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New Town Monitoring from Sequential Aerial Photographs

Sequential aerial photographs for 1956, 1967, and 1980 were successfully applied to monitoring the development and growth of the first new town in Hong Kong.

ABSTRACT: *Kwun Tong, the first planned new town of Hong Kong, is examined through a series of aerial photographs at scales ranging from 1: 8 000 to 1:12 500 taken in 1956, 1967, and 1980, with a view to monitoring its progress at each phase of development and evaluating the success of the plan. A photointerpretation key of building types was devised and a land-use classification scheme was designed to help mapping at the 1:10 000 scale. Field checks confirm an accuracy of 98.7 percent at the 95 percent level of confidence for the resultant maps. Subsequently, quantitative data are obtained and the changes in the transportation networks are also analyzed. It is concluded that the method of urban analysis by sequential aerial photography is particularly useful in providing insights into the planning of a new town.*

INTRODUCTION

THE POLICY of new town establishment has been commonly adopted by planners in both developed and developing countries as an effective strategy for diverting an excessive population from crowding into an already over-congested city region (Golany, 1978). It is believed that through the construction of new towns a better living environment can be created for the people and an alternate growth pole developed in a hitherto neglected region of the country. While it will be difficult to judge the success of a new town project before its completion, it is extremely useful from the planner's point of view to monitor the progress in the implementation of the town plan as it develops on the ground. In this paper, the use of sequential aerial photography to monitor the growth of a new town originally intended to accommodate a population of 500 000 in Hong Kong is described.

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THE STUDY AREA

Kwun Tong is the first planned new town of Hong Kong developed since February, 1955 (Wigglesworth, 1971). It was originally a refuse dump situated on the northeast coast of the harbor about 4.8 km from the urban complex of Victoria-Kowloon (Figure 1). This site was selected because of the possibility of large-scale reclamation along the coast. The series of hills inland could be easily leveled as they are composed of deeply weathered granite (Figure 2), and the spoils from these hills could be dumped into the sea to reclaim new land for industrial development while the leveled hills would provide residential building sites (Lai and Dwyer, 1965). The major advantage of the site is its proximity to the international airport as well as easy access to the harbor so that manufactured goods can be quickly dispatched by air or sea. Also, because of the emphasis on industry, the new town was not designed as a self-contained community but rather as an industrial satellite (Wigglesworth, 1971). The development plan was characterized by zoning: the

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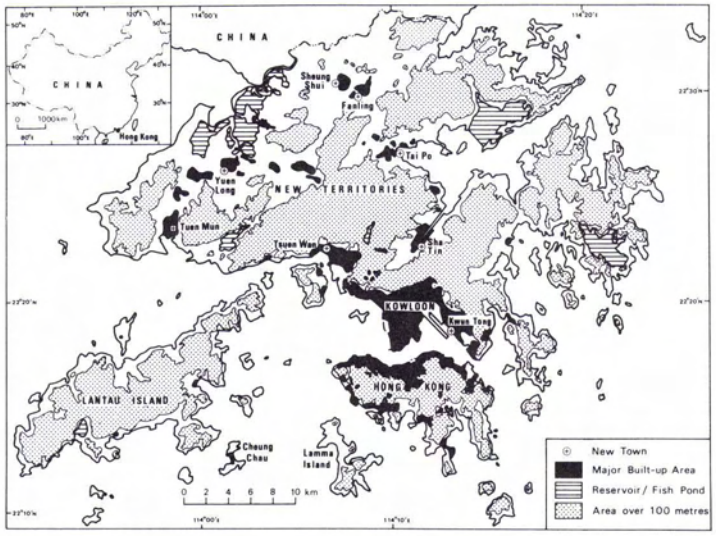

FIG. 1. Kwun Tong's location in relation to the whole of Hong Kong.

industrial zone, the commercial center, and the housing zone. The differentiation of urban functions is clear from the plan, and the whole town exhibits a high degree of regularity in street patterns. Another characteristic of the plan is the provision of government or government-aided housing in the housing zone (Figure 3).

METHOD OF ANALYSIS

In order to examine the different stages of growth of Kwun Tong, black-and-white aerial photography acquired in 1956 (1:10 020), 1967 (1:12 500), and 1980 (1:8 000) was analyzed with the aid of a mirror stereoscope and a Bausch and Lomb Zoom Transfer Scope. The latter instrument enables matching of details between an aerial photograph and a map covering the same area so that any changes that have occurred can be mapped with ease. The stereoscopic examination of the aerial photographs permits the photo interpreter to identify accurately individual building structures with reference to their roof forms, building heights, and plot sizes. The building structures so identified are associated with the functions for which the physical structures are intended. There may be a lack of correlation between the structure and the function as time goes by. Field surveys and checks are essential in the preparation of a building-use interpretation key and in the evaluation of the accuracy of the interpretation. A land-use map of ground floor use at a scale of 1:10 000 can be prepared based on the interpreted building use. In quantifying the land-use pattern at each period, the third dimension has to be included in order to obtain realistic land-use intensities.

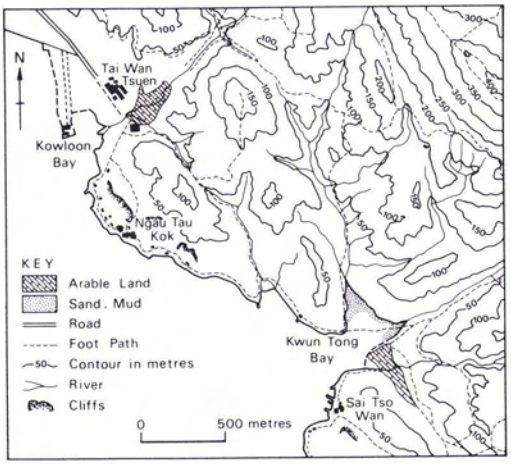

FIG. 2. The Kwun Tong area before any development (c. 1945).

The application of sequential aerial photography to study the morphology, function, and evolution of an urban place as described above is not new (Richter, 1969; Bowden, 1975). The present study attempts a refinement of the approach with the development of a structure-based land-use key aimed at monitoring the growth of the new town stage by stage.

PHOTO-KEY OF BUILDING TYPES AND LAND-USE CLASSIFICATION SCHEME

The present study only focuses on Tertiary Planning Units (TPU) 294 and 295 which form the core of Kwun Tong (Figure 4). These TPUs are defined by the Census and Statistics Department based on the requirements of the Government town planners. By following the TPU boundaries in the present study, it would be possible to compare pop-

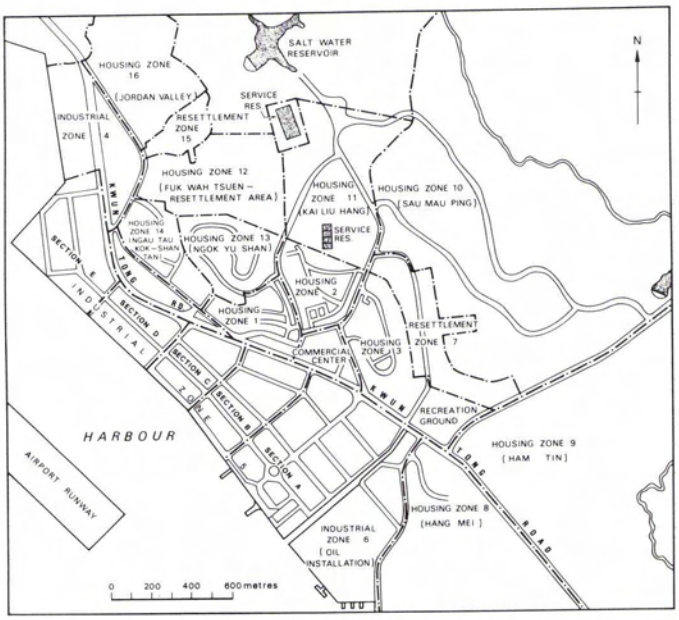

FIG. 3. The development plan for Kwun Tong (after Wigglesworth, 1971).

ulation growth with a certain development phase of the new towns.

The initial step is to design a photointerpretation key of building types, which requires a thorough steroscopic examination of the aerial photographs. In view of the fact that the nominal scales of these photographs varied from 1:8 000 to 1:12 500, the mean scale of 1:10 000 was selected as the final scale for mapping for the three different years. The photointerpretation key developed should be compatible to this mapping scale. The photoimages are classified according to some common attributes so that there is the greatest homogeneity within the same group but the greatest variance among different groups. In the present study, the discriminating attributes employed in designing the building type key are (a) roof form, (b) building height, (c) building area, (d) geometric characteris-

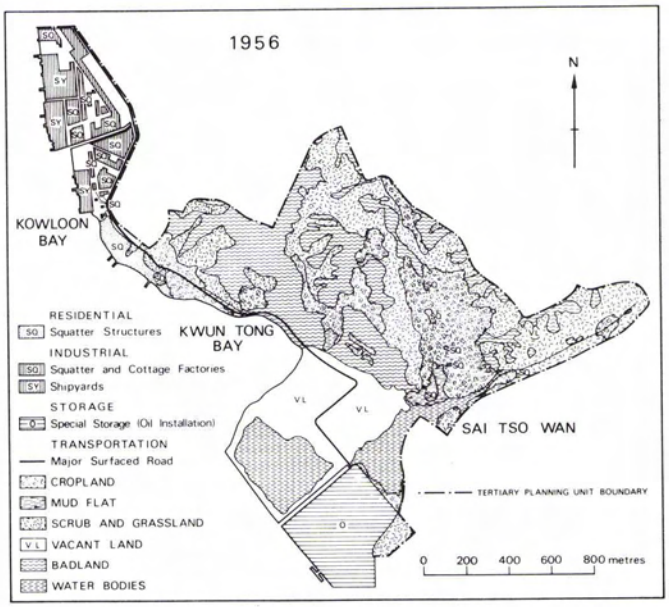

FIG. 4. Land-use map of Kwun Tong as interpreted from the aerial photographs, 1956.

TABLE 1. PHOTOINTERPRETATION KEY OF BUILDING TYPES

	Type	Roof Form	Roof Size	Number of Stories	Geometric and Associated Characteristics	Functional Characteristics	Example
RESIDENTIAL BUILDING	Building in government and government-aided housing estates	flat and usually rectangular in shape	750 m^2 to 1 500 m^2	7–16	rectangular or H-, L-, or I-shaped in layout, symmetrical, blocks of the same shape occur in groups, with bamboo sticks and aerials sticking out, sometimes accompanied by open air car-parks	overwhelmingly residential, commercial activities or public services may take place on the ground floor	Structure "A" in Plate 3
	Multistoried apartment building	flat	300 m^2 to about 400 m^2	10–25	mostly rectangular in shape, excellent structural conditions, lower housing density, separated from each other by wider open space, with car-parks attached	wholly residential with car parking facilities available on the ground floor or nearby area	Structure "B" in Plate 3
	Tenement building	flat, usually with extra structures on the roof tops	300 m^2 to 600 m^2	5–7	rectangular in shape, high housing density, located by the side of the road, compactly located next to each other	mainly residential, but service, retail, and industrial uses may occupy from ground floor up to the third or fourth floor	Structure "C" in Plate 3
	Temporary housing area	pitched	each block accounts for about 500 m^2	1	rectangular in shape buildings of the same shape occur in groups and are arranged in an orderly manner; clothes and furniture can be seen in the space among them; located away from the residential zone	completely residential	Structure "D" in Plate 3
INDUST. BLDG.	Government flatted factory building	flat	around 900 m^2	7	rectangular in shape, occur in pairs, with car-parks or loading areas in between, no chimney stack, no ventilation vent	mainly for small-scale light and workshop industries, multipurposed	Structure "F" in Plate 3

INDUSTRIAL BUILDINGS	Multistoried private factory building	flat	500 m^2 to 1 500 m^2	variable, about 10	rectangular in shape, chimney stacks and ventilation vents can be seen clearly	mostly light industries, sometimes textile yards and flour mills	Structure "G" in Plate 3
	Squatter and cottage factories	flat or pitched	60 m^2 to 100 m^2	usually 2	irregular in shape; poor structural conditions; located away from the industrial zone; roughly built and designed; chimney stacks may be seen on roof tops; raw materials piled up and trucks parked in the nearby area	mostly light industry, the upper floors may be used for residence	Structure "H" in Plate 3
STORAGE	Godowns and warehouses	flat roof	varies according to the size of goods stored, usually from 700 m^2 to 1 500 m^2	6–10	good structural conditions; rectangular in shape; usually with small platforms sticking out for loading purposes; no ventilation vent or chimney; located along the waterfront	completely devoted to storage uses	Structure "I" in Plate 3
SPECIAL BUILDINGS	Institutional and community	flat or pitched	400 m^2 to 700 m^2	varies according to use	structure varies according to use; usually located by the side of the road next to the residential areas	churches, schools, clinic, youth centers, and government offices	Structure "J" in Plate 3
	Entertainment	flat	around 200 m^2	varies around 4 to 5	located in the commercial center; rectangular in shape	cinema houses, usually associated with commercial activities	Structure "K" in Plate 3

tics, and (e) associations. The 1980 aerial photography (Plate 3) which records the latest stage of development of the new town was employed to develop the photointerpretation key. All the buildings, as detected from the aerial photographs, are first classified into the primary-level functional groupings, which are then further subdivided into their secondary-level groupings based on differences in morphological features. Thus, a building whose primary functional grouping is residential can be classified further as a building in the government or government-aided housing estates, or a multistoried apartment building,or a tenement building, or a temporary house, or a village, or squatter structure (Table 1). Similarly, for industrial buildings different sub-categories can be identified. The photo-interpretation key therefore relates the photoimages with the corresponding ground images.

Next, in preparing the land-use maps (Figures 4, 5, and 6) with the aim of showing the structural changes at each phase of development, a special land use scheme incorporating the building types was also devised (Table 2).

Accuracy Check

The accuracy of the photointerpretation and, hence, the resultant land-use map for 1980 (Figure 6) was checked afterwards in the field. A stratified random sampling procedure was employed to select samples for field checking. Each category of land use (Table 2) was treated as one stratum, but in the residental, industrial, storage, and transportation uses individual morphological sub-categories were also distinguished. The total number of "land-use units" in each category mapped was first counted. Because the new town is largely a built-up area, the "land use unit" is the building unit. In the case of recreational open space, the whole areal unit involved in the designated usage is taken as the "land-use unit." In order to obtain meaningful results with an optimum sample size of at least 20 units for each category in accordance with the recommendations of van Genderen and Lock (1977), a flat 20 percent sample for each category was taken. Each land-use unit within a category was numbered and, with the aid of the random numbers table, the required samples for each class were drawn. Altogether 300 samples were field checked and it was found that an overall accuracy of 98.7 percent at the 95 percent level of confidence was achieved. An analysis of the error matrix (Table 3) revealed only four cases of misinterpretation caused by confusing the "godowns* and warehouses" with "multistoried private factory buildings" or vice versa. Another misinterpretation arose as a result of mixing up squatter structures for residential use with those for industrial purpose. Despite the variable sample size for each category of land use, an average sample size of 15 "land use units" for the whole map suggested that an interpretation accuracy of at least 80 percent with 95 percent level of confidence was achievable (van Genderen and Lock, 1977). This high accuracy can be explained by two facts. Firstly, one of the authors (WU) who did the interpretation is very familiar with the environment of Kwun Tong in which he has lived. Secondly, the planned environment exhibits an excellent correlation between building structures and their intended functions. As for the accuracy of the 1956 and 1967 land-use maps (Figures 4 and 5), it is not possible to carry out any field check. However, in view of the fewer number of building structures and the predominantly rural human activities at the early stages of development of the new town, one can assume an equally good accuracy for these maps.

* Godowns—an Anglo-Indian word used in parts of Asia to mean warehouses

Interpreting the New Town Development, 1956-1980

The 1956 aerial photographs (Plate 1) and land-use map (Figure 4) depict very clearly the original landscape immediately after the Government had decided to go ahead with the new town project. Engineering work was started in February 1955 and is evident from the map in the large patch of reclaimed land adjoining the oil storage area. With reference to Plate 1, it is interesting to note the extensive badland area (A) behind the coast, where pockets of cropland (specializing in vegetable cultivation) were still found in the valleys (B) and on terraces at the lower hill slopes (C). The original village settlement (Ngau Tau Kok Village (D)) mixed with squatter structures (E) can still be seen on the coast, showing a high degree of compactness. The occurrence of factory sheds (F) to the north of the village along the coast suggests that a small-scale industrial base was already in existence. The shipyards (G) appeared to be of special importance as indicated by the activities found off the coast. Clearly, some degree of private reclamation (H) had already taken place in this area. The population size at this time was probably very small, around 1000 or so. The predominance of farming indicates that this was still basically a rural area.

By 1967, the impact of the planners on the environment became much greater (Figure 5 and Plate 2). The coastal areas south of the shipyard area and north of the oil storage (A) were completely reclaimed. The village of Ngau Tau Kok had disappeared and the old industrial area along the coast was being cleared away for further reclamation towards the north-west into Kowloon Bay. The grid street pattern was very obvious on the reclaimed land where modern multistoried factory buildings (B) either had emerged or were in the process of being built. A greatly improved road system took

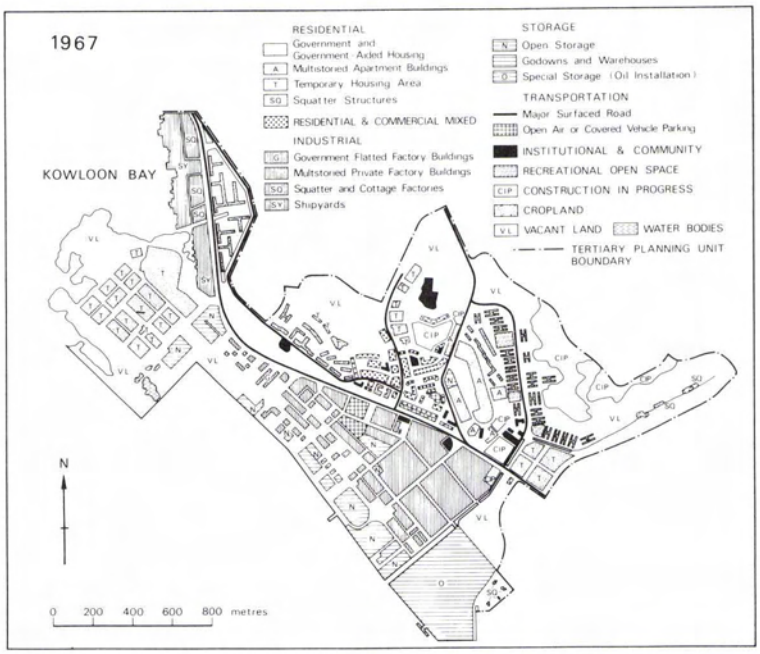

FIG. 5. Land-use map of Kwun Tong as interpreted from the aerial photographs, 1967.

shape and linked the Kowloon area more closely with Kwun Tong. It is noteworthy that different varieties of housing have been erected, but predominantly they are government or government-aided housing, such as the H-shaped (C), I-shaped (D), and L-shaped (E) buildings. Private residential buildings were also being developed on the hilly sites (F). All these residential structures seemed to

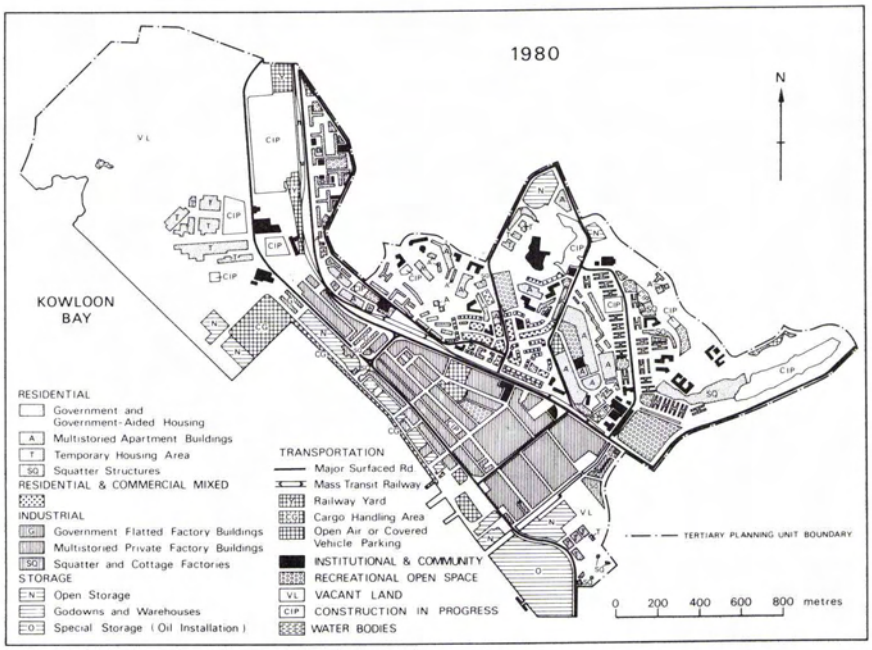

FIG. 6. Land-use map of Kwun Tong as interpreted from the aerial photographs, 1980.

TABLE 2. LAND-USE CLASSIFICATION SCHEME FOR MAPPING AT 1:10 000 SCALE WITH AERIAL PHOTOGRAPHIC DATA

Land-Use Type	Morphological Subdivision
1. Residential	(a) Buildings in government and government-aided housing estates
	(b) Multistoried apartment buildings
	(c) Temporary housing area
	(d) Squatter structures
2. Residential and Commercial Mixed	Tenement buildings
3. Industrial	(a) Government flatted factory buildings
	(b) Multistoried private factory buildings
	(c) Squatter and cottage factories
	(d) Shipyards
4. Storage	(a) Open Storage
	(b) Godowns and warehouses
	(c) Special storage (oil installation)
5. Transportation	(a) Surfaced roads and railways
	(b) Open air or covered vehicle parking space
	(c) Railway yard
	(d) Cargo handling area
6. Institutional and Community	(a) Schools
	(b) Others
7. Recreational open space	—
8. Cropland	—
9. Scrub and Grassland	—
10. Badland	—
11. Vacant Land	—
12. Construction in Progress	—
13. Others	—

be developed around a small commercial center. In all cases, the buildings are multistoried and are intended for high-density living. The housing development proceeded northwards from the coast as revealed by the numerous building sites formed (G). Extensive temporary housing areas (H) also appeared, suggesting that many people were temporarily housed here waiting to be resettled more permanently in the region after the completion of all the public housing estates. The curvilinear feature of the housing zone contrasted strongly with the rectilinear layout of the industrial zone, thus indicating the difference in relief between the two areas. It was clear that the industrial zone development took place first in the southeast and then proceeded northwestwards. However, construction work on the coastal belt (notably for the construction of a ferry pier at I) was still not completed. The coastal area also provided for storage and cargo handling space (J). By this time, the rudimentary town plan has already emerged, and one may call this the youthful stage of development. The population of the new town in 1966 was estimated to be about 180 000.

By 1980 Kwun Tong's town plan has reached maturity (Figure 6 and Plate 3). Construction work within the new town proper has largely been completed. A number of outstanding features can be discerned:

- There is an increasing number of private multistoried buildings for residential purpose erected on the hill tops of the housing zone (J).
- On the roof tops of most of the tenement buildings, non-permanent residential structures appear, suggesting a shortage of housing in the area (C).
- There is a high degree of intensification in the use of the factory buildings in the industrial zone. By comparing with the 1967 photographs (Plate 2), one sees that new, multistoried industrial buildings have replaced many of the larger and lower factory buildings. Even the oil tanks in the oil storage area have been rearranged and the storage area has been reduced in size.
- The emergence of some recreational open space becomes more evident (L).
- The road system has been further expanded and elaborated. The most noteworthy is the mass transit railway bridge running above the main road (M).
- Despite the continuing government effort in the construction of public housing estates, squatter and temporary housing areas remain.
- A cargo handling area and a cargo landing strip have been developed along the coast of the industrial zone (N). The intensive activities noted here witness the prosperity of this industrial zone.

TABLE 3. ERROR MATRIX OF AERIAL PHOTOGRAPHIC INTERPRETATION OF LAND USE

LAND-USE TYPE INTERPRETED FROM AERIAL PHOTOGRAPHS	LAND-USE TYPE VERIFIED ON GROUND																				
	1a	1b	1c	1d	2	3a	3b	3c	4a	4b	4c	5a	5b	5c	5d	6	7	11	12	13	Total
1a	16																				16
1b		25																			25
1c			7																		7
1d				6				1													7
2					25																25
3a						6															6
3b							48			2											50
3c								14													14
4a									22												22
4b							1			19											20
4c											8										8
5a												25									25
5b													17								17
5c														4							4
5d															4						4
6																15					15
7																	15				15
11																		8			8
12																			10		10
13																				2	2
Total	16	25	7	6	25	6	49	15	22	21	8	25	17	4	4	15	15	8	10	2	300

Average Sample Size for the whole map = 15 Overall accuracy = 296/300 = 98.7%

Note: For a full listing of the land-use types shown, refer to Table 2.

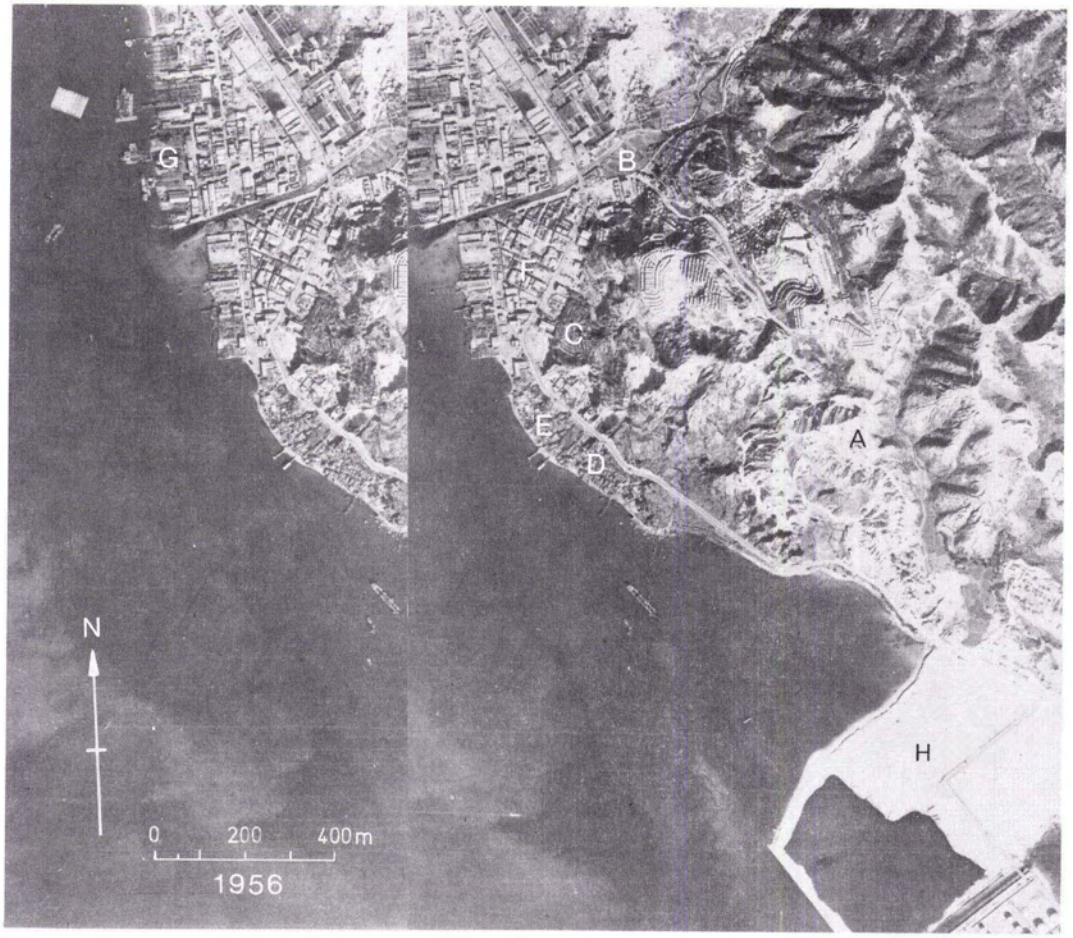

PLATE 1. Stereogram of Kwun Tong taken on 27 December 1956

By 1981, the population of Kwun Tong was found to be about 400 000, of which TPUs 294 and 295 under study had a population of about 186 000 only.

QUANTITATIVE LAND-USE CHANGES, 1956-1980

By measuring the areal extent of each land-use category with the aid of 1-mm grid cells superimposed onto the aerial photograph and examined with the aid of a mirror stereoscope, one can obtain accurate quantitative data depicting the land-use changes as the new town develops. For certain categories of land use, namely, residential, industrial and storage, the building height has to be incorporated to arrive at a more realistic pattern of land usage. Thus, from Figure 7, which presents the quantitative data graphically for easy comprehension, one sees that industrial usage has already been the major characteristic of the new town in 1967 (39.09 percent of the total land area) and has maintained that in 1980 (40.60 percent). The loss of the shipyards in 1980 explained the rather low increased percentage, but, in absolute terms, the floor area has increased by 1 250 000 m^2 because the multistoried private factory buildings have become much higher and also increased in number.

The next important use is residential (14.96 percent). However, the increase since 1967 has been slight even in absolute terms probably because most of the government and government-aided housing estates had already been built by 1967. Much of the increase is the result of the greater number of over 20-story high private residential buildings, another evidence of high density development. On the other hand, one notes that the extent of the temporary housing area had declined by 1980, but the area for the squatter structures had increased in size.

Closely associated with the factories are the "godowns and warehouses" which have shown high absolute as well as relative increases by 1980, although the overall figure for the storage usage has dropped due to the reduced oil storage area.

Another feature of interest from the town planning point of view is the provision of recreational facilities and community services, notably schools.

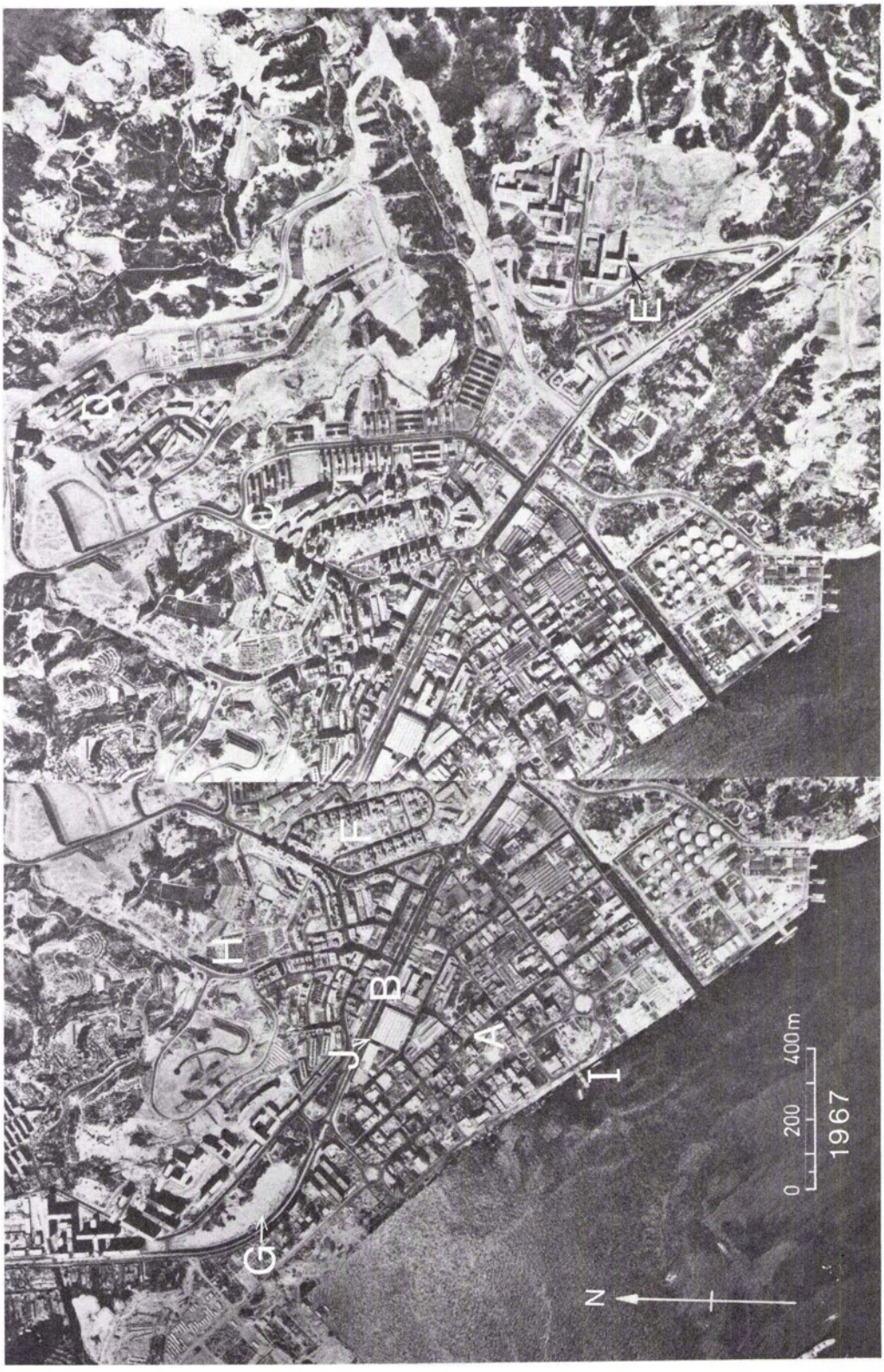

PLATE 2. Stereogram of Kwun Tong taken on 16 May 1967

PLATE 3. Stereotriplet of Kwun Tong taken on 12 November 1980

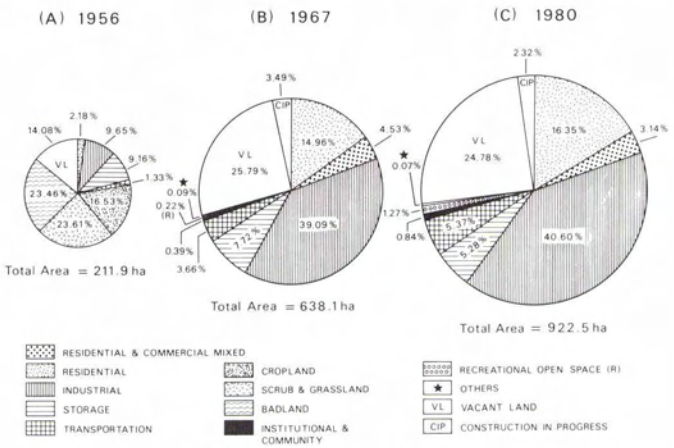

FIG. 7. Land-use changes in Kwun Tong, 1956-1980

Clearly, there have been some improvements since 1967.

TRANSPORTATION NETWORKS CHANGES

The transportation networks as they evolved in Kwun Tong could be accurately interpreted from the aerial photographs. This permits a topological analysis of the networks using the method introduced by Kansky (1963) to be carried out. Essentially, this method simplifies the transportation networks into topological diagrams as has been done for the three different periods of Kwun Tong's development (Figures 8a, 8b, and 8c). These diagrams emphasize three essential spatial features of these routes: (1) vertices (V) or nodes which are places or points connected or to be connected; (2) edges (E) or links which are connecting routes or lines; and (3) subgraphs (G) which are independent and unconnected parts in the whole network. Based on these characteristics, a number of indices could be computed (Table 4). The cyclomatic number (N) is an arithmetic comparison between individual elements of the network in the form of $N = E - V + G$. In a well connected network, N is equal to the maximum number of circuits whereas, in a disconnected network, G is greater than unity and N is equal to zero. Therefore, the higher the cyclomatic number (N) the more developed is the transportation network. The Alpha (α) index is an adjusted form of the cyclomatic number and may be regarded as the ratio between the observed numbers of circuits and the maximum number of circuits in the entire network. This is obtained mathematically as $\alpha = N/(2V-5)$. For a completely interconnected network the α index will be equal to unity. The Beta (β) index, on the other hand, measures the relationship between two individual elements of a network, i.e., $\beta = E/V$. A more sophisticated network will produce a higher β index, especially if there are more edges than vertices. Finally, the Gamma (γ) index or index of connectivity is a quotient of the observed number of edges to the maximum number of edges in the form $\gamma = E/(1/2(V^2-V))$. This value varies from 0 to 1. The value of 1 describes completely connected networks.

In our example of Kwun Tong (Table 4), the cyclomatic number (N) showed an increase from 0 to 47 with time, thus indicating that the number of circuits in the network had increased tremendously since 1956. The Alpha (α) index similarly increased

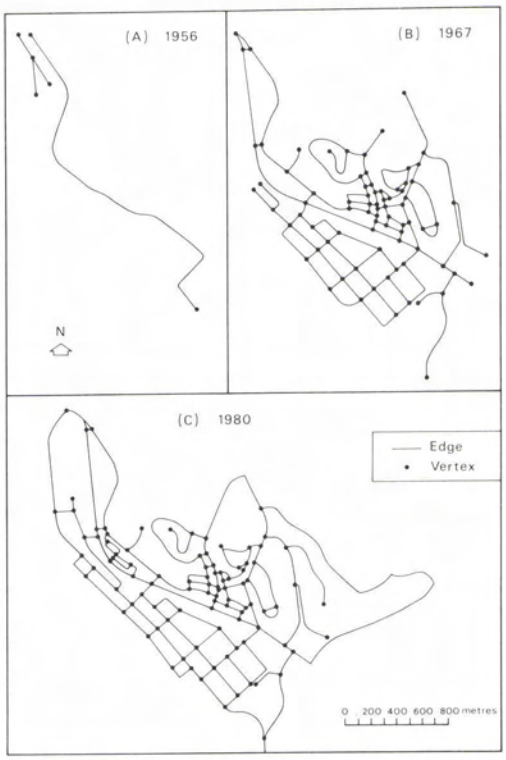

FIG. 8. Characteristics of transportation networks in Kwun Tong, 1956-1980.

TABLE 4. CHANGES IN NETWORK CHARACTERISTICS AND INDICES OF KWUN TONG, 1956–1980

Network Characteristics	1956	1967	1980
No. of Vertices (V)	6	79	98
No. of Edges (E)	4	111	144
No. of Sub-graphs (G)	2	1	1
Network Indices			
Cyclomatic Number (N)	0	33	47
Alpha (α) Index	0	0.216	0.246
Beta (β) Index	0.667	1.405	1.469
Gamma (γ) Index	0.267	0.036	0.030

from 0 to 0.246, indicating that the network was becoming more complete. Similarly, the Beta (β) index exhibited an increase from 0.667 to 1.469, indicating that the network structure became more complex as a result of the increasing number of edges in relation to vertices. On the other hand, the Gamma (γ) index or the index of connectivity revealed a decrease in value with time, suggesting that the connections in the network were less and less direct. To conclude, the transport network system in Kwun Tong has become more complete and complex, but the connections have also become less direct (i.e., lower connectivity) because most of the roads developed are short feeder roads only for connecting the industrial and housing zones with the main road.

The most important development in recent years has been the operation of the underground railway system which terminates in Kwun Tong on its eastern route. The infrastructure related to such a development can be readily seen in the 1980 aerial photographs (0 in Plate 3).

CONCLUSION

In this paper, the usefulness of sequential aerial photography for monitoring the growth of a new town is demonstrated. The emphasis has been placed on the design of a photointerpretation key of building types and its subsequent modification into a land-use classification scheme. The series of land-use maps produced are found to be accurate enough and permit one to see the building cycle, the direction of development, and the extent of change of the environment. Quantitative land-use data can be extracted from these maps and, with reference to the third dimension of the area studied, a realistic appraisal of the characteristics of the planned environment can be obtained. In addition, the sequential aerial photography permits objective topological analysis of the evolution of the transportation networks to be carried out.

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