# Application of Integrated UAV and TLS Point Clouds in Urban Road Renovation Design: A Case Study of Xiangjiang South Road Scenic Corridor in Changsha, China

Jiayin Liang *

School of Civil Engineering, Central South University, Changsha, China

* Corresponding Author Email: 1135554083@qq.com

**Abstract.** Urban road renovation projects often face complex site conditions, incomplete elevation information, dense roadside facilities, and limited support from conventional two-dimensional topographic data. To address these issues, this study investigates the integrated use of unmanned aerial vehicle (UAV) photogrammetry and terrestrial laser scanning (TLS) for 3D modeling and renovation design of an urban road corridor. The study area is Section B of Xiangjiang South Road Scenic Corridor in Tianxin District, Changsha, China, where the existing road is narrow, partially damaged, and characterized by mixed motorized and non-motorized traffic. The redesigned corridor is 871.861 m long, classified as an urban secondary arterial road, with a design speed of 40 km/h and a standard cross-section width of 16.5 m. UAV and TLS data were acquired and processed to generate integrated point cloud products for terrain correction and design support. The results show that the integrated point cloud data effectively improved the representation of existing terrain and roadside geometric conditions, especially in areas where the original topographic map contained sparse or unreliable elevation information. The combined dataset provided both corridor-scale terrain continuity and detailed local geometric features, which supported route design, vertical profile design, cross-section definition, drainage layout, pipeline coordination, and lighting design. Compared with a single data source, the integrated use of UAV photogrammetry and TLS provided a more practical 3D basis for road renovation in a constrained urban environment. The study demonstrates that multi-source point cloud technology can serve not only as a visualization tool, but also as an effective pre-design support dataset for urban road renovation engineering.

**Keywords:** Urban road renovation; UAV photogrammetry; TLS; point cloud integration.

## 1. Introduction

Renovation of the urban roads is becoming more significant in the framework of urban renewal, transportation revitalization, and the quality improvement of the public space. The renovation project is executed on limited areas that have been previously developed, including such factors as existing pavement, structures, utilities, vegetation, and traffic organization, which should be all considered. Therefore, the credibility of data of current condition is one of the vital requirements of good engineering judgement. It means in practice that inadequate or partial information about terrain conditions and geometry can impact adversely on the optimization of horizontal alignment, vertical grading, cross-section design, and drainage design, and the layout of supporting facilities.

Traditional pre-design surveys on urban road renovations are continued to depend mostly on 2D topographic maps and regular field measurements [1]. Even though such approaches are common in the corridors, they can be ineffective when the corridor is densely populated with roadside attributes, has a non-uniform surface, or cannot be easily accessed. In special cases, the lack of elevation points, the inability to show all local obstacles and inability to understand 3D could decrease the quality of design support.

The latest developments in 3D spatial data acquisitions have opened up opportunities that can be applied in road engineering applications. In these technologies, unmanned aerial vehicle (UAV) photogrammetry and terrestrial laser scanning (TLS) are the most representative technologies [2]. UAV photogrammetry can acquire large scale corridors of terrain or surface data quickly, easily and cheaply, and is especially applicable to acquire the whole morphology of linear infrastructure settings. On the other hand, TLS gives densely packed and highly precise point clouds of locally observable features and elaborate roadside features and thus has the benefits when describing geometrical details and detecting obstacles. Nevertheless, every approach has its own restrictions. The reconstruction obtained using UAVs is dependent on the viewpoint, occlusion, and resolution of the images, and TLS is limited by station coverage, field efficiency, and registration workloads in large linear projects.

It has been noted recently how the application of point cloud technologies in transportation surveying, digital terrain reconstruction, infrastructure testing, and corridor modeling has grown in popularity [3, 4]. However, most of the discussed works are related to the methods of data acquisition, quality of reconstruction, or the separate processes of modeling, but less attention is paid to the idea of how integrated multi-source point cloud data may directly contribute to real-life design decisions in urban road renovation efforts. In the context of an engineering project aiming at renovation, the main concern is not only how to create point clouds, but also how to convert the obtained 3D data into useful design support (alignment, profile, section, drainage, and utility coordination) with limited site conditions.

With these in mind, the research examines renovation of Section B of Xiangjiang South Road Scenic Corridor in Changsha Tianxin District, China. Being a narrow, partially broken, and exposed to the combination of motorized and non-motorized traffic, the road corridor is representative of the renovation issues of the existing urban environment. This paper tries to create and provide an overview of a workflow oriented at engineering that incorporates UAV photogrammetry and TLS in the context of helping to conduct 3D modeling and renovation design support. The value of the paper is to illustrate the usefulness of engineering multi-source point cloud data to enhance the representation of terrains as well as supporting useful road renovation design within limited city setting.

## 2. Study Area

The research site is in Section B of Xiangjiang South Road Scenic Corridor, which is in the urban developmental boundary of Tianxin District, Changsha, China. It is located in a regional setting that is ecologically sensitive and links the existing highway to the northern and southern parts of Xiangjiang embankment and connects it with the existing road to the scenic site, that is to say, the road links the present Xiangjiang embankment road on the north end to Zhaoshan Scenic Area on the south end. The road is a major city secondary artery in the regional network of roads and plays a significant role in enhancing accessibility and transportation services in the Changsha-Zhuzhou-Xiangtan ecological green center region. The current roadway is quite narrow and contains both a motorized and non-motorized mix of traffic, and there are some sections of the pavement heavily damaged. Moreover, it has poor interface with the Xiangjiang riverside topography. As the north-south roads network connectivity brings increasing traffic demand, the original road cannot meet the needs of regular traffic operations as well as the demands of local population and further development. Therefore, this section was chosen to be renovated.

## 3. Data and methods

The sequence of operations in this study will include four major stages, i.e., multi-source data collection through UAV photogrammetry and TLS, individual point clouds processing, merging of aerial and ground-based data, and incorporation of the combined 3D data into city road reconstruction design (Fig. 1).


**Fig 1.** Workflow of the proposed multi-source point cloud-based road renovation design.

### 3.1. Data acquisition

In order to enhance the reliability of the existing condition data that will be used during renovation design, both UAV photogrammetry and TLS were applied in this research.

After inspecting the site and equipment, UAV survey was performed. Takeoff and landing zone was organized on an open ground in close proximity to the western entrance of Zhaoshan Forest Park. To enhance the accuracy of space, a DJI UAV with assisted positioning (RTK) was used. The altitude of flight was 100 m, and the speed of flight was 7.9 m/s. Covered area of the survey: approx. 68,038 m 2, duration: approx. 8 min., no. of images: approx. 200.

To obtain precise ground-based information, a P50 terrestrial laser scanner was applied. Six scan stations have been placed in the road corridor to cover all the study sections. The first station was located at the UAV work area, the other ones, at the easily recognizable roadside objects to help register them later. Relative to UAV photogrammetry, TLS yielded denser and more detailed geometric data on the local features and areas where occlusions are likely.

### 3.2. Data processing and integration

Pix4Dmapper was used to process the images of the UAV to produce the outcome of aerial triangulation, sparse and dense point clouds, digital surface model (DSM) and ortho photos [5]. They supplied the general setting of the area and planimetric spatial information of the corridor.

The TLS data were computed with a Leica software [6] whereby the six scan stations were registered and optimized depending on the mutual geometrical properties of two adjacent scans like outlines of buildings and patterns of trees as well as other roadside objects (Fig. 2). Registered TLS point clouds contained highly accurate information about local structures, road boundaries, roadside poles, and other engineering related features.

**Fig 2.** TLS field acquisition using the P50 scanner and six-station registration result.

The strategy that was followed in this study was not to develop a point cloud fusion algorithm but rather adopt an engineering-focused integration process. Large scale terrain framework data were obtained by UAVs and the data by TLSs were used to complement the details at places where the aerial reconstruction failed to capture the local detail. Converted and imported into the original topographic mapping environment, the integrated point cloud information was thereafter used to fill in and rectify the elevation data that is needed in the remodeling plan. In this case, it was especially important because on the initial terrain map there were few and irregularly spaced natural elevation points.

### 3.3. Design application

It is notable that integrated point clouds data were not purely used in the visualization but extended to being practical datasets in road renovation design. With enhanced completeness and trustworthiness of the terrain model, integrated data could be used to support the design of horizontal alignment, vertical profile, definitions of cross sections, drainage layout, and integration of auxiliary engineering facilities.

## 4. Results and Discussion

### 4.1. Road renovation design

According to the enhanced topographic data that were derived by the point cloud data, the reconstruction project of road Section B was conducted, which included route work, subgrade and pavement work, road drainage and jointed pipeline work and road lighting work. The redesigned section spans a total length of around 871m and belongs to the category of urban secondary arterial roads with the standard width of cross-section of roads being 16.5m and two lanes in either direction. There is only one horizontal intersection point on the alignment, and the smallest horizontal radius of curvature is approximately 1120 m, and the length of the horizontal curve is approximately 702 m. The two points of grade change are placed in the vertical profile, and the least grade length is 262 m.

#### 4.1.1. Route design

The design of the route has horizontal alignment design, vertical profile design and cross-sectional design. There is one horizontal intersection at chainage 524.023 m in the horizontal design and the least curve radius is 1119.888 m. Total horizontal curve length is 702.28 m. The principle applied in the design is to harmonise road layout with its environment as well as maintain equilibrium between the horizontal and vertical geometric parameters to attain the continuity of vision, road safety, and economy.

Two grade change points have been placed in the vertical profile design at chainages of 270 m and 610 m respectively. The minimum grade length has been stated to be some 262 m but the detailed design description indicates that the minimum grade length meets the code requirements. The initial grade before the first-grade change point is designed with a grade of -0.919 percent, the grade before the second-grade change point is 0.311 percent, and the grade behind the second-grade change point is -1.167 percent. Relatively large vertical curve radii are used in order to enhance the driving experience and comfort with a minimum of 13683.043 m of minimum vertical curve radius.

During the cross-section design, after taking into consideration safety, road category, economy and social utilities, the chosen cross section is two-lane cross-section bidirectional. The conventional cross-section width is 16.5 m, and it consists of 1.5 m median, 3.5 m vehicle lanes, 1.0 m green zones and 3.0 m sidewalks. As far as cross slopes are concerned, the median and green zones are set at 0 percent, the carriage road at -1.5 percent and the sidewalks with 1.5 percent so that drainage efficiency is optimized and traffic safety assured (Fig. 3).

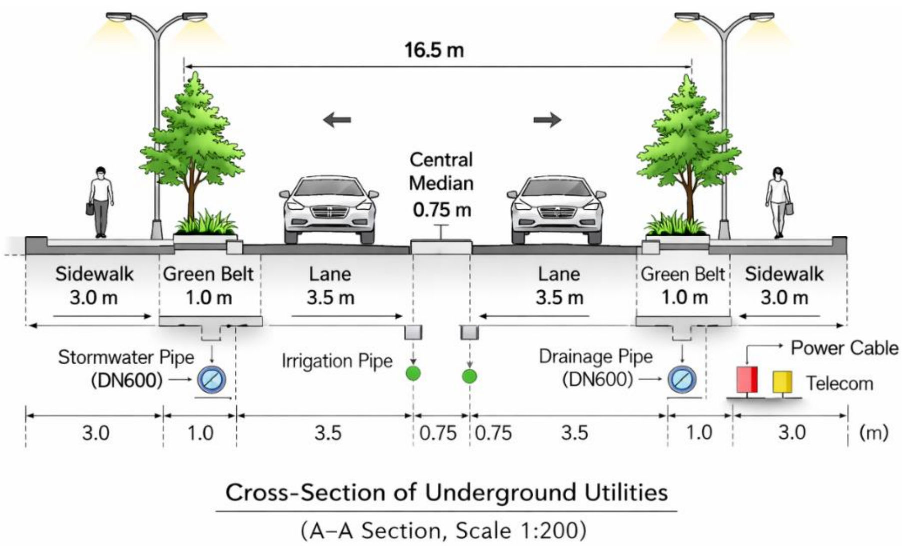


**Fig 3.** Standard cross-section and integrated pipeline layout.

### 4.1.2. Subgrade and pavement design

The principles of stability, durability, compatibility in appearance to the surrounding landscape, and economic viability are being used when designing the subgrade. It has subgrade filling as well as side slope protection. Slope protection on both sides of the road is made using cantilevered retaining walls.

In the pavement design, asphalt concrete pavement and cement concrete pavement were compared and on technical and economic consideration inside the design frame work asphalt concrete pavement was ultimately chosen.

### 4.1.3. Road drainage and integrated pipeline design

Conjointly with geometric design development, road drainage design and integrated pipeline design were designed as some of the most important elements of the road engineering scheme to create general unity in the functioning of the road and auxiliary municipal infrastructure. The section on drainage design and integrated pipeline design was considered as an additional part of the chapter on road design and it is clear that these sections were considered as essential parts of the overall renovation project (Fig. 3).

### 4.1.4. Road lighting design

The design of lights includes design principles and layout of street lights. The geometric design, drainage and pipeline coordination form a part of the total reconstruction plan of the road section together with the lighting design.

## 4.2. Design support provided by integrated point cloud data

This integrated point cloud data was a significant support in the whole process of renovation design. Not only as a tool to visualize the construction in 3D but the UAV and TLS products were implemented as practical tools to correct terrain and interpret geometrical relationships of the existing road corridor. It was especially critical since the initial topographic map had few poorly distributed natural elevation points whereas the new designed road goes over the land area of the old roadway.

To begin with, the combined point cloud data enhanced the representation of the current landscape conditions. UAV photogrammetry was efficient in covering corridors and enabled the reconstruction of the total topographic structure within the study region. Conversely, TLS offered finer and more detailed point clouds of nearby roadside objects, such as road edges, poles, fences, tree trunks and similar things pertinent to detailed engineering choices [7]. It is thus clear that this combination of these two sources of information offered a much better foundation on which to establish what the real spatial conditions of the road section are.

Second, the integrated dataset informed the amendment and addition of the elevation data to the design. The mapping conditions under which the renovation design was being done could be improved by importing the processed point cloud information into the original mapping environment particularly on areas when the current map did not have adequate elevation control. This enhanced the certainty of the vertical profile design, and minimized the unpredictability associated with the grade arrangement as well as the terrain fitness.

Third, the integrated point clouds data improved the understanding of regional geometry limitations within the passage. Side of the road structures and services present can also impact the alignment control, cross-section organisation, drainage organisation, and auxiliary engineering organisation. In particular, results of the terrestrial scan proved to be extremely useful when locating these local characteristics and when assisting with design coordination in cases of limited space.

The combined application of UAV photogrammetry and TLS generally enhanced the completeness of the pre-design data and made the existing road environment understandable. One of the significant benefits of the proposed workflow was engineering-related: correct design choices in urban road reconstruction are critically based upon accurate knowledge of the current topography and the limitations of the roadside.

### 4.3. Engineering implications

In spite of the fact that the current research is grounded in individual engineering practice, it offers practical lessons to urban road renovation practice.

First of all, the case demonstrates that multi-source point clouds can be effectively used as pre-design information base in restricted city streets. Integrated 3D datasets are more appropriate to depict real spatial relationships of roadway geometry, roadside features and utility conditions than conventional topographic maps.

The second point the research makes is that it shows both the feasibility of implementing corridor-scale aerial surveying alongside closely spaced ground-level scanning into the field of road engineering. The combination is especially applicable in the renovation cases when the continuity of the overall terrain and the control of the local geometries are needed.

Finally, the suggested workflow provides an achievable survey-to-design route of digital road rehabilitation. It allows supporting more data-based and visual interpretability design practice by interconnecting data gathering, correcting the site condition, and engineering design into one unbroken process.

## 5. Conclusions

The research has examined the use of integrated UAV photogrammetry and TLS in designing the renovation of an urban road in relation to the case study being Section B of Xiangjiang South Road Scenic Corridor in Changsha. The most important conclusions are:

The combination of the UAV photogrammetry and TLS was an efficient 3D data source in the renovation of the research corridor. UAV data made the process of corridor level terrain acquisition more efficient whereas TLS data complemented the geometric details at a local level and the roadside properties which are hard to acquire with aerial data.

The integrated point cloud products enhanced the presentation of the current topography and geometrical parameters, and it was used in the process of renovating, which included designing the route, vertical profile design, cross-section design and associated engineering coordination.

The case shows that multi-source point cloud data can be used not only to visualize multi-source point clouds, but also as practical pre-design support data in the context of urban road renovation projects, particularly when the space is limited and standard topography data can be absent, insufficient, or both.

From the engineering point of view, the suggested workflow offers a viable survey to design route in a digital road rehabilitation process. This paper also shows the possibility of a combined use of 3D spatial information in wider purposes of urban infrastructure enhancement as well as similar practice in engineering.

To sum up, the presented paper is the confirmation of a real-life benefit of applying UAV photogrammetry and TLS in road renovation works. Further development of this approach can be achieved by quantitative accuracy evaluation, comparative analysis of the data of one source and integrated sources, and more integration with digital road design platforms.

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