RESEARCH ON THE APPLICATION OF UAV OBLIQUE PHOTOGRAMMETRY TO LILONG HOUSING: TAKING MEILAN LANE AS AN EXAMPLE

Jianing Gao *, Yang Shi, Yuan Cai

Shanghai Posts & Telecommunications Designing Consulting Institute, Shanghai, China
jianing.gao@mail.mcgill.ca, chienbien41@hotmail.com, caiyuan.sh@chinaccs.cn

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ABSTRACT:

Vernacular architecture has always captured professionals' attention for its unique approaches to construction, its typical way of integrating man and nature and the way it is used. Being a combination of traditional courtyard houses in China with townhouses in the West, Lilong houses or Shikumen houses are representatives of Shanghai vernacular housing. In terms of applying UAV oblique photogrammetry to preserving and documenting historic architectures, some studies have been done in China, but scant literatures are found on Lilong houses. This research is an attempt to preserve and document Lilong houses by adopting UAV in 3D modelling, to explore a rational approach for the application of UAV oblique photogrammetry to narrow lanes and to establish a collection of models to document the ongoing changes as well as nuances of each building more carefully. In this research, Meilan Lane is chosen as an example. Aided by AutoCAD drawings, flight routes and angles are designed. parameters for each flight are pre-set in GoodStation to send quantified instructions to the drone. A total of 4,531 photos are gathered and 4 models are built by ContextCapture Master. Two models with flight height at 40m and 115m are generated for macro-level study and two models with flight height from 20m to 32m are for micro-level study. Through this research, this paper elaborates the pros and cons of using UAV techniques in documenting Lilong residences and tries to find an applicable approach to building other Lilong complex models for more comprehensive studies in the long run.

1. INTRODUCTION

Vernacular architecture as the materialized culture has always captured professionals' attention, due to its unique approaches of construction, its typical way of integrating man and specific environment and the way it is used. Lilong houses (里弄 in Chinese) or Shikumen houses (石库门 in Chinese) are typical Shanghai vernacular housing, a production of their conspicuous combination of traditional courtyard houses in China with townhouses in the West. Boomed during the period of colonization (French and Japanese Concession Period) in Shanghai，especially from 1876 till 1910 (Shen, 2018), Lilong houses have been housing people over 140 years. It is estimated, according to Shen (2018), that Lilong houses account for approximately 60% of the total houses in Shanghai in 1949 and over 35,000,000m^2 Lilong houses were still in use at the end of 1988. In addition, in the 82km^2 of Shanghai's old downtown, there are 3,700 Lilong complexes. Besides, as the most prominent residential buildings in Shanghai, it sheltered not only ordinary people but also the upper-class, such as literati, social activists, artists, doctors, professors, officials, capitalists, etc. For the former, it often wears a humble but decent façade, displaying the most practical use of an architecture; for the latter, it is often designed in more sophisticated appearances, featuring the urban contexts and the multi-cultural exchanges back in the days. As a type of residential architecture, it is highly demanding for radical preservation and conservation, for the sake of its fundamental use, historic remembrances as well as aesthetic values.

Since 1989, a total of 1,058 architectures and 44 historic and cultural districts have been enlisted in *Excellent Historic Architecture* by Shanghai Municipal Bureau of Housing. Meilan Lane, a complex of Shikumen architectures got enlisted in 2005 (Chen & Zheng, 2006). Being one of the 44 historic and cultural districts, Hengshan Rd.-Fuxing Rd. Historic and Cultural District where Meilan Lane is located took its form in 1950s. With the biggest number of Excellent Historic Architectures in comparison with other places, this district is recognised as the largest historic district in Shanghai. Situated at No. 1-58, Lane 596, South Huangpi Rd., Huangpu District, built in 1930, Meilan Lane is of great importance in terms of displaying the spatial arrangement of Shikumen houses, the patterns of plans and façades, the everyday life of the residents, the conflicts between dwellers' needs and physical conditions, etc. In 2022, due to the proper ideas of conservation and the exterior design which lead to a convivial neighbourhood, the regeneration design of Meilan Lane is on the shortlist of Open Door Project, delivered in partnership with RIBA and British Council, dedicated to promoting and celebrating outstanding conservation work in mainland China and the UK.

Facilitated by *Ordinance of the Protection of Shanghai Historic Districts and Excellent Historic Architectures* issued by Shanghai Municipal People's Government in 2002, *Ordinance of Shanghai Urban Regeneration* issued by Shanghai Municipal People's Government in 2021 and *Operational Guidelines for the Investigation and Evaluation of Shanghai Historic Architecture* issued by Shanghai Municipal Bureau of Housing and Centre of Shanghai Historic Architecture Protection in 2022, historic architectures are being more carefully protected and regenerated. Over the past decades, ideas about repair work of these heritages have been well developed from single buildings to complexes and from façade preservation to

* Corresponding author

functional amelioration. For the preservation and conservation of Lilong housing, preliminary researches and construction techniques are systematically required throughout the entire workflow. However, information is still captured or collected in a traditional manner, such as manual measuring, on-site photo-picturing, AutoCAD mapping, without much aid of leading-edge approaches and technologies such as laser scanning, BIM, digital twins, etc., which leaves a considerable margin for better monitoring and guarding these buildings as well as improving work efficiencies. Furthermore, for Lilong houses that are still in use, the locked unapproved projects, the discord within the neighbourhood are eminent obstacles to the first-hand information collection, an urgent call for the appropriate regulatory countermeasures from the government.

2. LITERATURE REVIEW

In terms of applying UAV oblique photogrammetry to preserving and documenting historic architectures, some studies have been done by professionals in China.

Propelled by the development of smart city and digital city in China, there is a growing body of literature focusing on using digital techniques in documenting and presenting cities, historic architectures, relics, archaeological sites, etc. In regard of architecture, such technologies are mainly used on a macro-level, or rather, on urban and geographical level (Hu, 2022) (Yu, 2021). For historic architectures, Xin Yang gave a general introduction to using laser scanning, BIM and UAV in the preservation of historic buildings (2021). Through the study of Guangren Temple in Xi’an, Shaanxi Province, Chi and Zhang (2022) elaborate the protection ideas of utilising 3D model information for restoring and constructing temple buildings. Zhang et al. build 3D models of historic architectures in Tangwei Village and Nanshe Village in Dongguan City, Guangzhou Province, proving that UAV performs both efficiently and accurately in documenting historic buildings (2020). For vernacular architectures, studies have been conducted from different perspectives. Song et al. (2019) note that the application of UAV oblique photogrammetry to village surveys could accelerate the speed of terrestrial reconnaissance of vernacular architecture on large scales by studying a village situated in the Yellow River Delta. Liang and Pan (2022) document the preservations and inheritances of ethnic minority villages by using UAV tilt photography and ContextCapture in constructing 3D models. Equipped with UAV and laser scanners, Chen and Li (2022) point out that digital techniques advance the information collection of vernacular architectures particularly of those degraded ones. For Lilong housing, few studies are found. Shang et al. (2019) states that laser scanning, UAV, BIM and GIS provide more feasibilities for future restoration and lifecycle management of Lilong architectures. Zhong Tie draws a general workflow of building an interaction display of Lilong buildings through HDS (High-Definition Surveying) and laser scanning which help in obtaining digital data (2015).

Confronted with scarce studies on digital interventions on Lilong houses, this research is conducted with three main objectives, to apply UAV to 3D modelling of Lilong houses to better take precautionary measures in a visual responsive way, to search appropriate methods of utilising UAV to Lilong housing particularly in narrow spaces and to establish a group of models of Meilan Lane so as to document and analyse the ongoing changes and nuances of each building in a more careful and systematic way. For these purposes, Meilan Lane is chosen as an example, both due to its forms and historic values as described above.

3. METHODOLOGY

Rapoport (1969), after pointing out the fact that no letters, diaries and architectural theories in journals, books and drawings and all other evidences of the intellectual development of a designer are available for the study of vernacular architecture, recommends that people analyse them through a specific point of view instead of tracing its development. Based upon this, this research is an attempt to document and analyse Meilan Lane digitally by finding out the proper way of data collection to generate 3D models at two levels, namely the macro-level and the micro-level. The former helps urban planners, architects and scholars to grasp the context of the area in the process of regeneration and revitalisation design of the whole district through studying the spatial configurations, the open spaces, the commercial and cultural spaces and spatial interactions between Meilan Lane and its surrounding environment, the uniformity and distinction of roofs, façades, materials, colours, etc. within the area. The latter focuses more on presenting smaller particles of Lilong houses other than the whole complex, such as the window styles, the roof patterns, the pipes, the parapets, etc.

Covering an area of 6,140m^2, Meilan Lane is composed of four rows of three-storeyed Shikumen buildings and five lanes (弄堂 in Chinese) (Fig. 1). There are two major lanes, one is the main lane which is 5.5m wide running from east to west, leading to the main gate of the whole complex, the other the sub-lane which is 3.6m wide from north to south, connecting all buildings together (Fig. 2). Compared with the width of lanes, the average height of Shikumen buildings is relatively high which is 12.5m. Limited by GEO Zone in this district that flight height ought to be below 120m and the stringent controls of aerial vehicles in this area, DJI Mini 2 is chosen as the appropriate device for aerial photographs taking.

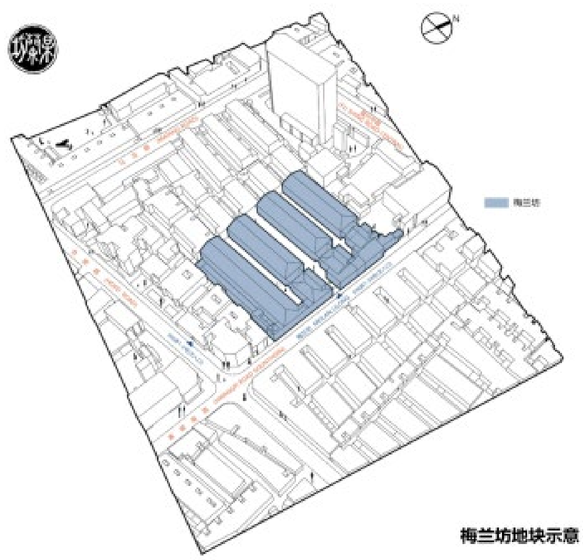


Figure 1. Configuration of Meilan Lane.

Figure 2. Dimension of main lanes and sub-Lanes.

This research is conducted both quantitatively and qualitatively. A total of three rounds of experiments are conducted. During each round, GoodStation is used to quantify the flight such as the flying heights, angles, routes, and the number of pictures to be taken.

Round 1: 45m, 60m, 90m, 118m, 30m for the main lane.
Round 2: 40m, 80m, 115m, 25m for the main lane.
Round 3: 40m, 115m, multiple heights for the main lane and the sub-lane.

Below are the detailed information of Round 1 and Round 2.

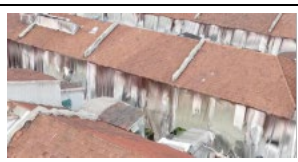
Round 1		
Flight Height	**Photo Numbers**	**Models**
45m	117	
60m	76	
90m	86	
118m	72	
30m Main lane	83	
Problems	○Images distortions of south façade	
	○Incomplete images of roofs, north façade,	
	○Difficulty in controlling drone while flying at the height of 118m	
	○Little differences between models of 60m and 90m	
Solutions	○Expansion of flight route for complete coverage	
	○Pre-designed routes guided by AutoCAD mappings	
	○Lower the flight height from 118m to 115m	
	○Flight height adjustment	

Table 1. Detailed information of Round 1.

Round 2		
Flight Height	**Photo Number**	**Models**
40m	828	
80m	498	
115m	590	
25m Main lane	145	
Problems	○Images distortions of windows under eaves	
	○Obscurity caused by shadows	
	○Little differences between models of 80m and 115m	
	○Blocks caused by platan tree leaves	
Solutions	○Amelioration of flight route for finer images	
	○Research conducted on cloudy days instead of sunny days to avoid shadows	
	○Removal of model of 80m	
	○Choose the best time to conduct the research: December to February to avoid leaves blockings	

Table 2. Detailed information of Round 2.

parameters of each round are calibrated according to the outcome of the last round. Contrasts and comparisons are then made to get a more appropriate way of data collection for Meilan Lane. Though in contrast with Round 3, the first two rounds underperform in displaying the details and the completeness of the whole residential complex, they serve as the foundation for Round 3. Problems exposed in Round 1 and Round 2 mainly lies in poor image resolution and distortion that in Round 3 drone is operated to fly in lower heights with calculated angles and routes for the best quality of photos and for the full coverage of both the elevations and the roofs of Shikumen buildings.

4. THE APPLICATION OF UAV OBLIQUE PHOTOGRAMMETRY TO LILONG HOUSING

Guided by two groups of experimental models, it is found that 40m and 115m are best for documenting the general information of the whole complex and heights from 20m to 32m are best for the main lane and the sub-lane. Four models are chosen as the final ones for documenting Meilan Lane in Round 3. Model 1 is established by 1,109 photos taken from the height of 40m for more detailed studies of the complex, Model 2 is built by 1,393 photos taken from the height of 115m for documenting the general conditions of the whole block, Model 3 and Model 4 are generated by 815 and 1,214 photos taken from various heights specifically for the documentation of the main lane and the sub-lane.

Round 3			
Model	**Flight Height**	**Photo Numbers**	**Models**
Model 1	40m	1,109	
Model 2	115m	1,393	
Model 3	Main lane (Multiple heights**)	815	
Model 4	Sub-lane (Multiple heights**)	1,214	
Problems	○Difficulty in controlling drone caused by close building intervals		
Solutions	○Manual manipulation of drone in specific places		

Table 3. Detailed information of Round 3.

(*Detailed information about heights and angles of each flight routes are shown in Table 4.)*

Considering that the closeness of Shikumen buildings might be obstacles for the flight of UAV, flying routes are firstly drawn by an AutoCAD map and then parameters such as the speed of flying, the angles of camera, the intervals of each photo are set in GoodStation.

For Model 1 and Model 2, three routes are set. One is in the east-west direction where pictures are taken vertical to roofs to fully cover the whole complex. The other two are in the north-south direction with an angle of 60° for grasping both the north and the south façades of each Shikumen building (Fig. 3).

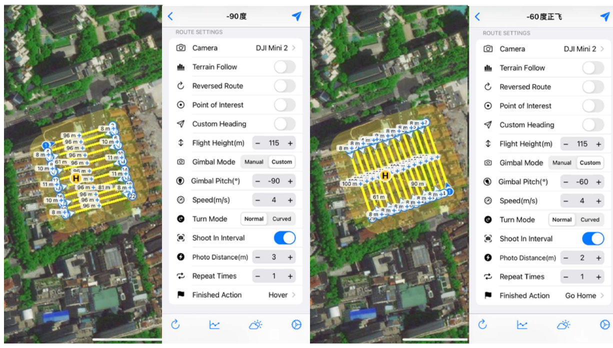


Figure 3. Parameters of Model 1 and Model 2 set on GoodStation.

Model 1 shows more detailed information than Models 2 while Model 2 contains more urban information than Model 1. Both models assist professionals when studying the district on a macro-level (Fig. 4-5). With the aid of online platforms, it is more convenient for people from all walks of life to get the accessibility to digitalised models of Lilong complexes. Taking Meilan Lane as an example, models can be found via Sketchfab (https://sketchfab.com/3d-models/40m-merged-mesh-combined-3-04032021-e522b6e026114373b728bf9beb3740e2).

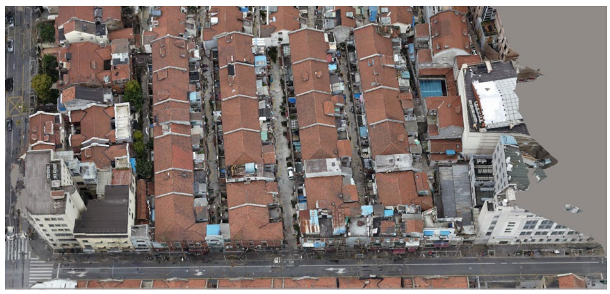


Figure 4. Model 1.

Figure 5. Model 2.

Model 3 and Model 4 are the results of applying UAV to narrow lanes. In this study, two difficulties are overcome. One is the messy wires, bamboo poles for clothes drying (typical in shanghai that usually extend two to three metres outside balconies for airing clothes), and the unauthorised makeshift buildings on the roof floors, usually three to four metres high, making it impossible to lower the drone, forcing the drone to keep a safe distance from the buildings (Fig. 6). The other is the narrowness of the lanes, which makes it a big challenge to get full pictures of the whole façades from roof to the base of Shikumen building.

Figure 6. The unapproved architectures.

To get photos with less distortions and with more information, 12 routes with different flight heights and angles are designed. One is to make a square tour of the lane to get the information of roofs. Three are right above the centre of the lane to capture the information of the narrow passages. Four flights are made over the roof ridge and four flights are made along the building footprints. Angles and flight heights are set by the analysis drawings on AutoCAD (Table 3) (Fig. 7 - 9).

NO.	Items	Main lane		Sub-lane	
		Flight Height (m)	Flight Angle (°)	Flight Height (m)	Flight Angle (°)
1	South façade	29	30	32	25
2		20	22	20	17
3			57		54
4			36		28
5	North façade	20	15	24	26
6			34	20	16
7			36		25
8			61		57
9	Lane (Vertical)	20	0	20	0
10	Lane (East-West)	25	14	25	9
11	Lane (West-East)		14		9
12	Roof	25	0	25	0

Table 4. Flight heights and angles for the main lane and the sub-lane.

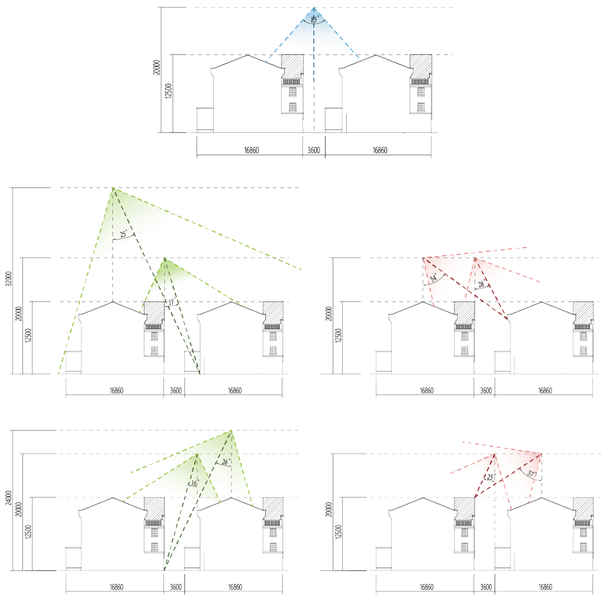


Figure 7. Route design of sub-lane.

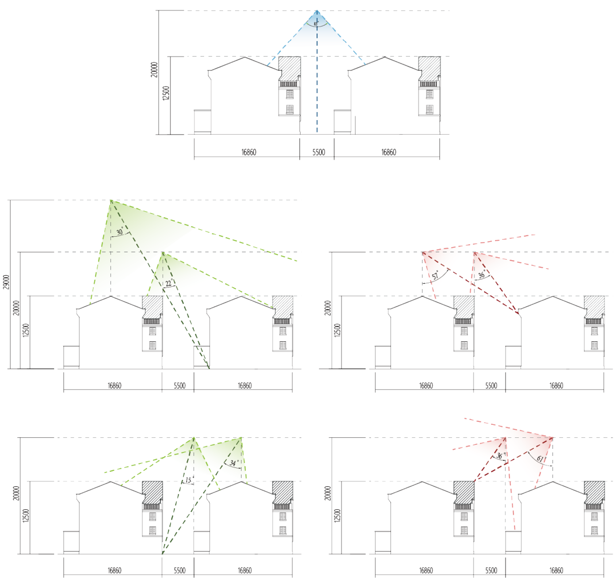


Figure 8. Route design of main lane.

Figure 9. Routes of Model 3 on GoodStation.

Model 3 and Model 4 proves that the methods used in capturing photographic information in narrow lanes are appropriate and efficient. Flight parameters are of vital importance in generating good models. It should be well noticed that flight parameters differ from one Lilong complex to another and proper parameters are acquired from supportive materials such as the scales of buildings and comprehensive understandings of each complex that helps customization.

Model 3 and Model 4 excels in providing the actual conditions of the façades to craftsmen during the preparation stages of repair and maintenance and they perform well in supplying an efficient way to electricians while carrying out the cable tray work in Meilan Lane which is an essential part in the regeneration phase required by the government. Apart from documenting physical aspects of Meilan Lane, both models present the mundane life of dwellers digitally, such as the way residents dry their clothes, their quotidian usage of the sky wells in Shikumen buildings, and the common places where inhabitants socialize with each other (Fig. 10-11).

Figure 10. Model 3 - Main Lane.

Figure 11. Model 4 - Sub-lane.

Through the four models, this paper explores more possibilities by applying UAV technologies to Lilong housing and makes an effort in preserving cultural heritages like Meilan Lane with a more systematic and sustainable approach.

5. CONCLUSIONS

In this research, UAV oblique photogrammetry shows its advantages in documenting the actual conditions of the upper part of Shikumen buildings, or rather, the roofs and the unapproved constructions on the third floor. Models of high resolution will serve as a guidance for the following preventative maintenance and repair of roofs, eaves, gutters and pipes which is difficult for regular check. For the first stages of preservation, it may assist researchers by locating the degradation of bricks, cement, roof tiles and by spotting the deterioration of window frames, etc. Besides, it poses least interventions in documenting the illegal constructions for the government supervision when confronted with the locked units. Compared with the traditional way that takes five people two weeks to carry out the reconnaissance work in Meilan Lane, UAV tilt photogrammetry takes only two people four days to generate a series of models. Undoubtedly, UAV oblique photogrammetry, as an efficient and economical approach at preliminary stages of a project, reduces field surveying time and labour cost. In addition, advanced by online platforms for 3D model displaying such as Sketchfab, it provides people with a more virtual and vivid perspective particularly when the project is combined with schematic designs. Last but not least, with the growing number of models generated, a data bank for Lilong houses will be established and will call for studies beyond the status quo. Comparisons and contrasts of the fluid content will stimulate more interdisciplinary approaches of heritage preservation.

However, the technology of UAV oblique photogrammetry is constrained in several ways when it is applied to Lilong complex. First and foremost, the technology is severely time and season limited in this densely built area because of the shadow cast by the buildings as they are close to one another. Secondly, the age–old well-nourished and flourishing platan trees very popular over what used to be French Concession Area in history poses another great hindrance with their broad thick leaves. The best time is between December and February when platans are leaveless in Shanghai. Thirdly, while an excellent UAV flight depends largely on the assistance of AutoCAD mapping and the relevant information of the buildings which are necessary, the old vernacular architectures tend to be anonymous without their original owners and as a result, there is no way to trace back to their original documentations including drawings, the calculation of structures, the materials, etc. Under these conditions, for buildings like Lilong complexes, probably it would be better to have the measurements of the houses first to develop a general drawing of both the complex and its surrounding buildings before carrying out the flight missions.

However, some of these limitations are external and could be avoided and even eliminated. UAV tilt photogrammetry, as one of the best technologies, should be brought into full play. And the rapid pace of demolition of vernacular architectures due to urbanisation in China makes it necessary for scholars to deem the present time the high time that digital documentation be placed in a vital position in the course of heritage preservation and conservation.

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