, the positions of the control points can be properly defined and can help align the measured points with the expected points.

ArcGIS Pro provides a measure of the RMS errors. Using more control points is likely to increase the accuracy of the georeferencing and reduce the RMS error. Table 3 shows details concerning the transformation, number of control points, and RMS error breakdown. Because both the basemap and the historical maps shared the same Hong Kong 1980 Grid coordinate system, and sufficient control points were used, none of the RMS errors were particularly large. This indicates a higher level of georeferencing accuracy.

Table 3. RMS Errors Table

			RMS Errors		
Map	Transformation	# Control Points	Forward	Inverse	Forward-Inverse
TPU114_1982	1st Order Polynomial	7/7	1.92904	3.790704	0.00000
TPU114_1972	1st Order Polynomial	6/6	1.021159	1.930441	0.00000
TPU122_1967	1st Order Polynomial	6/6	2.02319	3.783216	0.00000
TPU123_1967	1st Order Polynomial	10/10	3.792342	7.172299	0.00000
TPU123_1985	1st Order Polynomial	7/7	1.235924	2.249308	0.00000

4.2 Spatial Data Created

The first goal of this project was the creation of spatial data from images of historic maps. The creation of this spatial data was the most time-consuming part of the project's development. The results offer a better visual experience when observing and a much improved opportunity for analysis of the content of each particular layer.

The first layer is of TPU123 from year 1967 and is shown in **Error! Reference source not found.**. This layer contains 17 of the 25 different land use categories from all 6 historical maps. The distribution of the categories is relatively even and not one category dominates the map. The categories are divided into separate quadrants of the TPU. The northwest quadrant mainly consists of categories Business and Office and Residential (Tenement Buildings). The center of the TPU is where the Commercial category is located including the Commercial/Residential category which signifies hotels. The northeastern quadrant mainly consists of Public Open Space (Passive) and Institution and Community with both Private and Government subtypes. There is one large Private Open Space (Active) category which was the location of the Cricket club. The lower half of the map contains a mix of Private and Government Institution and Community categories as well a Public and Private Open Space (Passive), car parks, and other unused land.

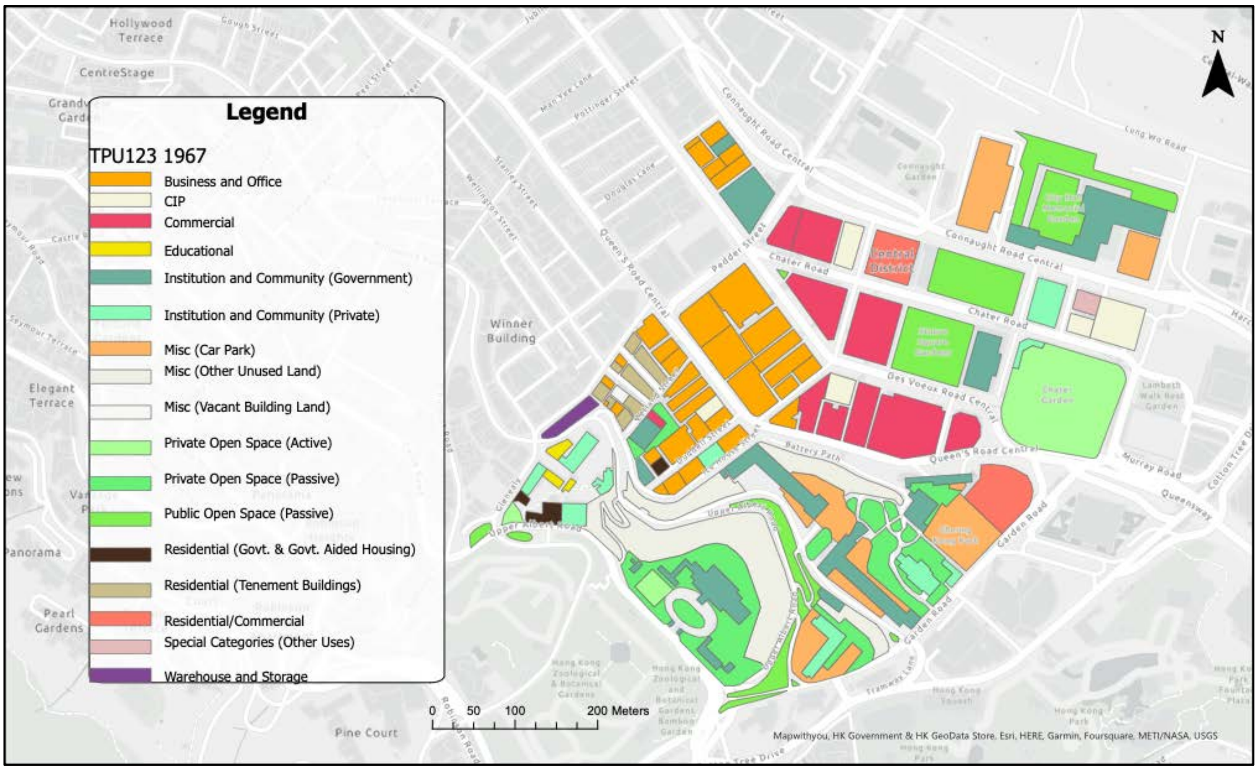

Figure 10. Map of TPU 123 layer from year 1967

The following layer is also of TPU 123 but from year 1985. As shown in **Error! Reference source not found.**, this layer only has 8 land use categories. The distribution of the Business and Office category appears very similar to the 1967 layer but includes some of the land labeled in the Commercial category. Some of the open space categories have changed included the Statue Square Gardens which was a passive Public Open Space in 1967 and became a passive Private Open Space. The active Private Open Space of the Cricket club transformed to a passive Private Open Space. Another noteworthy aspect of the 1985 layer is that it includes some Institution and Community categories that were ferry piers. When viewed with the modern basemap, it is clear to see how much land has been reclaimed since this survey.

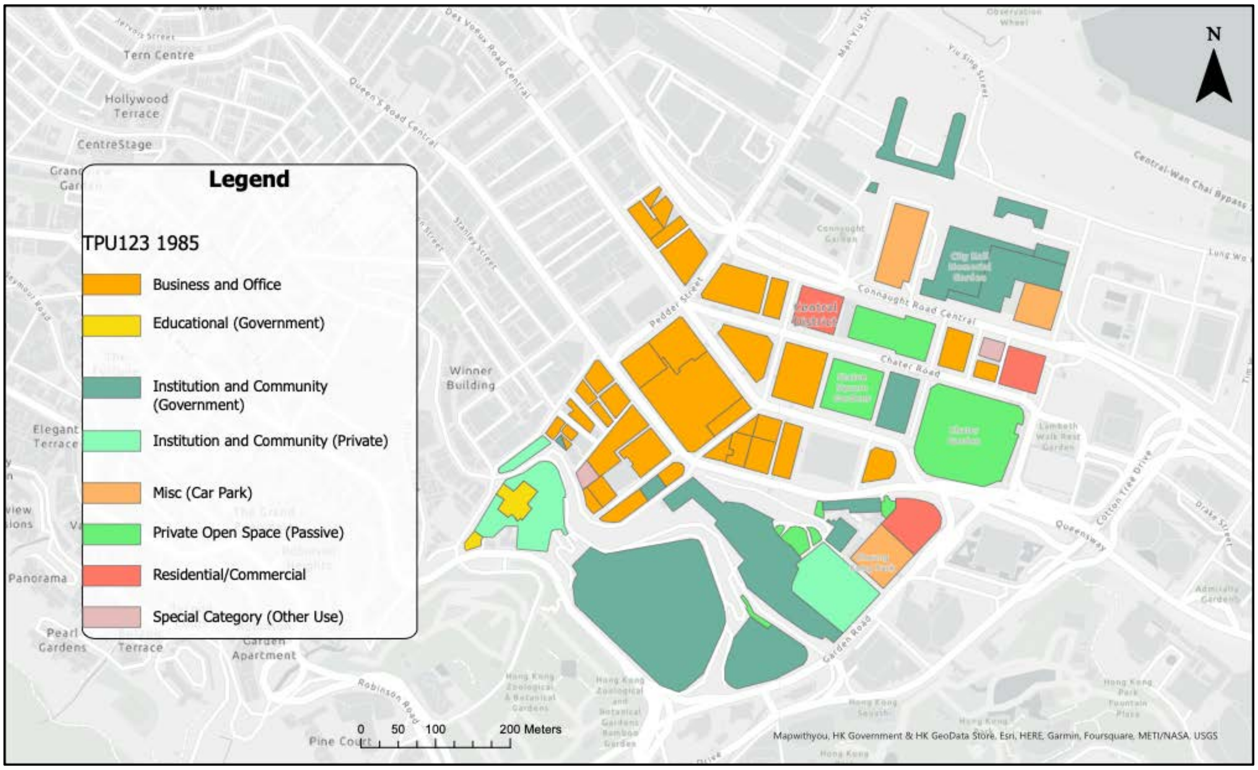

Figure 11. Map of TPU 123 layer from year 1985

The layer for TPU 122 from year 1967 has 12 land use categories and is depicted in **Error! Reference source not found.**. The focal point of this map is the major block of Institution and Community (Government) category while the surrounding land use is heavily dominated by the Residential (Tenement Buildings) category.

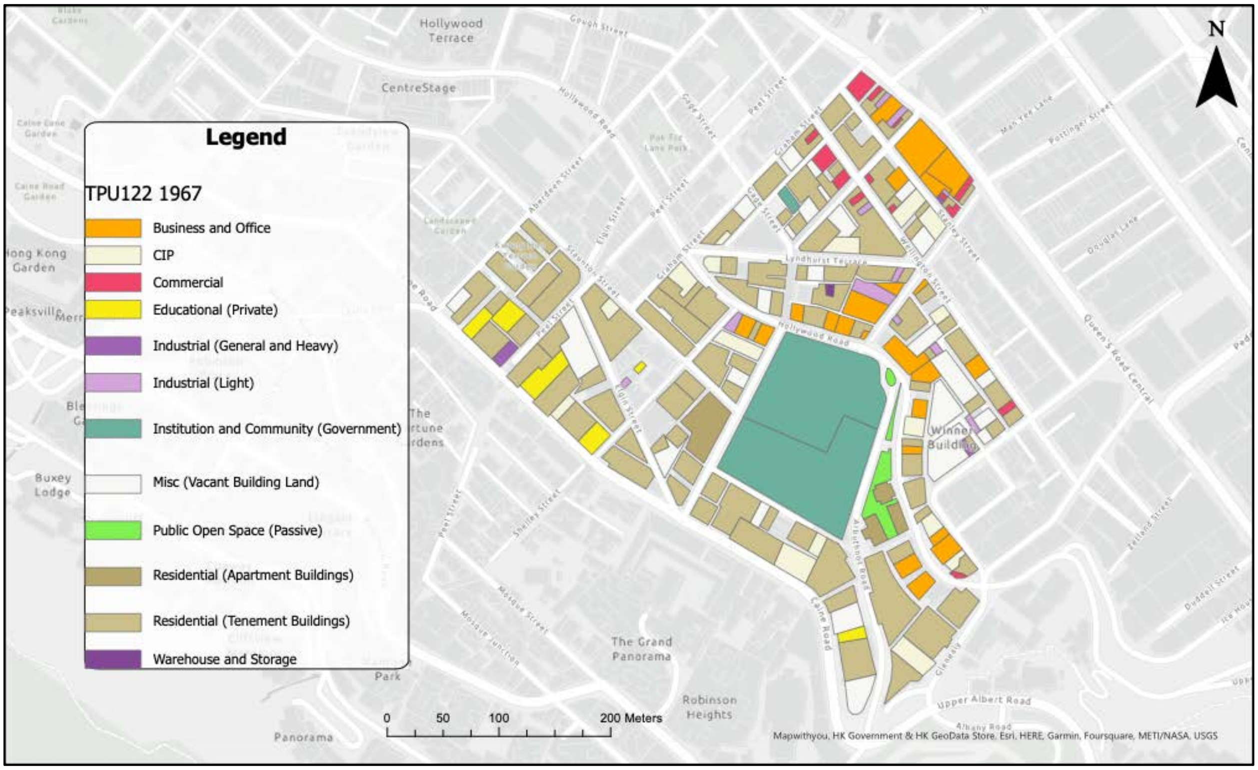

Figure 12. Map of TPU 122 layer from year 1967

Error! Reference source not found.Error! Reference source not found. shows the layer for TPU 122 from year 1985 reflects almost a complete change in categories. This layer contains 10 land use categories, again with the focal point on a large block of Institution and Community but this time under the Private subtype. The dominant category around the rest of the map is also Residential but in 1985 there no longer was a Tenement Building subtype and instead the subtype of Zone 1 is used.

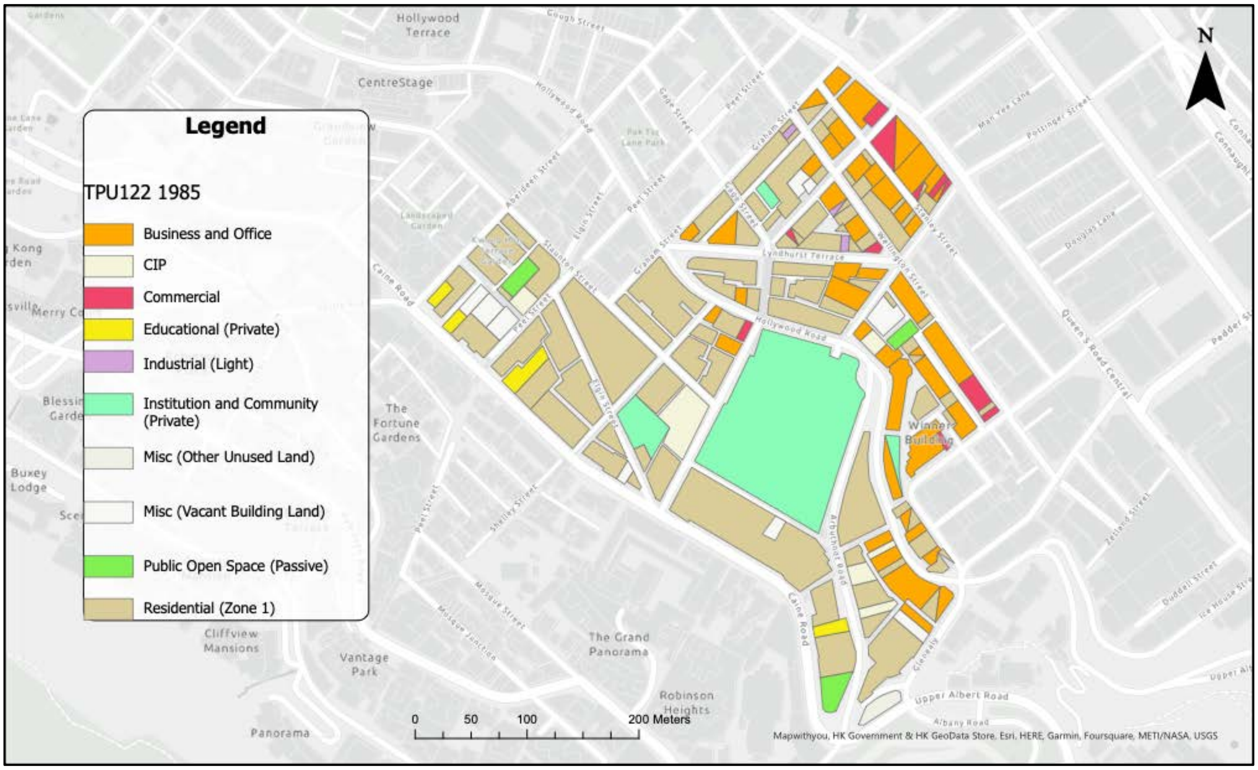

Figure 13. Map of TPU 122 layer from year 1985

The layer for TPU 114 from year 1972 was the most intricate layer as can be seen in **Error! Reference source not found.**. This layer consists of 18 land use categories. The upper part of the map mainly consists of Institution and Community (Government) and Car Park categories. It is also clear that in 1972 these areas were along the harbor front as some of the land use was obviously ferry piers. The rest of the map includes all the other categories with a slight majority of Residential (Tenement Buildings) and Misc (Vacant Building Land) categories. What makes this map layer stand out is how detailed it is, showing many blocks divided into many categories with no apparent organizational order.

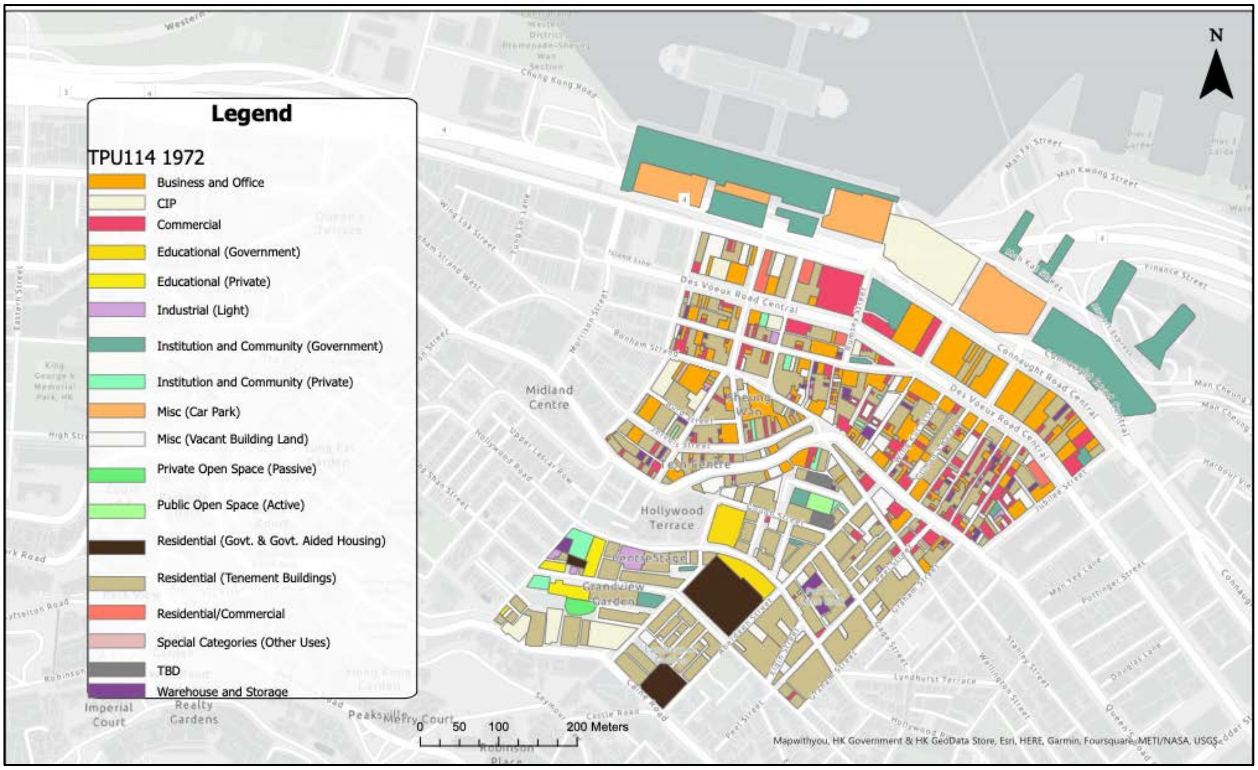

Figure 14. Map of TPU 114 layer from year 1972

The TPU 114 from year 1982 layer, shown in **Error! Reference source not found.**, contains 13 categories and does not include the waterfront areas from the 1972 layer. The northern part of the map is mainly made up of the Business and Office category while the southern part is mainly Residential (Zone 1). This layer is not as complexly detailed as the 1972 layer but interestingly there is a cluster of land that is mainly Residential (Zone 1) but has cut outs with the Commercial category.

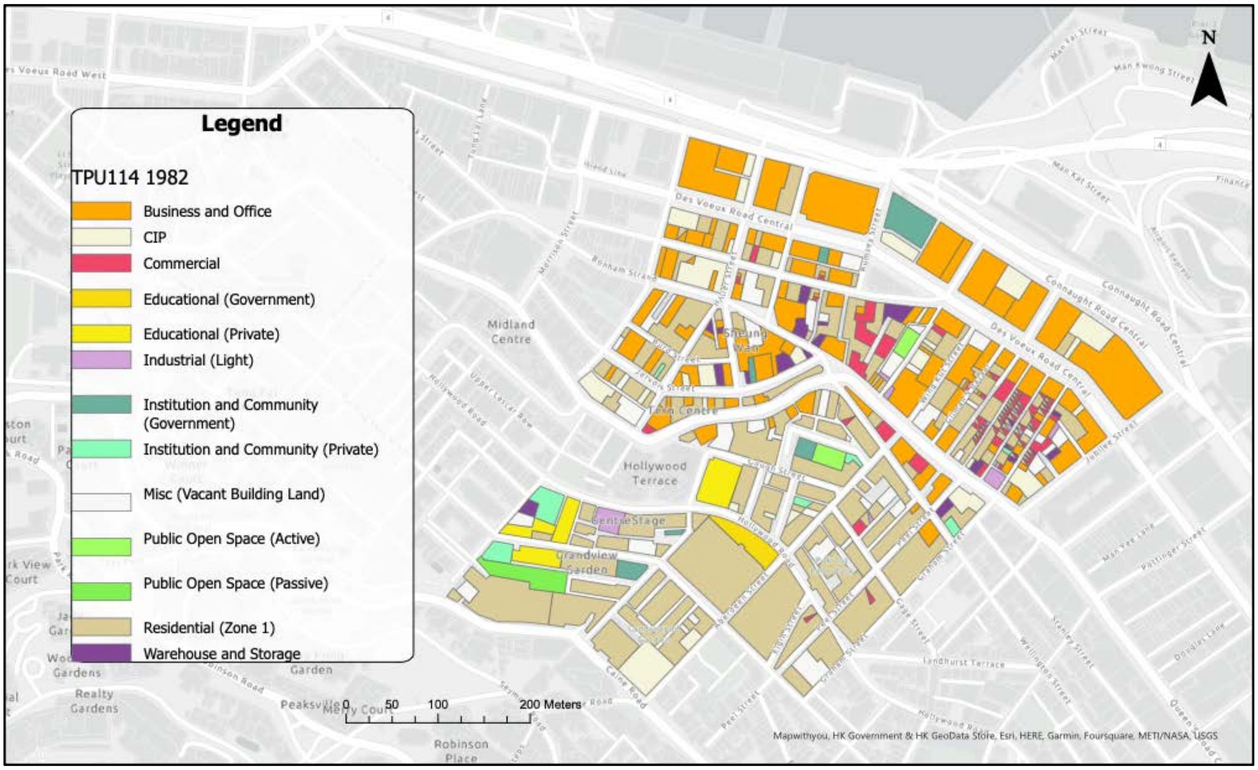

Figure 15. Map of TPU 114 layer from year 1982

4.3 Web Map

All layers of the created spatial data were brought into ArcGIS Online as a web map before further development into the application. The web map displays the same map layers as they were in ArcGIS Pro but does not include the other data that was used to create the layers. The web map is where the final symbology was edited. Since there are 25 unique land use categories, it was important to find colors for the polygons that could easily be distinguished. Creating a table with unique RGB values provided better results than simply choosing default colors from the color palette. The colors are bright and colorful which contrast the grey basemap. The web map is where the map was reviewed and deemed ready for export to the application. **Error! Reference source not found.** shows the web map in ArcGIS Online with all 6 layers.

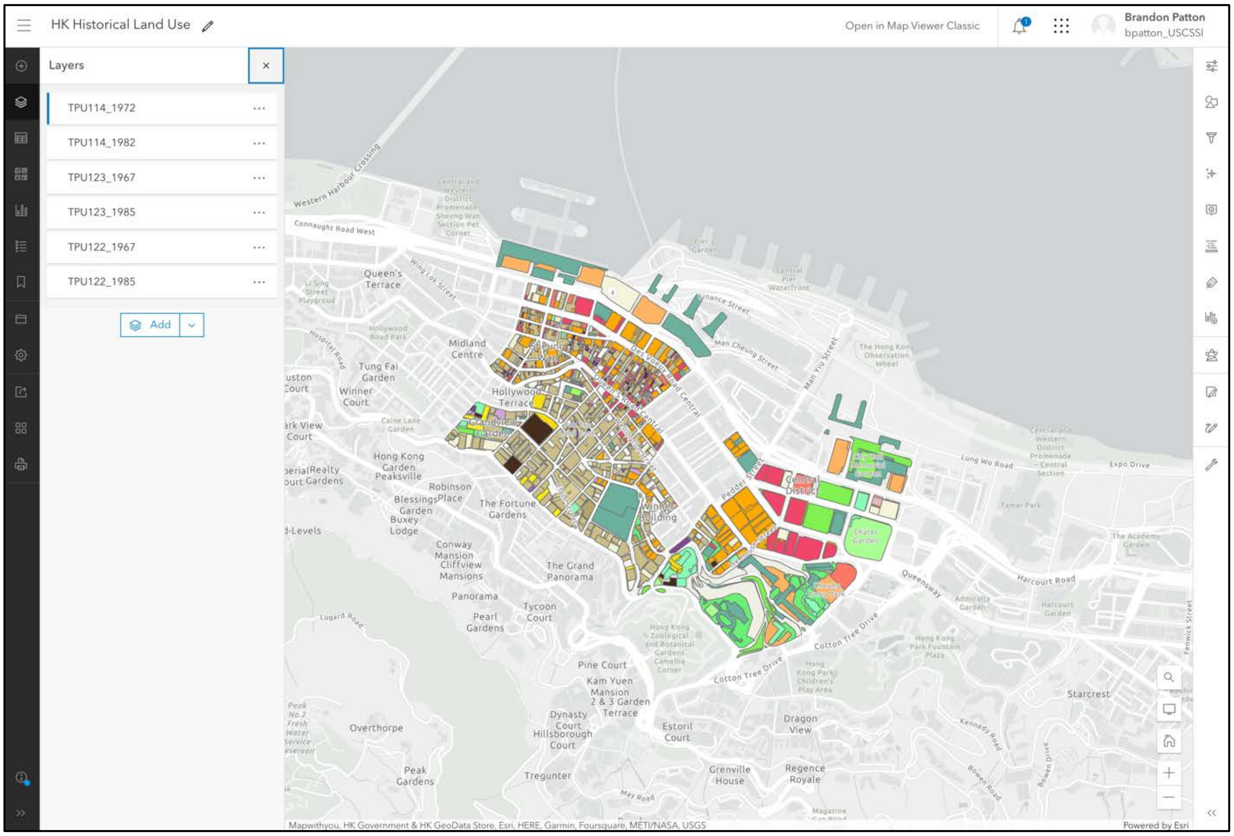

Figure 16. Web Map of all TPU layers in ArcGIS Online

4.4 Web App

When the web app is launched, users arrive to a page with a light grey background and control panel and in the center of the page is a brightly colored section of the map of Hong Kong (**Error! Reference source not found.**). These are the layers of the application that are turned on by default. Users can immediately start zooming and panning the map with their mouse directly or use the zoom in and out buttons. Along the bottom of the page is a ribbon in darker grey that contains the widgets to access the functionality of the application.

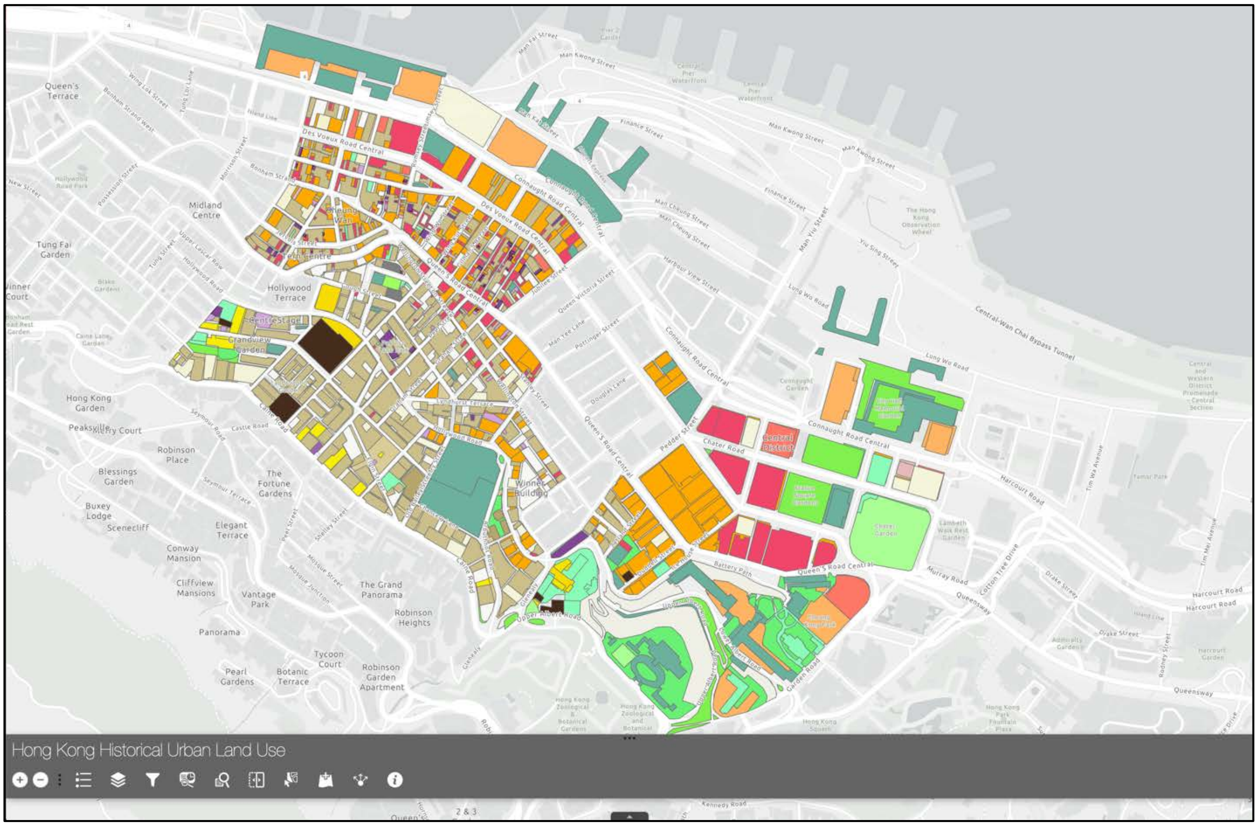

Figure 17. Landing page of the web application

The widgets open up to smaller windows that stack on top of each other as depicted in **Error! Reference source not found.**. All widgets can be moved anywhere on the page except for the Swipe widget. When the Swipe widget is activated, it splits the page down the line vertically and minimizes the control ribbon. To exit out of the Swipe widget, the user must click on the three dots on the minimized control ribbon. At the very bottom of the page there is a small tab that opens the attribute table. When it is open it consumes one third of the page by default but can be dragged to take up the entire length of the page.

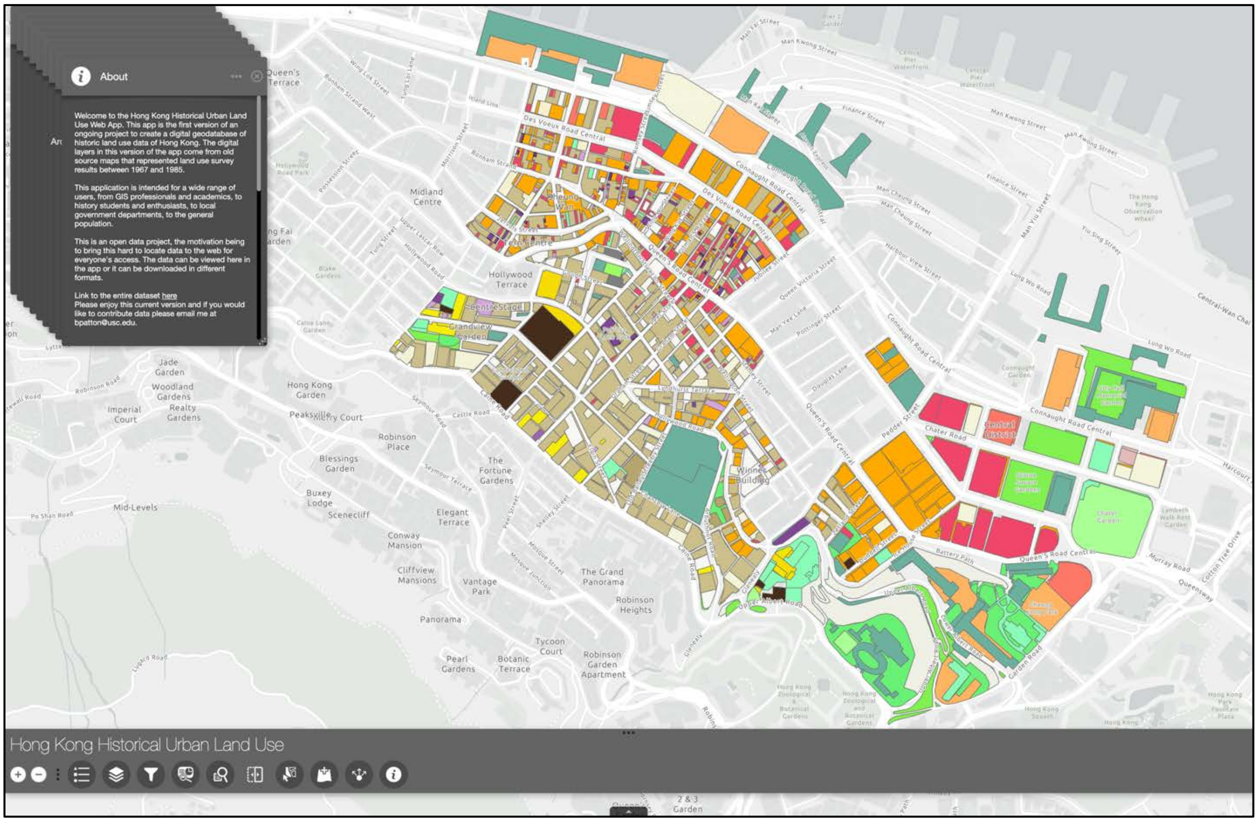

Figure 18. Layout of web app with all widgets engaged

Users can open as many widgets as they like and use the page of the app to spread them out as shown in **Error! Reference source not found.**. This is an important feature, as accessing multiple widgets simultaneously is essential to getting the full functionality from the application. An academic user could start here to decide how to use the app for their specific analysis needs.

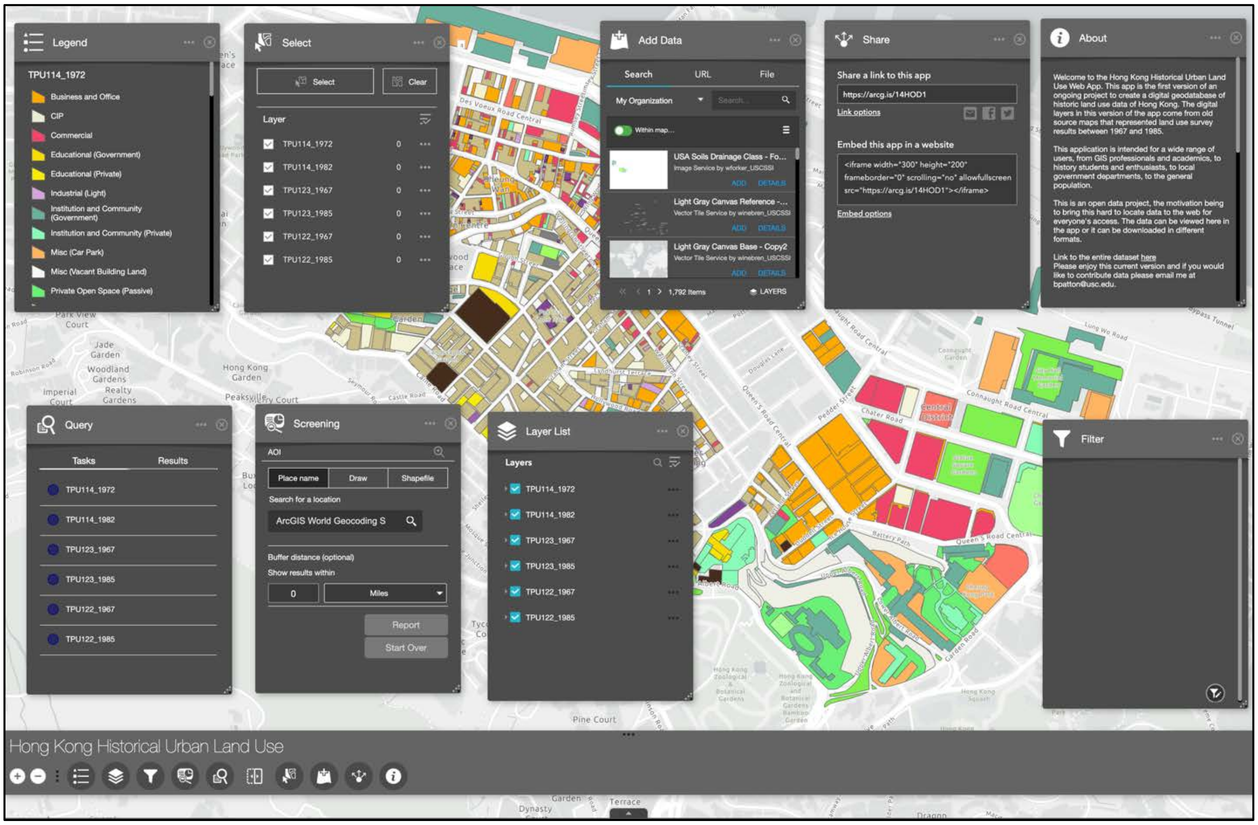

Figure 19. Layout of widgets open and moved across page

When using the Swipe widget, the widget toolbar minimizes and the screen is split down the middle as shown in **Error! Reference source not found.**. A drop-down menu appears in the lower right corner where the user can select the layer they want to compare from what is already displayed on the map. There is a button on the vertical line splitting the screen that when selected, allows users to view between the different layers by moving the vertical line left or right. A Planning Department user could use this function as a quick way to observe if a TPU layer warranted further research on its land use change over time.

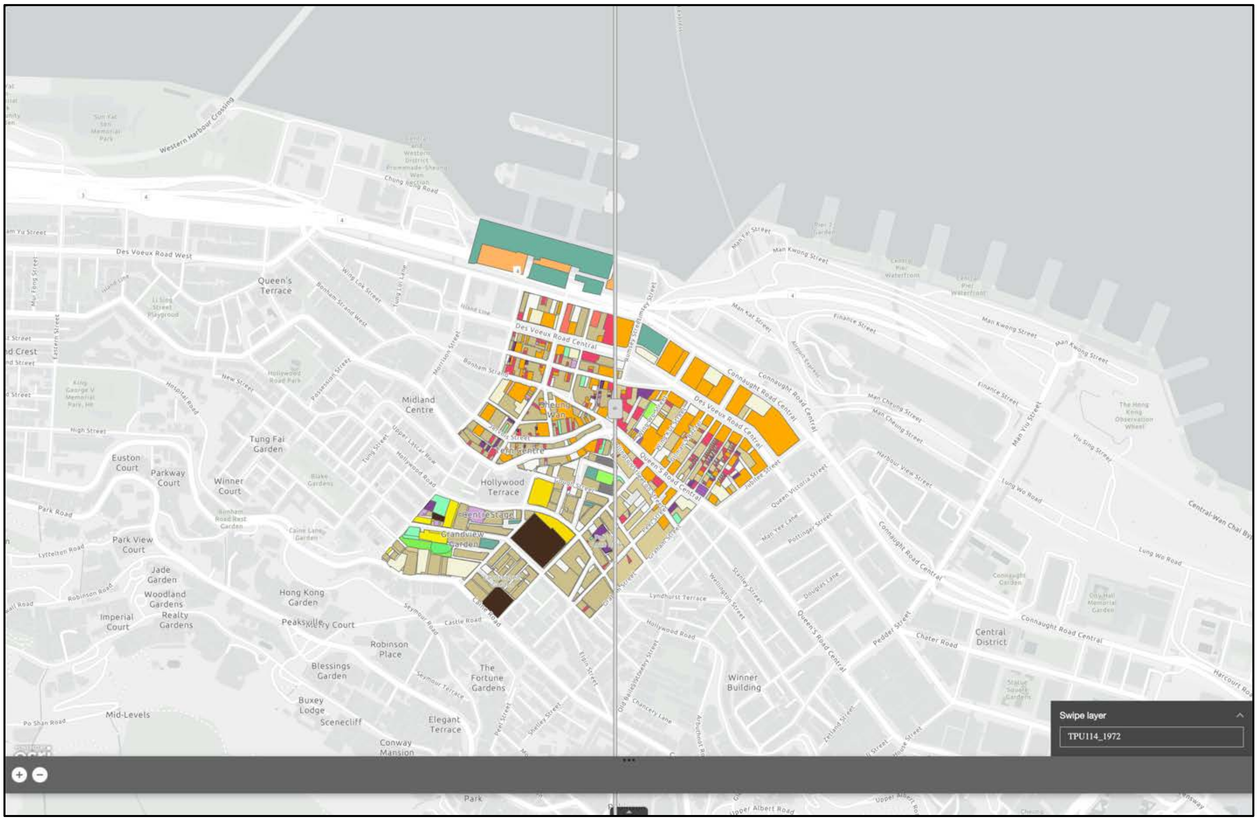

Figure 20. Example of Swiping widget

The user can access the attribute table for the layers in the app by clicking the small tab at the bottom center of the page. The default display of the table takes up approximately one third of the page as shown in **Error! Reference source not found.** but the user can adjust as needed. This function could be particularly useful for a GIS student user who is also involved in an HGIS project.

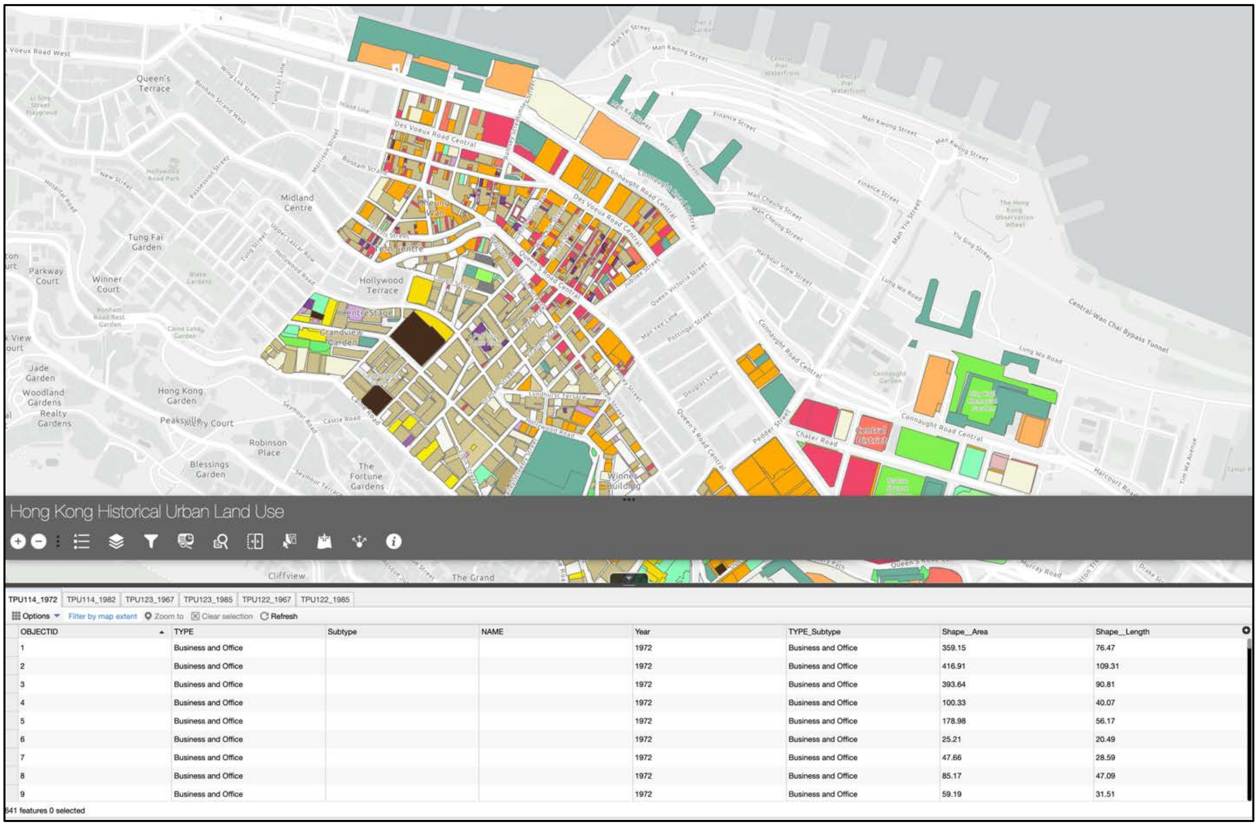

Figure 21. Attribute table opened from bottom of app screen

The Filter widget allows for the user to search and view components of the layers based on their categories. **Error! Reference source not found.** shows the example of filtering for the Business and Office category for the TPU114 1972 layer where only polygons that correspond to that type are displayed. This widget could be used by a land developer who is interested in a particular land use category.

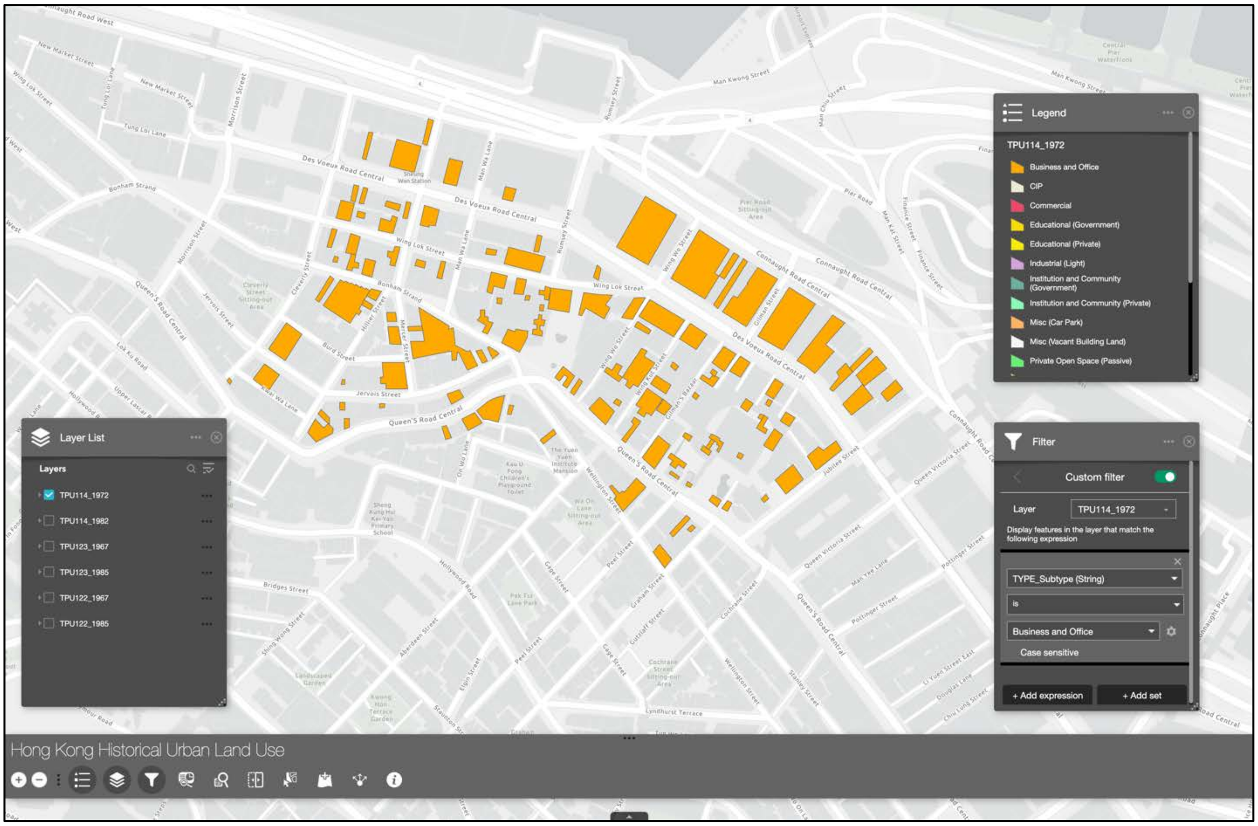

Figure 22. Filtering Business and Office land use type from layer TPU114 1972

The Screening widget is the widget used for when users want to download shapefiles of a selection. Using the “draw” function in the widget allows users to draw a box around the area of interest. Once the selection is made, users can select the download icon and choose their desired format, an example is shown in **Error! Reference source not found.**. This widget was added specifically so that the application could provide open data to users.

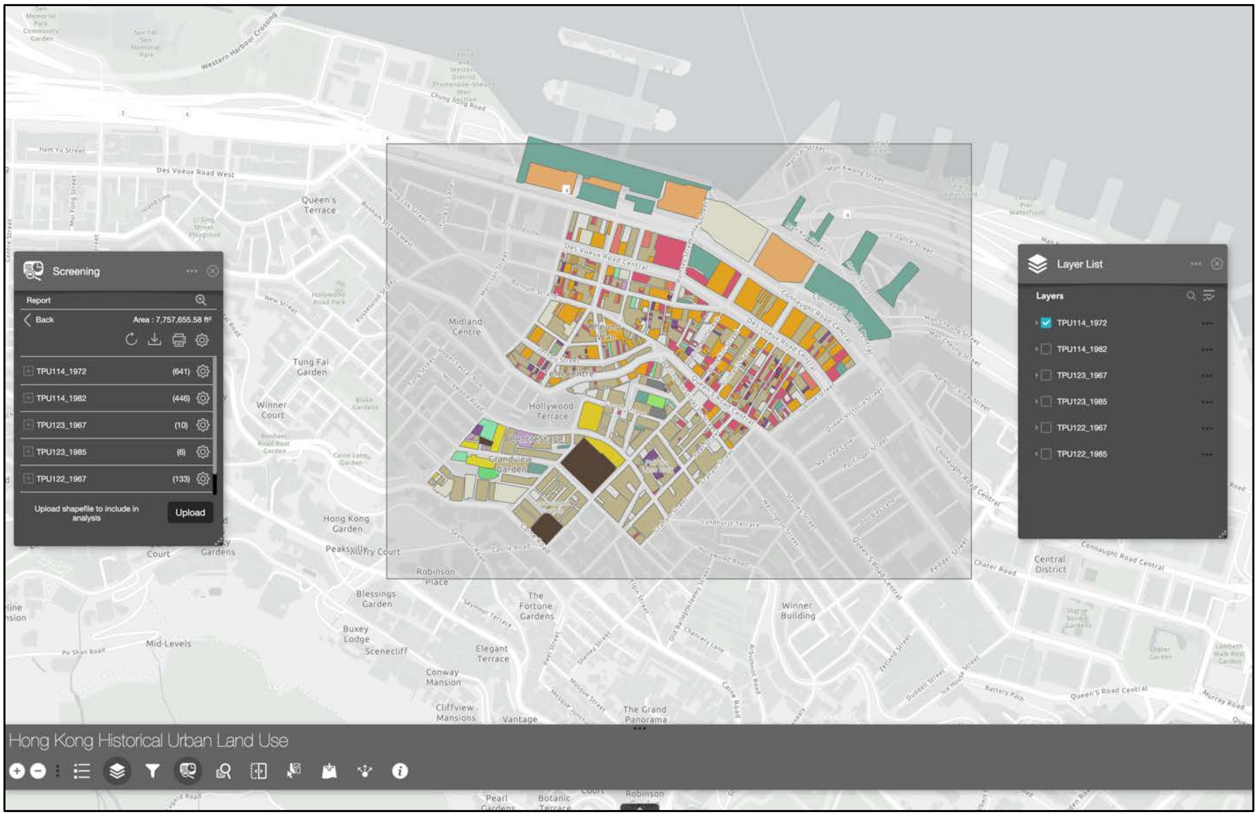

Figure 23. Screening widget opened to access shapefile download function

The About widget opens to a pane with an introduction to the Hong Kong Historical Urban Land Use web app as seen in **Error! Reference source not found.**. Included in the introduction is a brief statement describing what the project is about, who it can be used by and a link to download the entire dataset on github. There is also a short step by step guide to navigating the Screening widget to download specific elements of the dataset.

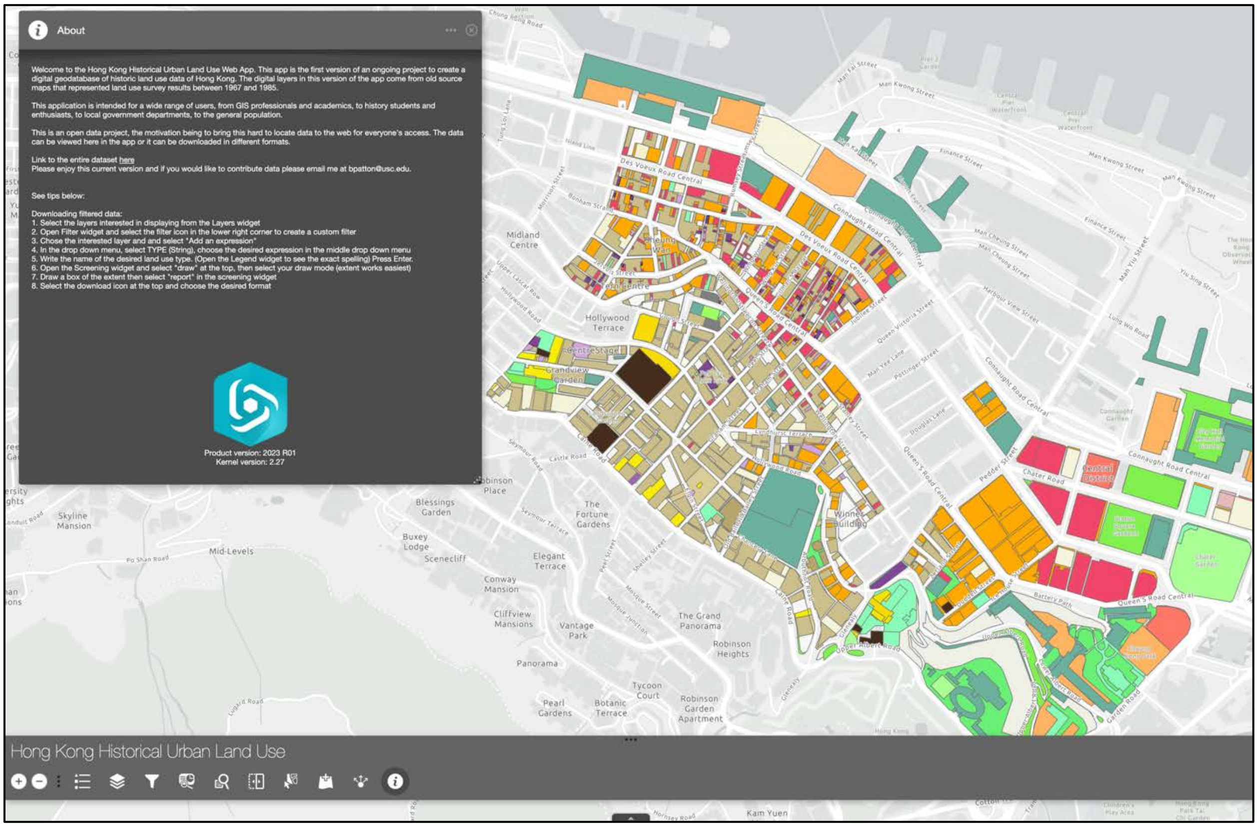

Figure 24. About widget opened with introduction and user tips

The Add Data widget allows users to bring other data into the app to visually analyze it with the built-in land use layers. Users that have an ArcGIS Online account can search their own content, their organizations content, or the Living Atlas. Alternatively, if the user does not have an ArcGIS Online, they can bring in data from a file. **Error! Reference source not found.** shows an example of data brought in depicting the original coastline of Hong Kong. Government Records Office users could use this widget when responding to historical enquiries.

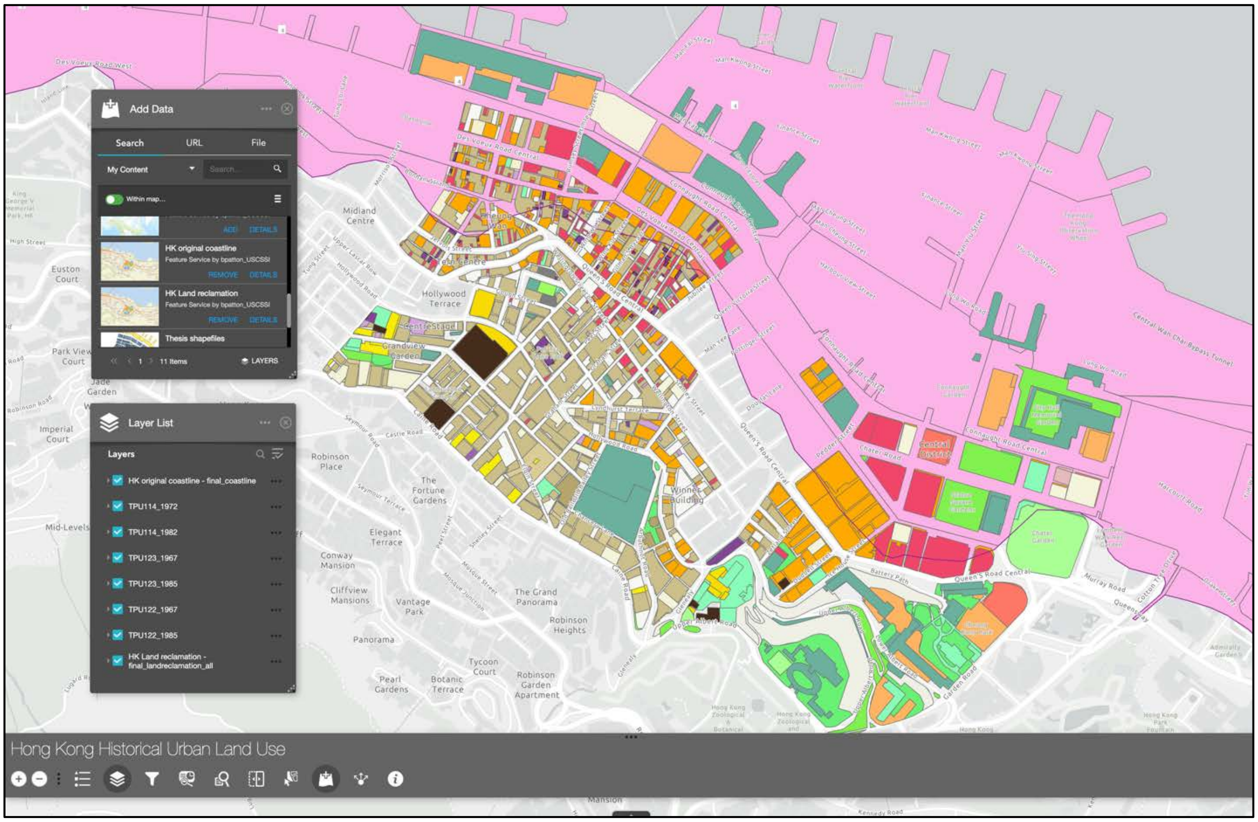

Figure 25. Add Data widget opened with original coastline and land reclamation data added

The URL for the web application is https://arcg.is/1GHWPW0. A video tutorial was made and uploaded to Youtube to show users how to use the app and its functions, the URL to the tutorial is https://youtu.be/s05ZcU3CumY. In an effort to make the data truly open, the full dataset of all TPU layers is hosted on a github page for public access and download. The URL is https://github.com/geoHKG/HK-Historical-Urban-Land-Use.

Chapter 5 Discussion

The Hong Kong Historical Urban Land Use Web App has proven to be a successful HGIS project and is in alignment with the main motivation of creating a user friendly, online database of historical data. For discussion, this chapter contains three sections. Frist, section 5.1 reviews the successes of the project. Section 5.2 discusses the potential uses of the application. Section 5.3 discusses an interesting insight about the Tenement Building category gained from using the application. Finally, Section 5.4 discusses the challenges and limitations of the project as well as what future work could improve it.

5.1 Project Successes

Overall, the project achieves its intended goals. It is a successful application of an HGIS project that has utility in various academic and government workflows. It brings a needed upgrade to data that was previously virtually unusable. Before bringing in this historical data into to the Hong Kong Historical Urban Land Use Web App, this data would have likely continued to be unused. Not only does the application improve the usability of this data, it also creates an alternative method of preservation as paper maps are at risk of deterioration.

Another major success of the project is that is provides a clear and reusable framework for other HGIS projects. Digitizing historical maps could be considered a must-do for countless history, GIS, and land/urban planning departments. Eventually, all historical maps may need to be digitized to be properly preserved for future generations, this project highlights a straightforward methodology for developing a modern GIS application to address that need.

5.2 Utility of the Web App

The application does more than just preserve the historic land use data from older source maps, it allows for easy visual analysis of how land use of the 1960s-1980s fits into the greater story of Hong Kong's urban history. By way of an example, this section now describes an interesting insight about historical land use classification that was learned by the author while exploring the Hong Kong Historical Urban Land Use Web App.

The change in the land use classification from Residential (Tenement Buildings) to Residential (Zone 1) is an obvious land use change detected via the app and although both categories are Residential, it begs the question as to what happened for the subcategories to change over the decade time span between the two surveys.

The key to understanding this subcategory land use change is understanding the urban architectural history of tenement buildings in Hong Kong. The older streets of Hong Kong maintain the same topography and layout as when Hong Kong was first established. The prevailing layout being the "shophouse" style of buildings, in which the street-level space was dedicated to commerce and the upper floors designated for living space. The history of Hong Kong's architecture has two defining styles, the colonial-influenced *tong lau* that dates from pre-World War II, and the high-rise composite buildings that came after the war.

The literal translation of *tong lau* is "Chinese house" but the building type was often referred to as "tenement houses" in British colonial records (Davis 2019). These shophouse buildings date back to the mid-19th century when they were pioneered by merchants across South China and Southeast Asia and have since become a critical part of Hong Kong's urban landscape. After Hong Kong Island became a British crown colony in 1843, many people from China's coastal cities emigrated to supply manual labor for the construction of the city of

Victoria. These types of buildings were a response to the needs of the original builders and were a convenient and economical way of addressing the growing housing problem at the time. The sociopolitical factors of Hong Kong at that time are what made the local versions of *tong lau* unique, but they featured European variations that spoke to their colonial origins. The pre-war *tong lau* were between three and four stories. There are not many examples of pre-war *tong lau* that remain in their original state. While there have been attempts to restore the *tong lau*, most of them have vanished due to Hong Kong's rapid redevelopment. There are only a few examples of pre-war *tong lau* that have been preserved and renovated as an homage to Hong Kong's urban heritage. Most of these remodeled *tong lau* were dilapidated but then converted to community spaces or upscale flats by wealthy individuals.

After World War II, there was a massive influx of refugees escaping the conflict as well as the subsequent communist takeover of mainland China. Hong Kong desperately needed to meet the demands of the exponential rise in population, but the pre-war *tong lau* was an insufficient housing solution. They were soon replaced with composite buildings in the 1950s and 1960s which were up to eight stories tall. According to the Buildings Ordinance they are in the same vein as the earlier versions, built for both for commercial and domestic purposes (Davis 2019). Essentially, the composite buildings were just an upsized version of the *tong lau*, with ground level reserved for retail and the floors above for living spaces, although it was common for business offices to operate on upper floors and living spaces to be subdivided into smaller units.

Composite buildings are the hallmark of how Hong Kong began to expand upward on the z-axis. Hong Kong's population was increasing by over fifty thousand per year, and the Buildings Ordinance allowed for construction of up to 9 stories without a lift (Davis 2019).

Many developers leapt at the opportunity. This first wave of high-rises had little to no restrictions on what their internal use could be, so they quickly developed into complicated and crowded buildings. Between 1959 and 1979, approximately five thousand composite buildings were constructed, with five hundred of those buildings housing more than fifteen hundred residents (Davis 2019). Today, many composite buildings are being replaced as there is a government policy to sell buildings that are over fifty years old.

This history helps paint a more complete picture when understanding the changing of the land use categories on the TPU maps from the late 1960s to the mid-1980s. Both the *tong lau* and the composite buildings would have been classified under "Tenement Buildings" in the earlier versions of the land use surveys. When compared to the later versions where the classification is considered "Residential (Zone 1)", it can be inferred that the physical construction of the buildings within those polygons have undergone noticeable redevelopment to meet the growing housing needs. This change in buildings structure, and the development history it speaks to, is thus made apparent in the Hong Kong Historical Urban Land Use Web App.

5.3 Esri Versus Open Geospatial Software

The choice of using the Esri product suite was made in comparison to the open geospatial software option. The considerations for the selection were made around functionality, and scalability and performance.

ArcGIS offers a wide range of advanced functionalities for geospatial analysis and data visualization. Open geospatial software also has this functionality but not as comprehensive as ArcGIS. For the purposes of the HK HULU app, both options offer the functionality needed.

Future versions of the application can be expected to include more historical datasets, and therefore scalability is an important consideration. Open geospatial software can be scalable but could require customization and configuration. Esri software is natively capable of handling large datasets with high performance. Since one of the core software requirements for the application is that it must allow for development without any code, Esri was the superior option.

5.4 Challenges/Limitations

There are some limitations to the project that may affect its final output. It is important to note that this HGIS project does not claim to be entirely accurate. This project relies heavily on the source maps it was built on. Some of the source maps were difficult to read accurately as the colors on the paper had faded, making it difficult to discern if a certain area was one category or another.

The TPU maps included building lines but in order to streamline the digitizing process, some buildings were lumped together when creating the digital polygons. This inhibits the detail of analysis that can be done. There was also some uncertainty regarding legibility of the paper maps' labels and legend, this could have impacted the accuracy of the land use categories.

Georeferencing was a fundamental part of the methodology for this project. Georeferencing heavily relies on the GIS operator to make the correct choices of control points. There are some best practices to increase the accuracy of georectification such as choosing points in the corners of the source maps and using known historical or geological landmarks that can be assumed to be consistent from the historical map to the modern one. But the fact remains that georeferencing is not an exact formula and some degree of inaccuracy is to be expected. Although the TPU maps were georeferenced to a high standard, minor inaccuracies can be seen when zooming in on polygons from two layers of the same TPU. In some cases, the border of polygons from one layer can be seen sticking out slightly compared to the other. Since the source maps were hand traced in ArcGIS Pro, if one layer is georeferenced slightly different from its corresponding layer of a different temporal scale, then these minor inaccuracies are likely to occur.

Another minor limitation is regarding the basemap. The choice of basemap was made based on what would best visualize the overlaid digitized layers. Of the basemaps available in ArcGIS Pro, the light grey basemap was most appropriate option. However, the references labels connected to the basemap could not be removed or customized, resulting in some labels still being displayed when the TPU layers were selected. The accuracy of the web map may be affected as the labels reference a modern map and may not perfectly align with the historical layers.

5.5 Future Work

Further work for the future could include including Outline Zoning Maps into the web app. Outline Zoning maps are official maps that provide a comprehensive framework for land use planning in Hong Kong. The Hong Kong Planning Department is responsible for maintaining and updating the Outline Zoning maps. These maps divide the land in Hong Kong into various zones based on the intended use of that land, whether it be residential, commercial, industrial, recreational, or agricultural. The zones are labeled to indicate the permitted land use, as well as any specific development restrictions. Outline Zoning maps are used to guide the development of land in accordance with Hong Kong’s long-term social, economic, and environmental goals.

At the time of this project’s completion, the application contains six TPU layers. The Government Records office holds many more land use survey maps of TPUs that encompass all of Hong Kong Island and Kowloon. A more complete version of this application would include digitized versions of all the recorded TPU land use surveys. Outline Zoning Plan data is complementary to land use data as it shows how the land was zoned for its intended use. There are paper maps of historical Outline Zoning Plans available at the Hong Kong Planning Department's enquiry desk. The complete version of this application would include all historical TPU land survey maps and all historical Outline Zoning Plan maps. This would result in a rich HGIS application that preserves the historical data and is complete enough for deep investigative analysis.

More functionalities could be added to a future version of the application to make it more robust. Adding a dashboard that could provide summary statistics of the change in land use and reorganization of urban space could save time for future users when performing analysis. Flagging specific areas where there was uncertainty during the digitizing process could increase the transparency of the application. Finally, adding a time animation slider tool could improve the visual experience for all users by allowing them to see a quick and clear overview of how the land use categories changed over time.

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