Bridging the Digital Divide and Shaping a Beautiful Earth
3D Real Scene Technology Solution
(ReS3D V1.0)

Chinese Academy of Surveying & Mapping
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Preface

The rapid advancement of global digitalization has made spatiotemporal information and positioning navigation services significant new infrastructure. In this ever-evolving digital era, 3D Real Scene technology is transforming our understanding of and interaction with the world at an unprecedented pace. With the swift development of data collection, processing, and visualization technologies, 3D Real Scene technology has transcended its initial applications in natural resource management and urban planning, expanding across borders and finding widespread use in various global contexts, thus becoming a vital force driving social progress, industrial upgrading, and the construction of smart cities.

3D Real Scene technology, with its high-precision, all-round and three-dimensional characteristics, can truly restore every detail of the earth's surface, from mountains, rivers, lakes and seas to city streets, from microscopic cells to the macroscopic universe, everything is included. The global application of this technology not only greatly enriches the connotation of geographic information systems but also provides unprecedented data support and decision-making basis for numerous fields such as urban planning, environmental protection, disaster warning, traffic management, cultural heritage preservation, agricultural monitoring, and tourism development, etc.

According to the logical hierarchy, digital twins focus on mirroring physical space in digital space; 3D Real Scene emphasizes both the digital mapping of physical space and the scheduling of perceivable and receivable signalling units in physical space by digital space, achieving "interoperability" between the two.

Regarding the granularity of detail representation, 3D Real Scene data is classified into terrain level, urban level, and component level, each with different demands and application scenarios. Terrain-level 3D Real Scene reflects landforms and geographical landscapes, primarily serving macro application scenarios; for example, in the construction of high-speed railways and highways, it can significantly reduce the workload of field surveys and improve the scientific nature of planning. Urban-level 3D Real Scene is detailed to the three-dimensional shapes of buildings, primarily used to support smart urban management; for instance, in low-altitude economies, it facilitates airspace planning, route design, three-dimensional navigation, and monitoring and scheduling. Component-level 3D Real Scene targets fine application scenarios, providing detailed "3D archives" for historical buildings and cultural relics; for example, the phenomenal game "Black Myth: Wukong" utilizes component-level 3D Real Scene to deliver an immersive experience to players.

This ReS3D solution is the result of collaboration between the Chinese Academy of Surveying and Mapping, the University of Melbourne, and the Qingdao Survey and Mapping Institute. Focusing on the global application of 3D Real Scene technology, it aims to construct a complete process for building realistic 3D models through various data sources such as remote sensing satellites, drones, and ground scanning. By integrating advanced technologies like cloud computing, big data, and artificial intelligence, this solution covers multiple aspects including drone aerial photography, satellite imagery, LiDAR SLAM (Simultaneous Localization and Mapping) data acquisition, control measurement, aerial triangulation encryption, 3D reconstruction, model refinement, and entity creation. From the release of temporal-spatial information platforms to integrated application services, it forms a comprehensive solution that is quick, efficient, and stable in its application. This China-Australia solution provides end-to-end, customized services for global users in 3D geographic information collection, processing, reconstruction, and platform integration. It offers more scientific and precise government decision-making, more efficient and intelligent enterprise operations, and more convenient and intuitive public participation.

In the context of global climate change, accelerated urbanization, and increasing pressure on resources and the environment, the global application of 3D Real Scene technology has become particularly important. It not only helps us better understand and protect our planet but also promotes sustainable economic development globally and enhances the overall well-being of human society. The ReS3D solution is founded on this vision, dedicated to advancing the global popularization and deepened application of 3D Real Scene technology. By collaborating with global partners, we aim to create vivid, accurate, and dynamic depictions of the Earth, contributing technological strength to foster a global community of shared future.

Let’s move forward together, guided by 3D Real Scene technology to explore the infinite possibilities of our planet, using "geospatial intelligence for a better world" and create a new chapter in global development that is smarter, greener, and more harmonious.

1. Technical Process Overview

The ReS3D solution primarily encompasses four key stages: data acquisition, data processing, platform construction, and application and services. The overview of ReS3D technical process is illustrated in Figure 1.

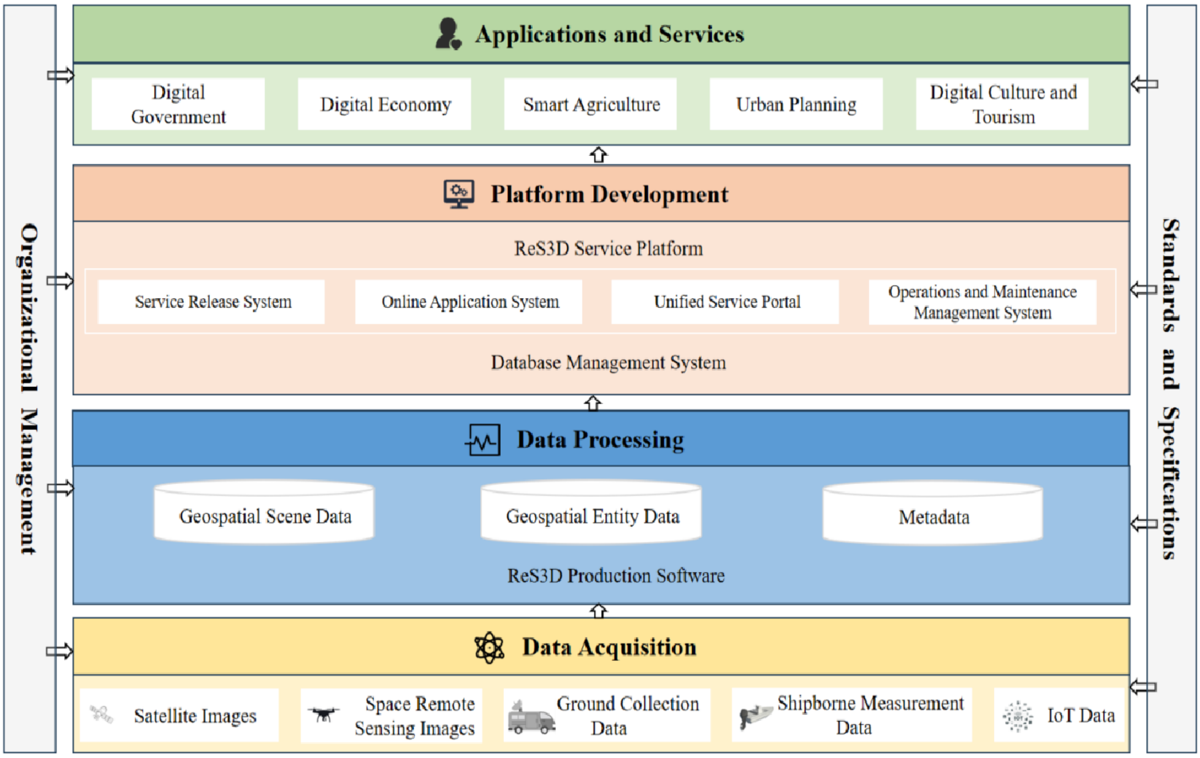

Figure 1: ReS3D technical process overview

(1) Data Acquisition

Data acquisition is conducted through satellite imagery, aerial remote sensing imagery, and ground surveys, demonstrating capabilities for multi-source and multi-precision data acquisition.

(2) Data Processing

The ReS3D solution provides comprehensive tools for 3D Real Scene modelling, refinement, and materialization, achieving high precision, high efficiency, and high-quality reconstruction of 3D Real Scene.

(3) Platform Development

The ReS3D solution offers a 3D Real Scene database management system and a 3D Real Scene service platform, facilitating the massive storage, distribution, and application of 3D Real Scene data, while providing thematic services, data services and analytics services.

(4) Applications and Services

Focusing on the needs of digital government and digital economy, the ReS3D solution addresses government decision-making, production scheduling, and lifestyle planning, providing a three-dimensional spatial positioning framework and analytical foundation. It promotes the application of 3D Real Scene across various industries, assisting in the realization of ubiquitous 3D Real Scene services.

2. High Precision and Speed Data Acquisition

Different cities acquire 3D Real Scene data based on their specific regional conditions, flight conditions, and application requirements. The main techniques used include satellite imagery, aerial oblique photography, and airborne laser scanning. These methods are often combined to form a comprehensive approach for data acquisition. Specifically, satellite imagery and aerial oblique photography primarily serve as the main data sources for terrain-level geographic scenes and basic geographic entity products. Aerial oblique photography, airborne laser measurements, ground images, or lidar data mainly serve as the primary data sources for city-scale geographic scenes and basic geographic entity products.

2.1 Satellite Data Acquisition

By using two or more satellites to capture images of the same region from different angles at the same time, or by capturing multiple images of the same area with the same satellite at different times or orbits, it is possible to form stereoscopic image pairs. These images provide different perspectives such as forward-looking, backward-looking, and vertical views. Through specific processing techniques, these stereoscopic images can be used to construct 3D images that contain depth information, thereby revealing the shape, colour, and texture of the terrain. The key to rapidly creating high-resolution (typically sub-meter) stereo satellite imagery for terrain-level 3D Real Scene models is to obtain multi-angle images with high resolution. This can usually be achieved by purchasing existing satellite images from commercial channels during a specific period or by custom-ordering images for a particular time frame in the future.

Currently, the main satellites providing stereo imagery include the WorldView series (WorldView-1, WorldView-2, WorldView-3, and WorldView-4) from DigitalGlobe, Japan's ALOS satellite, France's Pleiades satellite, and China's Resource Satellite 3. These satellites can provide high-quality stereo image data. Notably, the Gaofen-7 satellite, part of China's high-resolution Earth observation satellite network, was launched in 2019. This satellite is at the forefront of global remote sensing in terms of its stereoscopic mapping capabilities and is equipped with a laser altimeter to obtain three-dimensional information about terrain. It is particularly suitable for precise mapping, urban planning, traffic network design, and environmental protection applications. Its high-precision topographic data provide strong support for infrastructure development and geographic information systems in the country.

2.2 Aerial Data Acquisition

Aerial data such as oblique imagery and airborne point clouds are the primary sources for 3D Real Scene modelling. Depending on the required resolution and level of detail, appropriate acquisition equipment is selected, and a targeted aerial flight plan is developed. The main technical workflow is shown in the following diagram.

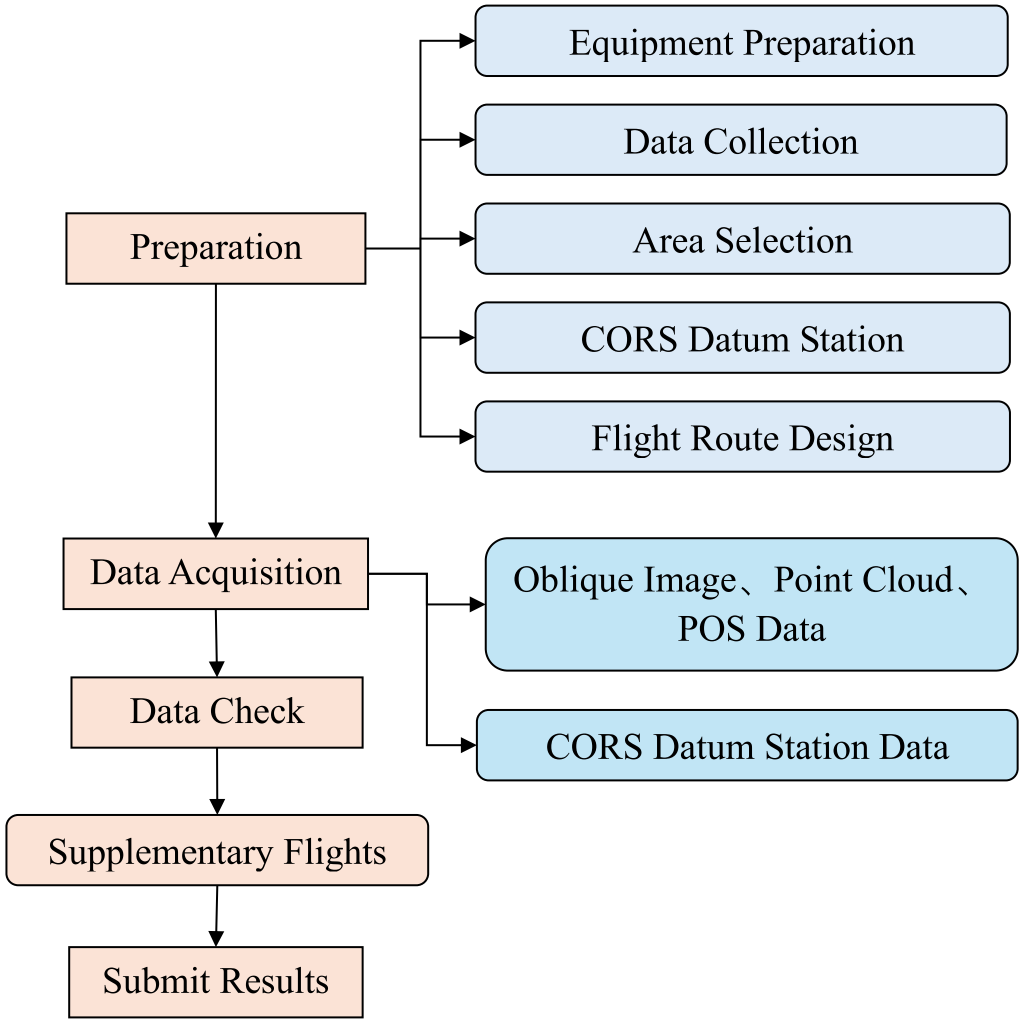

Figure 2: Aerial data acquisition process

2.2.1 Oblique Imagery Acquisition

The construction of 3D Real Scene models using oblique imagery is the primary technical method employed in this solution. It offers high operational efficiency, extensive coverage, and broad adaptability. For different scales and precision levels of 3D Real Scene modelling tasks, this solution supports various types of oblique imagery data acquisition methods:

(1) For large areas requiring medium to high-resolution oblique imagery (10-30 cm ground resolution), a fixed-wing manned aircraft combined with an oblique aerial camera can be used.

(2) For large areas requiring high-resolution oblique imagery (3-10 cm ground resolution), a helicopter combined with an oblique aerial camera, such as the AMC5150, AMC5100, or PAN-U5 large oblique digital aerial systems, can be employed. These systems utilize an IMU/GNSS-based positioning system to assist digital aerial photography in acquiring oblique imagery, providing data for producing oblique 3D models.

(3) For small areas requiring high-resolution oblique imagery (1-5 cm ground resolution), a drone equipped with an oblique camera, such as the CW-15 hybrid-wing drone, Feima D200 rotary drone, or DJI M300 drone, can be utilized to obtain oblique imagery.

2.2.2 Laser Point Cloud Acquisition

Airborne LiDAR (Laser Radar) is an efficient and high-precision three-dimensional terrain measurement technology. By combining data collected with LiDAR equipment and high-resolution cameras, point cloud data can be directly used for 3D Real Scene Mesh modelling or fused with oblique imagery for modelling. It can also be used for individual building processing at different levels of accuracy.

(1) For large areas requiring low-density point cloud acquisition (e.g., below 25 points/m^2), a fixed-wing manned aircraft combined with a large laser scanner can be used, such as the combination of a KODIAK 100 fixed-wing aircraft and the ALTM Galaxy T1000 laser scanner.

(2) For large areas requiring medium to high-density point cloud acquisition (e.g., 25-200 points/m^2), a helicopter combined with a large laser scanner can be utilized.

(3) For small areas requiring high-density point cloud acquisition (over 200 points/m^2), a drone combined with a medium or small laser scanner can be employed.

2.3 Ground Data Acquisition

In the ReS3D solution, ground data acquisition is a crucial step. This phase primarily involves the use of various technical means to collect high-precision ground point cloud data, supplementary photographs, and mobile street view imagery. This data serves as multi-source input for creating detailed terrain and building 3D models, enhancing detail information, and increasing the model's realism. Additionally, panoramic imagery of streets can be collected using mobile street view vehicles or backpack-mounted mobile mapping systems, providing rich visual information for subsequent data processing and 3D modelling.

3. Efficient and Convenient Data Processing

3.1 3D Real Scene Production Software

The ReS3D solution offers a comprehensive set of professional, fully self-developed software tools for multi-source remote sensing imagery. It includes automatic relative orientation and bundle adjustment, terrain extraction, orthophoto production, and automated 3D modelling based on multiple views. The software also features post-model interactive editing capabilities. It integrates the latest research findings in photogrammetry, computer vision, and other fields, allowing the generation of high-precision true 3D grid models from oblique photos. The core algorithms are implemented using C++/CUDA programming, enabling efficient CPU/GPU parallel computing. This solution meets the demands for high-accuracy and high-efficiency production of large-scale image mapping products without limitations on the number of images. It can be deployed in a distributed manner to handle extensive data processing efficiently.

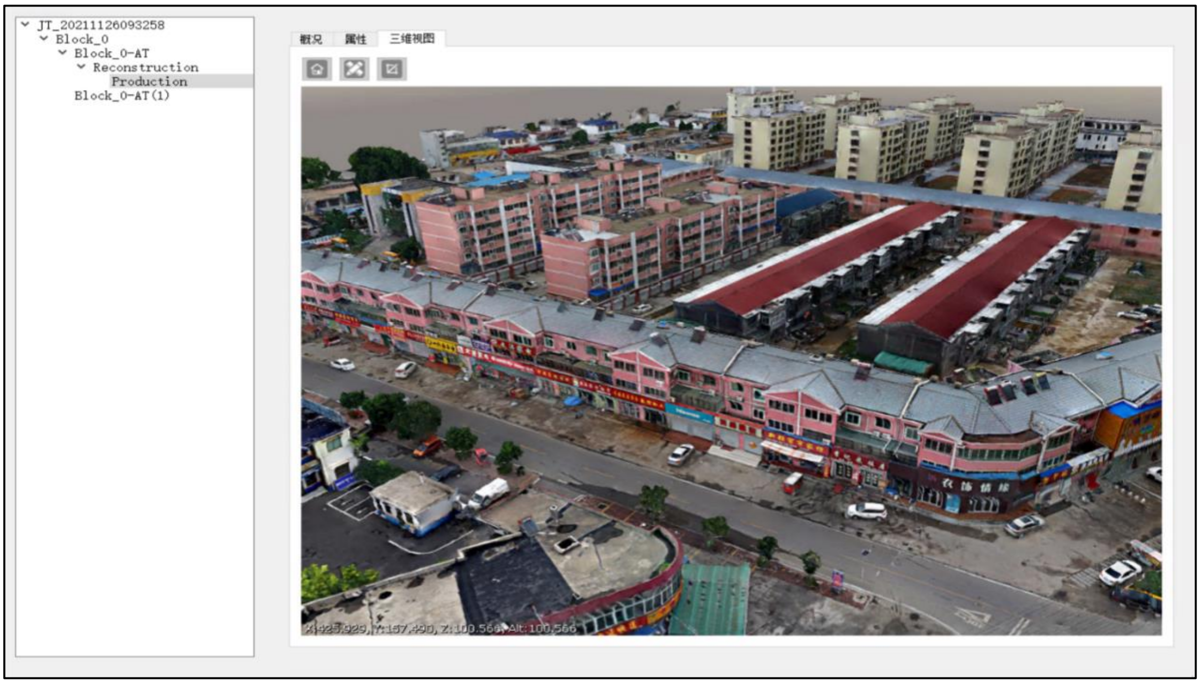

Figure 3: ReS3D production interface (Software: EntityMVE)

Key Functions and Technical Advantages:

A Robust and Stable Aerial Triangulation System: Supports one-click, cluster-based parallel processing of a massive number of unordered images (including satellite imagery, oblique aerial photography from manned/unmanned aircraft, and ground cameras). It fully automates the extraction of control points and connection points and performs regional network adjustment. Additionally, it offers high-precision adjustment with GNSS-assisted beam method, ensuring both efficiency and accuracy when processing large volumes of data.

Integrated Modelling Updates**:** Supports full automation and seamless merging of 3D mesh models across multiple temporal, multiple precision, or spatially adjacent regions within the same area.

Detailed Editing of 3D Mesh Models: The Mesh editing module allows for interactive model editing of 3D Real Scene, enabling functions such as flattening of features, hole repair, batch deletion of floating objects, detailed editing of models and textures, planning design, and data quality checking.

Creation of DSM/DEM/DOM Products: Automatic DSM filtering, high-precision DEM creation, efficient linkage processing, and intelligent mosaic line extraction.

3.2 3D Real Scene Reconstruction

The ReS3D solution primarily utilizes flying platforms such as helicopters and drones equipped with professional oblique photography systems to acquire detailed urban textures and construct high-precision urban 3D base maps. The specific technical process is illustrated in the following figure:

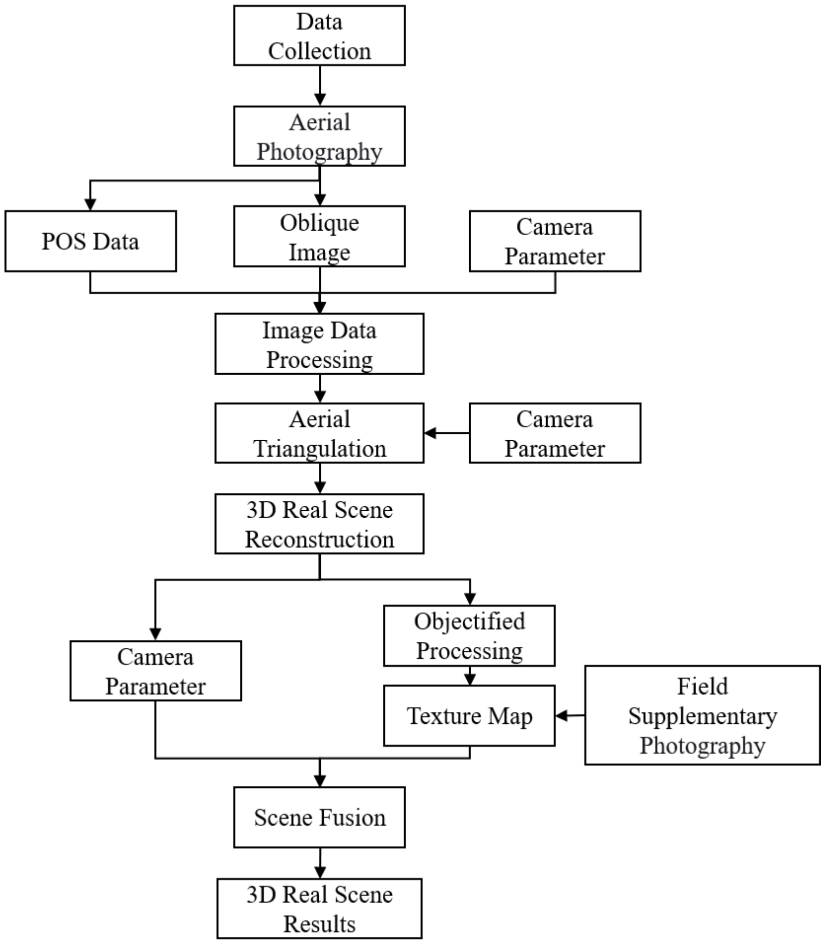

Figure 4: 3D Real Scene technical process

Based on aerial triangulation, block-based 3D Real Scene models are created. For computational efficiency, the second type of block partitioning—regular planar grid slicing—is generally adopted. To ensure data consistency, suitable block sizes (100x100, 500x500) and a unified coordinate origin are used during the modelling process.

Automatically, based on the stereo model and corresponding aerial triangulation data, the clearest images from each perspective are retrieved for the initial texture mapping of each model face. During flight, the oblique images taken from different perspectives can have colour imbalance due to varying light conditions. After the initial texturing, a colour balancing algorithm is applied to the textured tiles that have already been processed.

All texturized tiles are included in the calculation to determine an overall balance value. This value will be used in subsequent production steps. The colour-balancing process resets the texture of the reference 3D model, and any changes to the texture will be applied to all new production outputs.

Figure 5: Results of 3D Real Scene reconstruction

3.3 Model Entity Realization and Scene Refinement

For specific urban refined management demands, it is necessary to realize the entity of 3D Real Scene in key areas and refine the scene. This is achieved through the reconstruction of building models and texture mapping to create a separation effect based on the original scene. The mesh of 3D models other than those entity realized ones will be repaired, levelled or deleted.

Building Entity Realization: The accuracy indicators for building entity realization are as follows:

Table 1: Accuracy requirements of building entity realization modelling

Content	Key Buildings	Other Buildings
Main structure, including parapet, skylight, dormant window, open balcony, pillar, pier, etc.）	Structures larger than 0.2 meters in model representation	Structures larger than 0.5 meters in model representation
Carved Decorations	Texture representation	
Façade protrusions or decorations	Larger than 0.5 meters for main body modelling	
Large steps	Model representation	
Porticus	Structures larger than 0.5 meters in model representation	
Eave corridor	Structures larger than 0.5 meters in model representation	
Hanging corridor	Structures larger than 0.5 meters in model representation	
Understructure	Structures larger than 0.5 meters in model representation	
Elevator machine room	Model representation	
Chimney	Chimneys above 0.5 meters	Chimneys above 2 meters
Ventilation shaft	Ventilation shaft above 0.5 meters	Texture representation
Stairs	Main structure representation	
Air conditioning outdoor unit	Main structure representation	
Decorative structure	Main structure representation	
Pipeline	Large cylinder pipeline (diameter >= 1 meter): Main structure representation Small cylinder pipeline (diameter < 1 meter): Texture representation	

After the white (non-textured) model is constructed, it needs to be textured. This process utilizes a cluster-based intelligent texturing technology. The technique involves selecting the optimal texture for each triangular face in the original model based on the best perspective. This helps minimize issues with texture occlusion due to foreground objects blocking background objects during capture. Additionally, the textures are processed to achieve uniform lighting and colour balance within the model's scene. This ensures both the efficiency and quality of the texture mapping. For areas where the texture from oblique photography cannot be utilized due to limited perspectives, supplementary texture can be added through field photography.

(a) (b) (c)

Figure 6: Texture mapping effect comparison (a: original scene; b: single machine texture mapping; c: cluster version texture mapping)

Component Entity Realization: For commonly used urban management components (such as streetlights, traffic signals, trash cans, surveillance cameras, bus stop shelters, traffic signs, and road signs), detailed entity models are created and stored in a component entity library. All urban components on key city roads taller than 0.4 meters are fully realized. The 3D Real Scene results after component realization can satisfy the high-precision urban management needs for tasks such as fire safety and police deployments. The results of the formed component entity library are illustrated in figure 7.

Scene Refinement: Damaged features in the model base map are repaired, and the buildings and component elements in the mesh scene are levelled and deleted as needed.

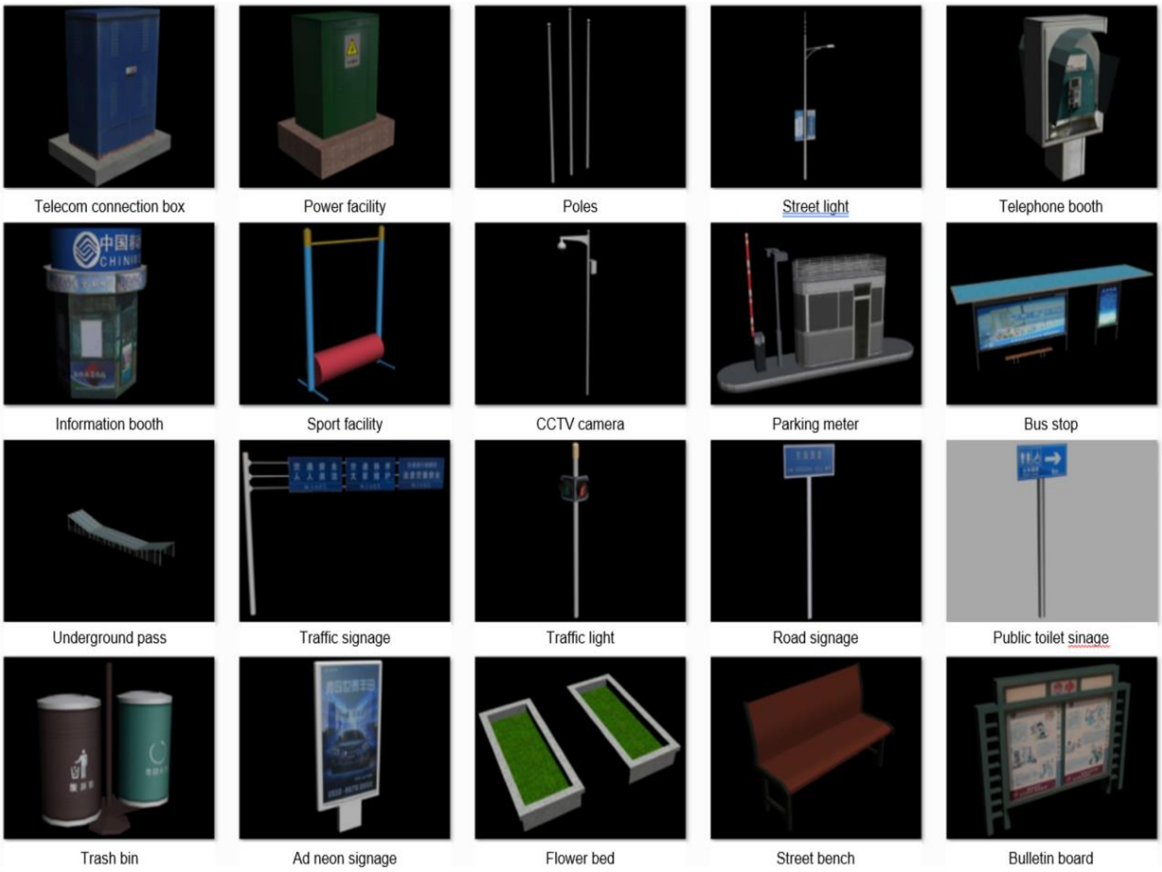

Figure 7: Results of component entity library

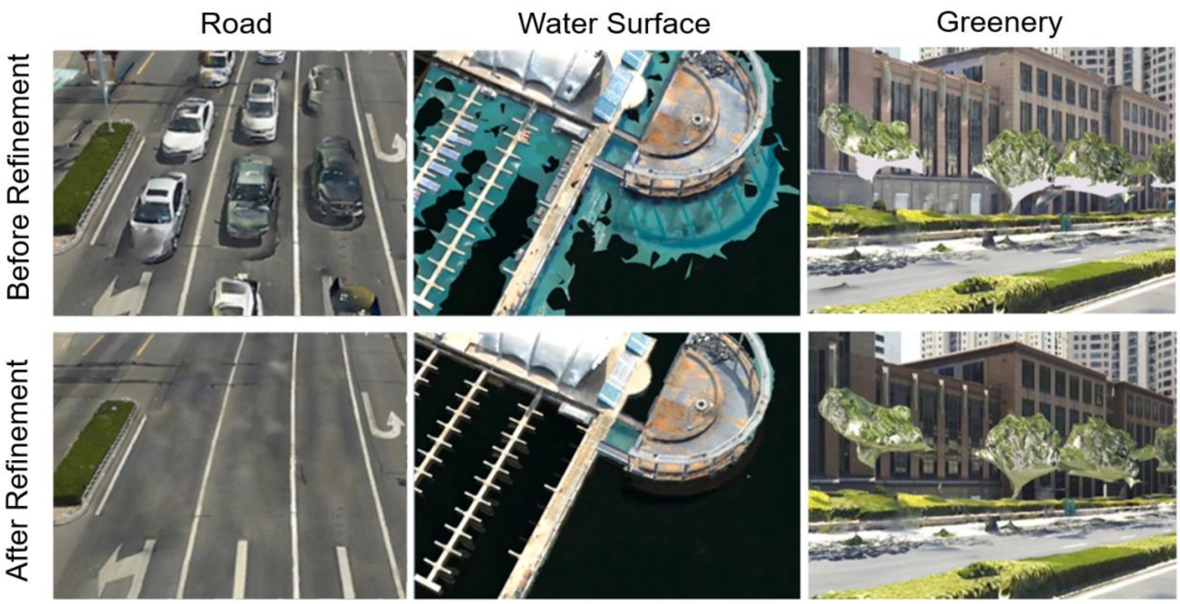

Figure 8: Scene refinement contents

4. Platform Development and Shared Services

To achieve online services for large-scale, high-precision real-world 3D mapping, the 3D Real Scene Platform is being developed upon ReS3D solution. This platform focuses on data fusion, platform integration, and application integration to create a smart city spatial digital foundation. It supports the application of basic spatial elements and business information on a spatial base layer, serving as an application service for the results of 3DRS development.

The platform provides visualization, analysis, sharing, and distribution services across different platforms and terminals. It forms a unified platform that integrates 2D and 3D data, combines surface and underground environments, and unifies indoor and outdoor spaces, creating a comprehensive digital twin platform.

4.1 Technical Architecture

The platform is designed according to the principles of "unified framework, distributed microservices combinability, high availability, and scalability." This involves developing system development standards and integration guidelines to establish unified interface interaction rules. The overall architecture consists of a standard specification system, as well as an operation and maintenance and security assurance system, composed of the infrastructure layer, data layer, service layer, and application layer.

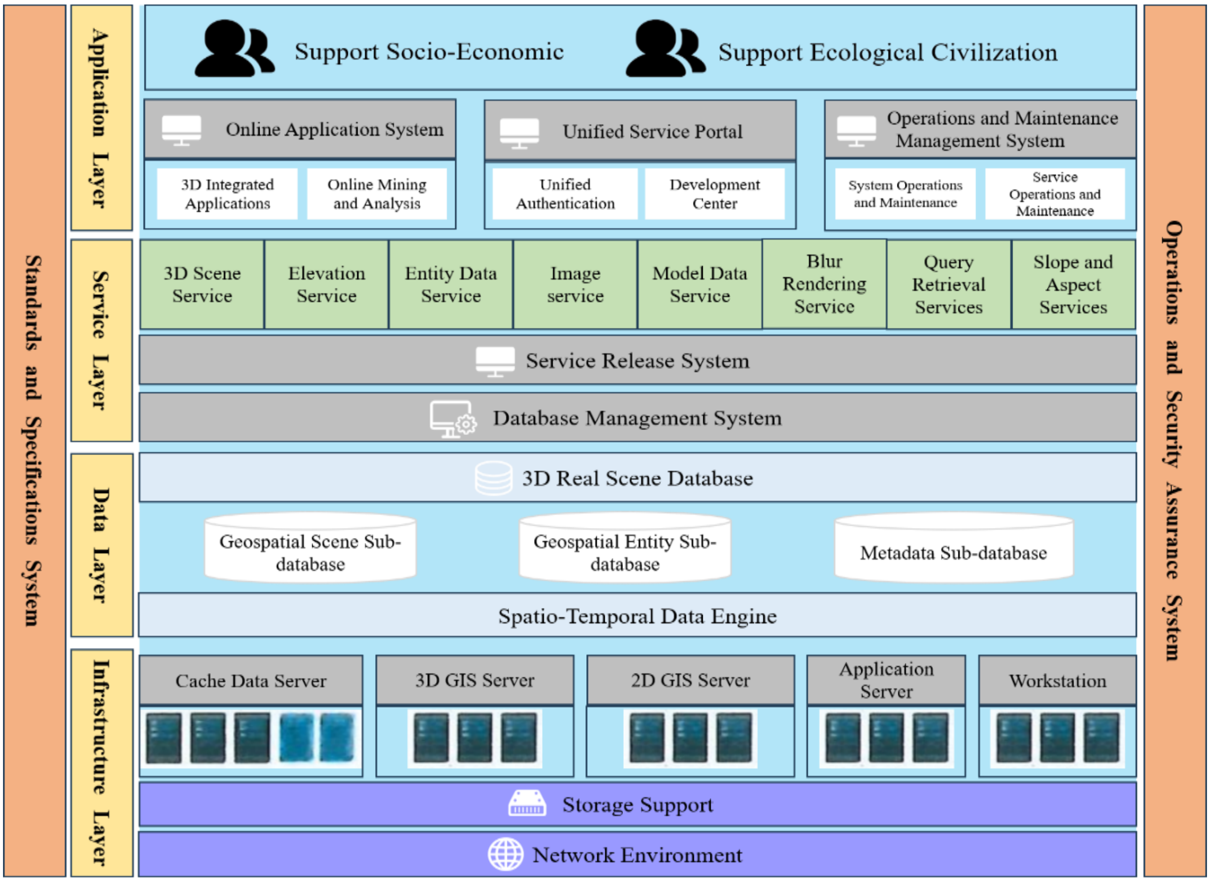

Figure 9: Platform architecture diagram

Infrastructure Layer: Utilizes storage and service resources provided by cloud resources and existing hardware and software facilities upgrades to realize capabilities such as data storage, transmission, and computation.

Data Layer: Aggregates DEM, DOM and Mesh models, etc., to form a geographical scene sub-database; combines data on mountains, water systems, courtyards, buildings, etc., to create a basic geographical entity sub-database in conjunction with a metadata sub-database, constituting the real-world 3D database.

Service Layer: Encapsulates common business logic into standardized service APIs or generalized tools. This will provide users with basic services such as 3D scene services and entity data services, as well as customized services to meet diverse business requirements.

Application Layer: Providing online application services to natural resources authorities, government agencies, enterprises, institutions, and the general public.

4.2 Database Management System

The ReS3D database management system consists of modules such as database construction, data management, spatial application, and on-demand assembly. It is designed to integrate, store, manage, analyze, and produce products from 3D Real Scene data.

Database Construction Module: This module uses an open and customizable system framework to build data quality inspection, pre-processing, and data import functions. It provides full lifecycle management capabilities for geographic entity and scene data modelling, storage planning, pre-processing, quality inspection, and data entry.

Data Management Module: This module achieves integrated spatiotemporal management of geographic entity data, geographic scene data, and other relevant data. It offers functionalities such as metadata catalogue, query display, statistical analysis, semantic management, data extraction, and data update.

Spatial Application Module: Leveraging key technologies such as comparative analysis, spatiotemporal modelling, and knowledge reasoning, this module conducts 2D/3D spatial analysis, change detection analysis, spatiotemporal evolution analysis, and graph association analysis. It deeply explores patterns and insights hidden in geographic entity data to support data-driven business decisions.

On-Demand Assembly Module: This module assembles relevant geographic entities and their scene data from the basic geographic entity database based on spatial ranges or categories, granularity, modes, and attribute structures. It forms 4E (Entity for combined and aggregated class, Entity for non-scale map representation, Entity for terrain-level 3DRS, Entity for city-level 3DRS) standardized products. It supports deriving 4D products through adaptive assembly of geographic entities and scenes.

4.3 ReS3D Service Platform

The platform enables massive 3D data management, 3D scene browsing, comprehensive spatial overlay, online statistical analysis functions, and supports real-time access, invocation, and 3D visualisation of multi-source IoT sensing data. It provides a real-time and realistic presentation of natural resource conditions and natural geographical patterns, offering a unified digital spatial base for smart city development. The main components include service publishing, service portals, online applications, and operation management, realizing online service applications for 3D Real Scene data.

4.4 IoT Sensing Data Access and Integration

The platform possesses the capability to integrate and fuse IoT sensing data, primarily through IoT data acquisition and connection, establishing spatiotemporal and semantic associations between IoT data and basic geographic entity data, and multi-level fusion of IoT data with 3D Real Scene data. The platform provides an IoT middleware that supports the access of diverse IoT data, including changes in location, attribute changes, or both, such as video surveillance, meteorological data, and vessel information.

Through a combination of static and dynamic data, it enhances the ubiquitous services of 3D Real Scene.

4.5 Platform Usage

The platform is presented as a portal website, providing services for 3D map applications and re-development. These include various interfaces for 2D/3D base map data services, thematic data services, place name and address services, and spatial analysis services (including buffer analysis and overlay analysis).

The map application focuses on comprehensive usage at the client end, meeting the basic viewing and querying needs of general users. The backend resource portal includes data management, service management, and operations and maintenance management. These functions are primarily responsible for storing, managing, and sharing 2D/3D data and services.

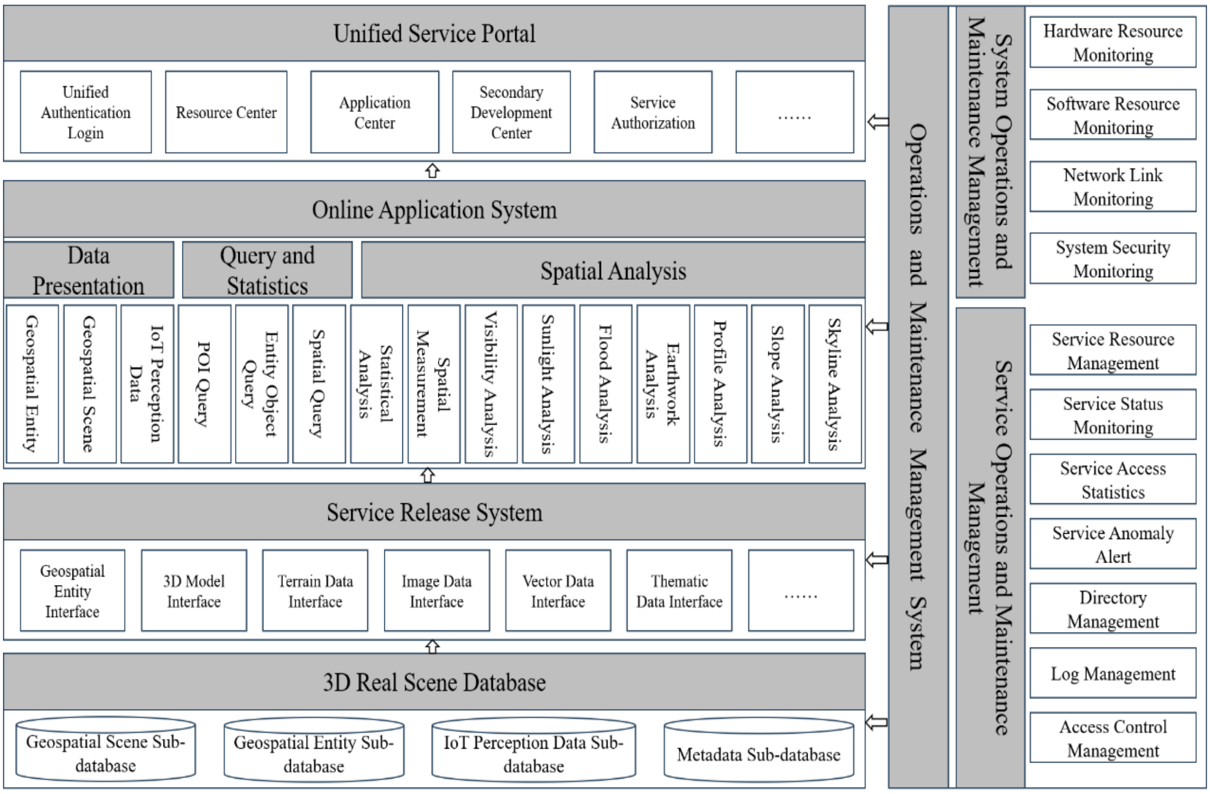

Figure 10: ReS3D service platform functions

5. Application Support and Innovation Leadership

The ReS3D solution, with its unique twin capabilities and high-precision characteristics, has demonstrated extensive application potential and significant value in numerous scenarios. From urban planning to environmental monitoring, from disaster response to cultural tourism, 3D Real Scene not only provides us with a comprehensive and intuitive viewpoint to understand the world but also plays indispensable roles in decision support, resource management, and public services.

With continuous technological advancements and ongoing expansion of application areas, 3D Real Scene will undoubtedly shine in more fields, contributing to the coordinated development of global economic, social, and environmental sectors, promoting the extensive and deep application of geospatial information and knowledge innovation, and using geographic spatial intelligence to benefit the world.