Integrating Low-Altitude Takeoff and Landing Infrastructure into Smart City Systems

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ABSTRACT Low-altitude mobility is expanding from pilot services to urban-scale deployment, but its physical infrastructure is still planned outside many city data and operations systems. This paper develops and tests an integrated method for embedding takeoff and landing infrastructure into smart city infrastructure. The method combines dynamic UAV acquisition, BIM-based semantic modelling, hierarchical facility coding, a unified BIM/CIM data foundation and multi-agent simulation. It classifies takeoff and landing infrastructure into four functional levels and eight facility types, and maps facility codes to GB/T 51269-2017 and IFC entities to support cross-system data exchange. The method was evaluated in Hefei Luogang Urban Park and Wuhu Wanzhi Low-Altitude Economy Industrial Park, covering 16 takeoff and landing facilities and 64 related urban elements. In the integrated scheme, the mean transfer distance between landing facilities and transport hubs decreased by about 35%, cross-department work-order processing time decreased by 60.7%, and the Comprehensive Synergy Index increased from 0.78 to 0.85. These results indicate that BIM/CIM-centred integration can improve spatial coordination, data sharing and operational management for low-altitude urban infrastructure. Further validation is still needed under real wind conditions and in larger metropolitan settings.

INDEX TERMS low-altitude economy; takeoff and landing infrastructure; BIM; CIM; smart city; UAV acquisition; multi-agent simulation

I. INTRODUCTION

THE low-altitude economy links airspace resources, unmanned aircraft, electric vertical takeoff and landing aircraft (eVTOL) and urban services into a new infrastructure-intensive sector. Research on flying cars and advanced air mobility shows that sustainability benefits depend on coordinated vehicles, energy systems, infrastructure and operating conditions [1]. Reviews of urban air mobility further show that market introduction depends on coordinated aircraft, infrastructure, regulation and service ecosystems [2]. The UAM ecosystem therefore faces technical, institutional and service-design challenges that cannot be solved by isolated landing-site provision [3]. Comparative research on UAM and autonomous ground transport also indicates that air and ground systems should be analysed as coupled urban mobility systems [4]. Scaling low-altitude services therefore requires more than additional landing sites. It requires those sites to be planned, modelled and operated as part of smart city infrastructure.

Planning practice remains fragmented. Takeoff and landing facilities are often selected and designed separately from existing buildings, transport hubs and urban operation platforms, despite systematic evidence that vertiport design and regulation directly affect safe UAM operation [5]. Vertiport design research further shows that pad layout and ground operation logic affect throughput and operational efficiency [6]. BIM for existing buildings supports reuse of existing assets [7]. Semantic construction digital twins support lifecycle information exchange [8]. Digital-twin studies in engineering systems also show that sensing, modelling and simulation need to be connected through a continuous data pipeline [9]. These findings indicate that low-altitude takeoff and landing infrastructure should be embedded into the modelling, data and operation systems of smart cities.

II. RESEARCH STATUS

A. PLANNING AND CONSTRUCTION OF LOW-ALTITUDE TAKEOFF AND LANDING INFRASTRUCTURE

The construction of low-altitude takeoff and landing infrastructure is accelerating nationwide. Hefei Luogang Urban Park has built and put into operation an urban air-traffic hub port. Wuhu Wanzhi has gathered a cluster of aviation enterprises and is developing low-altitude economy scenarios.

B. PROGRESS IN BIM/CIM TECHNOLOGIES

BIM can integrate multi-disciplinary models for existing buildings, but modelling effort, level of detail and data quality strongly affect reuse and analysis. CityGML provides a semantic basis for interoperable three-dimensional city modelling [10]. Level of detail also affects modelling effort and downstream analysis reliability [11]. BIM-GIS integration provides a methodological basis for linking building-scale models with urban-scale spatial data [12]. Bibliometric evidence also shows that BIM, GIS and web-environment integration has become a distinct research stream for urban-scale digital collaboration [13]. Refined rooftop BIM checking is therefore critical for implementing column-coupled facility insertion.

C. PROGRESS IN UAV-BIM INTEGRATION

Automated acquisition and reconstruction have become important approaches for existing-building BIM and infrastructure modelling [14]. Point-cloud semantic segmentation can improve the extraction of structural elements from dense three-dimensional data [15]. Multi-agent UAM operation research provides a basis for autonomous on-demand flight coordination [16], while UAV path-planning studies provide algorithmic support for safe flight in obstacle-rich environments [17].

D. LIMITATIONS OF EXISTING RESEARCH AND CONTRIBUTIONS OF THIS STUDY

Existing studies provide limited BIM modelling specifications and parametric family libraries for takeoff and landing facilities. They also make limited use of CIM platforms as unified data foundations for cross-department integration, and give insufficient attention to spatial coupling with existing roofs and transport hubs. This gap matters because semantic construction digital twins require consistent data semantics across lifecycle systems. Interoperable semantic 3D city models also show that cross-scale urban modelling depends on shared semantic schemas .

III. CONNOTATION AND CLASSIFICATION OF LOW-ALTITUDE TAKEOFF AND LANDING INFRASTRUCTURE

A. CONCEPTUAL CONNOTATION AND CORE FEATURES

Low-altitude takeoff and landing infrastructure is defined here as the physical spatial facilities and ancillary assets that support safe takeoff, landing, parking and ground handling for low-altitude aircraft, including UAVs and eVTOL aircraft. Six features are central to this definition. First, deployment must shift from large centralised airports to distributed small-scale sites. Second, facilities are embedded across urban space, where rooftop landing points and conventional buildings form column-coupled configurations. Third, high-density operation requires each rooftop landing point to define three-dimensional clear-zone protection surfaces and electromagnetic protection zones in BIM. Fourth, the system depends on real-time links with flight service stations and CIM platforms, with communication latency below 10 ms. Fifth, cross-domain coordination is needed because about 71% of takeoff and landing facilities are within 500 m of urban transport hubs. These facilities are therefore aerial access nodes in three-dimensional urban transport networks. Sixth, standardisation and modularisation are key routes for reducing cost and accelerating deployment.

B. CLASSIFICATION SYSTEM

Focusing on low-altitude takeoff and landing infrastructure, this study develops a classification system based on functional level and spatial form (Table 1). The system draws on the classification logic used in Chinese BIM classification and coding standards [18] and provides a standardised basis for subsequent BIM parametric modelling and information coding.

This classification system covers four functional levels and eight facility types, ranging from hub ports to terminal UAV nests. In BIM software, each facility type is managed as a parametric family. Component instances are associated with facility codes, operation and maintenance records, and topological relationships with surrounding elements.

C. SPATIAL DISTRIBUTION CHARACTERISTICS

Low-altitude takeoff and landing infrastructure shows a spatial radiation structure characterised by high density in core areas, point-axis extension in near-suburban areas and backbone nodes in outer-suburban areas. Planning should not rely on independent site selection. Instead, facilities should be actively embedded into the existing functional spatial system of cities.

IV. INTEGRATION DEMAND ANALYSIS AND IDENTIFICATION OF COORDINATION BARRIERS

A. SPATIAL INTEGRATION DIMENSION

Spatial integration includes vertical stratification, horizontal coupling and node sharing. In vertical stratification, rooftop landing sites form column-coupled relationships with existing buildings and require structural review based on existing building BIM. The dynamic amplification factor should not be less than 1.5. Horizontal coupling includes co-located coupling, where the landing platform and roof are integrated; adjacent coupling, where a vertiport is within 200 m of a rail-transit station; corridor coupling, where routes are combined with urban linear space; and node coupling, where a general aviation airport is co-located with an integrated transport hub.

B. DATA-STANDARD INTEGRATION DIMENSION

Data-standard integration faces three major barriers. The first is heterogeneous data formats. BIM models of takeoff and landing facilities in IFC format, UAV telemetry data in JSON streams, monitoring video and airspace-management data lack a unified semantic transformation model. The second is dynamic-static spatio-temporal mismatch. Takeoff

TABLE 1. Classification System for Low-Altitude Takeoff and Landing Infrastructure

Level	Type	Typical Facility Elements	Service Capacity (Sorties per Day)	Required Modelling Detail
Hub Level	General Aviation Airport / Hub Takeoff and Landing Port	Runways, aprons, hangar groups, control towers and maintenance bases	$\geq$ 100	LOD300
Hub Level	eVTOL Hub Port	Composite-wing landing platforms, multi-stand waiting areas and fast-charging pile arrays	50–100	LOD350
Regional Level	Vertiport	Multi-stand landing pads, charging piles, simple waiting areas and weather stations	20–50	LOD350
Regional Level	Water Takeoff and Landing Platform	Pontoon landing platforms, mooring devices and waterproof charging piles	10–30	LOD350
Terminal Level	Rooftop Landing Point	Reinforced landing pads, elevators or ladders, charging piles and fire-protection facilities	5–20	LOD400
Terminal Level	Ground Landing Point	Hardened landing pads, fencing, charging piles and wind indicators	5–15	LOD350
Terminal Level	UAV Nest / Hangar	Automatic charging nests or depots, environmental control devices and communication relay modules	50–100 per nest	LOD400
Mobile / Temporary	Mobile Landing Platform	Vehicle-mounted landing platforms, temporary landing mats and portable charging equipment	On demand	LOD300

and landing slot allocation is a second-level dynamic process, whereas BIM is often a monthly snapshot, requiring real-time data access and incremental model updating. The third is the lack of a semantic mapping framework between low-altitude standards and BIM/CIM standards issued by the Ministry of Housing and Urban-Rural Development, which can easily create data silos.

C. CONSTRUCTION SEQUENCE AND OPERATION-MANAGEMENT INTEGRATION

The dynamic evolution of takeoff and landing facilities, which are built, operated and iterated simultaneously, conflicts with the long-cycle planning mode of traditional infrastructure. Operation and maintenance responsibilities are also dispersed, and data-sharing protocols and standardised coordination processes remain insufficient.

D. PROGRESSIVE HIERARCHY OF COORDINATION BARRIERS

This study constructs a four-layer progressive model of coordination barriers: L1 physical space, L2 data and information, L3 management mechanisms and L4 standards and specifications. Integrated construction must provide corresponding solutions at each layer.

V. INTEGRATED CONSTRUCTION METHOD

A. OVERALL IDEA AND TECHNICAL ROUTE

The integrated method uses UAVs for front-end acquisition, BIM for semantic modelling, classification coding for semantic alignment, CIM as the unified data foundation and multi-agent simulation for optimisation. It links low-altitude takeoff and landing infrastructure with smart city infrastructure across physical and digital space, static models and dynamic management, and independent and coordinated operation. The technical route in Fig. 1 combines four stages, acquisition, coding, data foundation and simulation, with five layers, standards, data, model, platform and application.

orm and application.

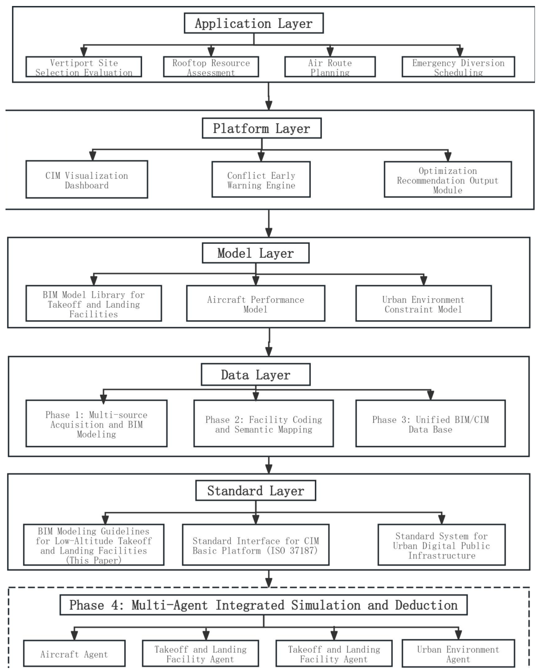

FIGURE 1. Overall technical route of the integrated construction method

Note: Data flow runs from bottom to top. The four stages and five layers intersect at the data and model layers and form a closed loop.

B. STAGE 1: MULTI-SOURCE UAV ACQUISITION AND BIM MODELLING OF TAKEOFF AND LANDING FACILITIES

Different sensor combinations and flight parameters are selected according to the functional level of the takeoff and landing facility. Surrounding urban infrastructure elements are collected synchronously. Parameter settings are designed to support automated acquisition and reconstruction of existing built assets and draw on low-altitude digital aerial photography specifications [19]. They are summarised in Table 2.

In addition to conventional geometric and attribute information, the BIM model must embed specialised takeoff and landing semantics, including clear-zone protection surface parameters, takeoff and landing paths, structural bearing-capacity annotations and charging-pile information. Revit and Dynamo parametric scripts are used to establish standardised family libraries for frequently repeated terminal-level facilities, such as rooftop landing points and UAV nests, enabling efficient batch modelling. Component instances are associated with facility codes and topological relationships with surrounding elements.

C. STAGE 2: FACILITY-ELEMENT CLASSIFICATION CODING AND SEMANTIC MAPPING

A 12-digit hierarchical code is adopted: functional level (1 digit), type (2 digits), administrative division code (4 digits) and instance serial number (5 digits). For example, 302340100001 denotes terminal level (3), rooftop landing point (02), Hefei (3401) and instance 00001.

A bidirectional semantic mapping is established between takeoff and landing facility codes, the national standard GB/T 51269-2017 Standard for Classification and Coding of Building Information Modelling , and IFC entities (Table 3).

D. STAGE 3: CONSTRUCTION OF A UNIFIED BIM/CIM DATA FOUNDATION

The unified data foundation has four layers: data source, data integration, core data and service interface. These layers support spatio-temporal registration and standardisation of multi-source data. Three integration technologies are used.

Semantic integration uses the Web Ontology Language (OWL) to define spatial relationships between takeoff and landing facilities and urban infrastructure. These include located_on, where a landing platform is located on a building roof; adjacent_to, where a vertiport is within 200 m of a metro station; shared_node, where a flight service station and an urban operation-management centre are co-located; and served_by, where a facility cluster is served by a designated charging or battery-swapping node. Semantic construction digital twins provide the modelling logic for these relationships , and BIM-GIS schema mediation provides a technical basis for mapping between building and city models [20].

Spatio-temporal integration adopts a dual-timestamp mechanism. Static BIM data are marked with model-update timestamps, and real-time UAV data are marked with UTC timestamps. The Apache Kafka stream-processing engine writes takeoff and landing slot allocation, charging-pile occupancy status and meteorological data into a TimescaleDB time-series database in real time, supporting both historical tracing and real-time sensing. BIM geometry is stored by level of detail from LOD100 to LOD400. UAV point clouds are compressed using an adaptive octree algorithm, reducing storage volume by about 60% while maintaining modelling accuracy.

Multi-source registration uses the iterative closest point (ICP) algorithm to unify BIM engineering coordinates and UAV point-cloud urban coordinates into the CGCS2000 coordinate system. The overall registration error is less than or equal to 0.05 m, and the component-level error is less than or equal to 0.02 m.

E. STAGE 4: MULTI-AGENT INTEGRATED SIMULATION

To quantify the degree of integrated fusion, the system's comprehensive performance V(t) at time t is defined as the Comprehensive Synergy Index (CSI):

$$V(t) = W_1 \cdot E'_{\text{spatial}} + W_2 \cdot E'_{\text{data}} + W_3 \cdot E'_{\text{conflict}} + W_4 \cdot E'_{\text{dispatch}}$$

Here, E_{spatial} is spatial-use efficiency, measured as sorties per day per square kilometre. E_{data} is data-response efficiency, defined as the reciprocal of the squared response delay from sensor acquisition to CIM-platform queryability. $E_{\text{conflict}} = 1 - f_{\text{conflict}}$, where f_{conflict} is the probability of spatial conflict between takeoff and landing facilities and urban building height limits. E_{dispatch} is the takeoff and landing plan completion rate. Each indicator is first min-max normalised to the interval [0,1] to remove dimensional effects.

$$E'_i = \frac{E_i - E_{i,\min}}{E_{i,\max} - E_{i,\min}}$$

The weights are calibrated using the analytic hierarchy process (AHP). Five experts used the 1-9 scale method to construct a judgement matrix. The eigenvalue method produced the weight vector $W = [0.2000, 0.2000, 0.4000, 0.2000]^{\mathrm{T}}$, with a maximum eigenvalue $\lambda_{\max} = 4.0000$ and a consistency ratio $\mathrm{CR} = 0 < 0.1$. The result passes the consistency test and indicates strong agreement among experts for evaluating low-altitude takeoff and landing infrastructure integration.

The simulation environment includes four agent types. The aircraft agent uses an improved A* algorithm for three-dimensional path planning. Building outlines and clear-zone protection surfaces stored in BIM are converted into an occupancy grid map in real time, following the logic of obstacle-aware UAV path planning [17], and a dynamic cost function is introduced:

$$C(x) = C_{\text{dist}}(x) + \beta \cdot C_{\text{obstacle}}(x) + \gamma \cdot C_{\text{wind}}(x)$$

$C_{\text{obstacle}}(x)$ is calculated by weighting the distance gradient from obstacles, and $C_{\text{wind}}(x)$ adds the crosswind drift cost according to the local wind-field vector. This ensures that flight paths avoid high-rise buildings and densely populated areas. Based on scenario-specific parameter sensitivity tests and prior research on UAV path planning, beta and gamma are calibrated as 0.8 and 0.5, respectively.

The takeoff and landing facility agent uses an M/M/c queuing model to calculate dynamic takeoff and landing capacity. Vertiport operation studies emphasise that pad layout, ground operations and turnaround processes strongly

TABLE 2. Recommended UAV Acquisition Parameters for Different Infrastructure Levels

Facility Type	Recommended Sensor Combination	Flight Height (m)	Point-Cloud Density (points m^{-2})	Image Overlap	Modelling Detail
Hub-level general aviation airport / hub port	LiDAR, multispectral sensors and oblique camera	80–120	$\geq$ 200	80% forward / 65% side	LOD300
Regional-level vertiport	LiDAR and high-resolution visible-light camera	50–80	$\geq$ 500	80% forward / 70% side	LOD350
Terminal-level rooftop landing point	Five-lens oblique photogrammetry camera	30–50	$\geq$ 1000	85% forward / 75% side	LOD400
Terminal-level UAV nest	LiDAR and high-resolution visible-light camera	20–35	$\geq$ 800	80% forward / 70% side	LOD400
Mobile / temporary landing platform	LiDAR and visible-light camera	25–40	$\geq$ 400	75% forward / 60% side	LOD300

TABLE 3. Semantic Mapping between Low-Altitude Takeoff and Landing Infrastructure, GB/T 51269-2017 and IFC

Facility Type	GB/T 51269-2017 Mapped Table	Example Category Code	IFC Entity Mapping	Extended Property Set
Vertiport	Table 30, Building Products by Function	30-35.10.00 Transportation Facilities	IfcBuilding	PsetVertiport
Rooftop Landing Platform	Table 14, Classification by Element Form	14-20.10.00 Roof Element	IfcSlab	PsetRooftopLandingPad
UAV Nest / Hangar	Table 33, Facilities by Function	33-35.10.00 Transportation Facilities	IfcElementAssembly	PsetDroneNest
General Aviation Airport / Hub Port	Table 30, Building Products by Function	30-35.10.10 Air Transport Facilities	IfcBuilding	PsetLowAltitudeAirport
Charging and Battery-Swapping Facilities	Table 21, Classification by Building Product	21-40.00.00 Electrical Equipment	IfcFlowTerminal	PsetChargingStation

affect facility throughput Referring to these operational constraints and to domestic eVTOL operating manuals, each landing pad is allocated standard 15 s slots, with two emergency alternate slots reserved. Allocation is automatically suspended when wind speed exceeds 10 m s^{-1}.

The management-platform agent runs a distributed constraint optimisation problem (DCOP) algorithm. Urban airspace is divided into 1 km grids for parallel solving, and the model converges to a near-optimal solution within 100 ms.

The urban-environment agent provides maps of building height limits, population heat distribution and electromagnetic-field intensity, supplying dynamic environmental constraints for path planning and capacity assessment.

The simulation engine is built on Unity3D. Physical calculations call C# scripts and Python scientific computing libraries, including NumPy and SciPy, for numerical solving. The modelling workflow follows automated acquisition and reconstruction logic for existing built assets [14]. Simulation outputs include heat maps of spatial conflict frequency, time-series curves of scheduling completion rate and radar charts of CSI.

F. FIVE-LAYER INTEGRATED TECHNICAL FRAMEWORK

The five-layer integrated technical framework covers standards, data, models, platforms and applications from bottom to top. The standards layer prepares BIM modelling guidelines for takeoff and landing facilities and extends CityGML semantic expression. The data layer integrates BIM, GIS and real-time operation data through a hybrid data-lake and data-warehouse architecture under a unified spatio-temporal reference. The model layer aggregates BIM model libraries for takeoff and landing facilities, aircraft performance parameters, urban wind-field models and noise-propagation models, providing multi-scale resources for multi-agent simulation. The platform layer integrates BIM engines, GIS engines and Internet-of-Things middleware based on a CIM platform, providing visual dashboards, conflict warnings and optimisation-suggestion modules. The application layer supports typical scenarios, including site-selection evaluation, rooftop bearing-capacity screening, low-altitude logistics route planning and emergency alternate landing scheduling. It outputs tools for integrated planning decision support and coordinated operation and maintenance.

G. METHOD COMPARISON

Table 4 systematically compares the proposed integrated construction method with the conventional separated method across six dimensions, including data integration paradigm, spatial planning logic and dynamic response mechanism.

VI. EMPIRICAL STUDY: HEFEI AND WUHU, ANHUI PROVINCE

A. STUDY AREA

Anhui Province has formed a relatively complete low-altitude economy industrial chain led by the dual cores of Hefei and Wuhu. Hefei Luogang Park covers about 12.7 km^2 and has built and put into operation an urban air-traffic hub port. Wuhu Wanzhi Low-Altitude Economy Industrial Park has gathered more than 200 aviation enterprises, with an output value of 35 billion yuan in 2025. The Hefei CIM

TABLE 4. Comparison between the Proposed Integrated Method and the Conventional Separated Method

Dimension	Conventional Separated Method	Proposed Integrated Method
Data Integration Paradigm	Mainly one-way and manual, with limited data sources	Bidirectional, automated, semantically enhanced and multi-source real-time integration
Site-Selection Logic	Independent site selection without considering coupling with urban infrastructure	Collaborative site optimisation based on four coupling types
Dynamic Response Mechanism	Static BIM-dependent, long update cycles and limited real-time interaction	Millisecond-level real-time data access and second-level situation updates
Use of Rooftop Resources	Mainly manual site inspection and post-hoc verification, with limited efficiency and precision	High-precision UAV acquisition and automated load-bearing checks using existing building BIM
Simulation Capacity	Single facility and single static scenario	Multi-agent simulation with dynamic environmental constraints and quantitative comparison of alternatives
Standards Compatibility	Low-altitude and CIM standards remain relatively independent	Extends existing BIM/CIM standards and establishes bidirectional semantic mapping

foundation platform has connected multiple types of urban operation data, including transport data.

B. STUDY SCOPE AND DATA ACQUISITION

Luogang Park and Wanzhi Industrial Park were selected as study areas. From October 2025 to January 2026, UAV aerial surveys, BIM modelling of 80 core facilities, including 16 takeoff and landing facilities, and collection of spatial data and operation-log data for urban infrastructure were completed. The statistics of takeoff and landing facility elements are shown in Table 5.

C. BIM MODEL CONSTRUCTION AND UNIFIED DATA FOUNDATION

Models were built according to the accuracy levels in Table 2. The Luogang hub port was modelled at LOD350 using LiDAR and oblique photogrammetry. Eight typical rooftop landing points were modelled at LOD400, with embedded load checks and clear-zone parameters. The unified data foundation completed standardisation and refined registration, with an overall error less than or equal to 0.05 m. Dynamic data were connected to the CIM time-series database.

D. INTEGRATED SIMULATION AND SCHEME EVALUATION

A digital twin simulation environment was built based on the unified data foundation. Multi-scheme evaluations were conducted for three typical integration scenarios.

Scenario 1 concerned collaborative layout optimisation between takeoff and landing facilities and urban transport hubs. The current Luogang condition, S0, was used as the baseline. Three comparative schemes were generated: S1 used multi-agent optimisation with CSI maximisation as the objective; S2 minimised transfer distance while ignoring airspace conflicts; and S3 minimised spatial conflict probability while ignoring transfer distance. A baseline-day flight plan of 213 sorties was injected into the simulation. Results are shown in Table 6.

The simulation results show that S1 shortened transfer distance by about 35%, reduced spatial conflict probability by about 28%, increased CSI from 0.78 to 0.85, and achieved a 100% structural-check pass rate for rooftop landing points. It therefore achieved the best balance between transfer convenience and airspace safety.

Scenario 2 concerned the integration of a flight service station with the urban CIM operation-management centre. The core takeoff and landing scheduling module was integrated with the park CIM platform. During testing, 182 cross-system requests were recorded. As shown in Table 7, work-order processing time decreased by 60.7%, and information-exchange frequency increased by 43.8%.

Scenario 3 concerned coordination between low-altitude logistics routes and the urban terminal delivery network. Route optimisation was conducted in Luogang Park and adjacent communities, with a daily average of 223 orders. As shown in Table 8, delivery time per item decreased by 33.3%, route-conflict rescheduling events decreased by 75.0%, and integrated delivery cost decreased by 20.6%.

TABLE 5. Statistics for Takeoff and Landing Facility Elements in the Study Areas

Infrastructure Level	Luogang Park	Wuhu Industrial Park	Total
Hub Level	1	1	2
Regional Level	2	1	3
Terminal Level	6	4	10
Mobile / Temporary	0	1	1
Total	9	7	16

TABLE 6. Comparison of Takeoff and Landing Facility Layout Schemes

Indicator	S0 (Current)	S1 (Integrated)	S2 (Transport-Priority)	S3 (Safety-Priority)
Average Transfer Distance to Landing Point (m)	412	268	185	493
Daily Scheduling Completion Rate (%)	94.2	96.8	95.1	95.6
Spatial Conflict Probability ($\times 10^{-4}$)	7.2	5.2	9.1	3.8
Structural-Check Pass Rate for Rooftop Landing Points (%)	75.0	100.0	87.5	75.0
Comprehensive Synergy Index	0.78	0.85	0.81	0.82

TABLE 7. Comparison of Operation-Management Modes

Indicator	Independent Operation	Integrated Operation	Change
Mean Response Time for Cross-System TOL Data Queries (s)	18.6	9.8	-47.3%
Mean Cross-Department Work-Order Processing Time (min)	54.2	21.3	-60.7%
Information Exchanges between TOL Facilities and Urban Transport and Security Departments (events day^{-1})	32	46	+43.8%

TABLE 8. Optimisation Results for Logistics Delivery Routes

Indicator	Before Optimisation (Daily Mean)	After Optimisation (Daily Mean, January 2026)	Change
Mean Delivery Time per Item (min)	39	26	-33.3%
Route-Conflict Rescheduling Events (events day^{-1})	4.8	1.2	-75.0%
Integrated Delivery Cost (yuan item^{-1})	6.8	5.4	-20.6%

E. OVERALL BENEFIT ANALYSIS

Combining the simulation and measured results from the three integration scenarios, the overall benefits of the proposed integrated construction method are shown in Table VI-E.

TABLE 9. Overall Benefits of the Integrated Construction Method

Benefit Dimension	Key Indicator	Before Optimisation	After Optimisation	Improvement
Spatial Coordination	Average Transfer Distance between Landing Points and Transport Hubs (m)	412	268	-35.0%
Spatial Coordination	Structural-Check Pass Rate for Rooftop Landing Points (%)	75	100	+33.3%
Data Sharing	Cross-System Data-Query Response Time (s)	18.6	9.8	-47.3%
Data Sharing	Information-Exchange Frequency (events day^{-1})	32	46	+43.8%
Operational Coordination	Cross-Department Work-Order Processing Time (min)	54.2	21.3	-60.7%
Operational Coordination	Logistics Delivery Efficiency (min item^{-1})	39	26	-33.3%
Safety Control	Spatial Conflict Probability ($\times 10^{-4}$)	7.2	5.2	-27.8%
Safety Control	Route-Conflict Rescheduling Events (events day^{-1})	4.8	1.2	75.0%

VII. DISCUSSION

The method depends on CIM platforms and high-precision UAV acquisition. The simulation uses idealised conditions, and the empirical study is limited to medium-scale areas. Legal responsibilities for rooftop landing points are not addressed. For standards alignment and institutional development, demonstration projects should establish semantic mapping tables and test whether integrated planning can enter the one-map review process for territorial spatial planning. Future work should introduce measured wind data, test online detection of dynamic obstacles and conduct multi-centre studies in megacities.

VIII. CONCLUSIONS

This paper presents an integrated construction method for coordination barriers between low-altitude takeoff and landing infrastructure and smart city infrastructure. Three conclusions follow. First, the classification system covers four functional levels and eight facility types, showing strong coupling between takeoff and landing facilities and urban space. Second, the four-stage method, acquisition, coding, data foundation and simulation, and the five-layer technical framework connect the workflow from rooftop survey to dynamic simulation. Third, the empirical results show that the method reduces transfer distance by 35%, reduces work-order processing time by 61%, and increases CSI from 0.78

to 0.85. The method offers a reference for integrating low-altitude infrastructure with smart city systems during the 15th Five-Year Plan period.

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