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Service model of smart tourism cities integrated with low-altitude technology

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ABSTRACT
The purpose of this study is to propose a comprehensive service model for integrating low-altitude technology into Guangzhou's smart tourism ecosystem. This model aims to address the critical technological, operational, and governance challenges faced by urban tourism systems, providing a scalable framework to enhance operational efficiency, visitor satisfaction, and collaborative management. The study employs a theoretical approach by developing a three-layered service model based on extensive literature analysis, policy review, and case studies of drone applications in tourism. The model comprises the Core Technology Layer, Service Application Layer, and Governance and Collaboration Layer, each of which incorporates specific influencing factors, such as R&D investments, operational efficiency, and policy support. The research identifies the critical role of low-altitude technology, including drones, AI, IoT, and big data platforms, in transforming urban tourism systems. The findings demonstrate how real-time data processing and seamless governance can enhance tourism services, such as monitoring, emergency response, and immersive experiences. Additionally, the study highlights the importance of collaboration among policymakers, businesses, and stakeholders in ensuring the sustainable implementation of low-altitude technology. This paper advances the theoretical understanding of integrating low-altitude technology into smart tourism cities by developing a structured service model. It enriches the academic discourse on urban tourism by addressing the interplay between technological innovation, service delivery, and regulatory frameworks, providing a foundational framework for future research. The proposed service model offers actionable insights for policymakers, urban planners, and businesses in Guangzhou and other urban tourism cities. By aligning technological infrastructure with service delivery and governance, the model provides a roadmap for improving operational efficiency, enhancing visitor experiences, and fostering public-private partnerships. It also offers guidance for addressing key challenges such as regulatory barriers, public acceptance, and cost-benefit considerations, paving the way for more efficient and sustainable tourism systems.

KEY WORDS
service model, smart tourism, low-altitude technology

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Introduction

With the continuous advancement of global smart city construction, smart tourism cities, as a type of smart city, are gradually becoming a key direction for the deep integration of the tourism industry and information technology (Buhalis & Amaranggana, 2015). By leveraging advanced technologies, such as the Internet of Things, big data, and artificial intelligence, smart tourism cities provide convenient, efficient, and personalised services to tourists while also enhancing the management and operational efficiency of urban tourism resources.

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However, existing smart tourism cities face challenges in cross-regional coordination, spatial expansion, and comprehensive management capabilities. Traditional technical approaches struggle to fully meet the diverse needs of modern tourists (Sevilla-Sevilla et al., 2024). Therefore, there is an urgent need to introduce innovative technologies to optimise service models and enhance the overall competitiveness of urban tourism.

In recent years, the rapid development of low-altitude technology has provided new technical means and service ideas for smart tourism cities. Low-altitude technology is centred on drones and general aviation. It enables data collection, real-time monitoring, and innovative tourist services in urban airspace (Abeyratne, 2018). However, the application of these technologies in urban contexts has yet to achieve large-scale implementation and remains in the pilot stage (Foina et al., 2015). For instance, in Shenzhen, drone technology has been used in smart tourism cities for traffic monitoring and landscape promotion. It allows for the rapid collection of real-time imagery from major urban attractions and surrounding areas, which is applied in city tourism branding and traffic flow analysis. Nevertheless, this has yet to be fully integrated into a holistic smart tourism service system. Similarly, Fukuoka, Japan, is exploring low-altitude technology for urban panoramic tours and nighttime light shows, utilising coordinated drone flights to enhance tourist experiences. However, the service scope and business model remain in the early exploratory stages.

Moreover, despite significant persistent challenges, low-altitude technology demonstrates potential in urban emergency services and resource management (Boucher, 2016). The West Lake Smart Tourism Zone in Hangzhou, China, has proposed using drones for tourist flow management and emergency rescue. However, at the city level, a comprehensive operational standard and technical support system have yet to be established (Erdelj et al., 2017). In Amsterdam, the Netherlands, low-altitude technology has been piloted to monitor real-time tourist movement and traffic conditions at key urban tourism nodes. Yet, issues such as flight safety in densely populated urban areas and regulatory restrictions have hindered large-scale deployment. These cases highlight the significant potential of low-altitude technology in smart tourism cities while revealing limitations in scalability, systematic integration, and challenges related to technology, policy, and costs.

As one of China's most vibrant and rapidly developing urban centres, Guangzhou has demonstrated a strong demand for the integration of low-altitude technology and smart tourism systems. Guangzhou's rich cultural heritage and diverse tourist attractions, such as the Canton Tower, Pearl River, and numerous historical sites, attract millions of visitors annually. However, the city faces significant challenges in managing increasing tourist flows, optimising resource allocation, and maintaining sustainable urban development. Current tourism management systems often lack the capacity for real-time data analysis, dynamic resource management, and comprehensive service integration, which are essential to meet the expectations of tech-savvy tourists. Moreover, regulatory bottlenecks, fragmented governance structures, and a lack of standardised technical frameworks for the deployment of low-altitude technology have hindered the widespread adoption of drones and related innovations in Guangzhou's tourism sector.

Based on the above background, this study addresses the academic issue of systematic insufficiency in the integration of smart tourism cities with low-altitude technologies, focusing on the current technological limitations of smart tourism cities in terms of tourist flow management, real-time monitoring, resource deployment, and emergency response. Despite the potential value of low-altitude technologies, such as drones, the Internet of Things (IoT), big data, and Artificial Intelligence (AI) in smart tourism, the existing research lacks a systematic technology integration framework and focuses mainly on single-scenario applications at the expense of cross-scenario synergy, technology interoperability, and the construction of city-level governance systems. In addition, current low-altitude technologies still have many challenges in terms of smart tourism policy regulation, data security, and public acceptance, making it difficult to effectively assess the feasibility and sustainability of technology applications. This study specifically focuses on the empirical research on the integration of low-altitude technology for smart tourism city development in Guangzhou and addresses the following two main research questions:

- What is the actual situation of Guangzhou's utilisation of low-altitude technology to develop urban construction? What are the problems?
- What are the potential application pathways of low-altitude technology in resource monitoring, tourist services, risk forecasting, and emergency

management, and how can these be systematically integrated into a new service system for smart tourism cities?

This study focuses on the need for service model innovation in smart tourism cities, addressing the limitations of existing models in terms of innovation and efficiency optimisation. It proposes integrating low-altitude technology into the service models of smart tourism cities. The theoretical significance of this research lies in expanding the research boundaries of the smart tourism field and providing a theoretical foundation for exploring the application of low-altitude technology in urban-level tourism management and services. Its practical significance lies in offering specific implementation plans and optimisation strategies for the construction of smart tourism cities, promoting the digital transformation of the tourism industry and innovation in service models. In summary, this study uses low-altitude technology as a focal point to provide new perspectives and development strategies for the construction of smart tourism cities.

1. Literature review

1.1. Research on smart tourism city

A smart city is a city that improves the efficiency of city management, enhances the quality of life of residents and realises sustainable development through information technology and digital means (Angelidou, 2014). The core features of smart cities include the widespread application of technologies, such as big data analytics, the Internet of Things (IoT), cloud computing, and artificial intelligence (AI), to help cities optimise in areas such as traffic management, energy use, public safety, and environmental monitoring (Anthopoulos, 2015). Smart cities aim to improve the level of intelligence and automation of all city services through the innovative integration of technologies to cope with increasingly complex urbanisation (Gretzel et al., 2015). The combination of these technologies makes cities more efficient and intelligent in terms of resource allocation, emergency response, and citizen services.

A smart tourism city is an important part of a smart city, focusing on utilising modern technology to enhance the overall service level and management efficiency of the tourism industry (Lee et al., 2020). Smart tourism city refers to the full use of modern information technology, especially big data, artificial intelligence, the Internet of Things and cloud computing, in the process of city management and tourism industry development to improve the management efficiency of the city, optimise the visitor experience as well as promote sustainable development. A smart tourism city is not just a digital transformation based on traditional city services, it also creates a smarter, more personalised and sustainable tourism environment through deep integration of technologies (Baggio et al., 2020).

When defining a smart tourism city, it is necessary to focus on its core functions: first, intelligent visitor services, which are achieved by providing tourists with real-time information, personalised travel recommendations, smart tour guides and other services. Second is the efficient management of tourism resources. Smart tourism cities rely on big data analytics and IoT technologies to optimise attraction flows, resource allocation, and emergency response, thereby improving resource utilisation and reducing pressure during peak periods (Um & Chung, 2019; Chung et al., 2021). Furthermore, smart tourism cities need to enhance their comprehensive city management capability through information technology, such as effective management in the areas of transportation, public safety, and environmental monitoring.

However, most of the existing smart tourism city research focuses on the optimisation of tourists' experience and neglects the deep integration at the city management level, especially in the application and coordination of cross-scenario technologies. The limitation of existing studies is demonstrated by the fact that many of them do not comprehensively explore how smart tourism cities can achieve city-level integrated coordination and management through technological innovation (Del Chiappa & Baggio, 2015). Therefore, integrating low-altitude technology with other management systems of smart tourism cities, aiming to improve the overall service quality and efficiency of the city, has become an important issue in the current research on smart tourism cities.

1.2. Research on low-altitude technology

Low-altitude technology refers to the use of technologies, such as unmanned aerial vehicles (UAVs), unmanned aerial vehicles (UAVs), and urban air traffic systems (UAMs), for data collection, monitoring, transportation, and other services, especially in urban airspace. These technologies can provide new perspectives for urban management, especially playing an important role in traffic monitoring, environmental monitoring, and emergency response (Abeyratne, 2018). The wide application of low-altitude technologies enhances the intelligent management capability of cities and shows great potential in improving the quality of urban public services, improving emergency response speed, and enhancing the experience of tourists.

The market applications of low-altitude technology have undergone gradual expansion from the military domain to the civilian market. Early studies primarily focused on optimising the hardware performance of drones, such as flight stability, endurance, and payload capacity, laying the foundation for drones' entry into the commercial sector (Giones & Brem, 2017). With the continuous maturation of the technology, drones have been widely applied in agriculture, environmental monitoring, and infrastructure inspection, demonstrating significant economic and social value. However, many studies focus on the technological development of drones while lacking in-depth analysis of their functional integration and application effectiveness in complex scenarios. For example, Kellermann et al. (2020) pointed out that while drones improve efficiency in agriculture and logistics, regulatory restrictions and a lack of operational standards hinder their large-scale adoption in the industry.

As drones entered the service sector, their applications gradually expanded to such industries as media, entertainment, and logistics (Askerbekov et al., 2024). In recent years, their potential in tourism and urban management has garnered increasing attention, with applications in such scenarios as urban landscape aerial photography, real-time traffic monitoring, and tourist flow management. However, existing studies often focus on exploring the technological possibilities without addressing the integrated application of low-altitude technology at the urban level. For instance, Floreano and Wood (2015) highlighted the significant challenges for drones operating in densely populated urban environments, where stringent requirements for flight safety exceed the current technological capabilities. Additionally, most studies emphasise the single-function applications of drones and fail to propose systematic solutions, limiting their role in smart cities to certain specific scenarios (Li, 2023).

Although drone technology has entered the research scope of smart city construction in recent years, its practical application still faces challenges. Current studies provide insufficient discussions on the scalability and operational standardisation of low-altitude technology, which restricts the large-scale adoption of drones (He et al., 2022; Eshtaiwi & Ahmed, 2024; Huang et al., 2024). On the other hand, there is a lack of evaluation of the effectiveness of low-altitude technology in the service sector. For example, while research emphasises the advantages of drones in monitoring, emergency response, and tourism, empirical data supporting these applications' actual value is scarce (Jiang et al., 2025; Madden et al., 2022; Ayamga et al., 2021). This indicates an urgent need for more systematic and comprehensive analysis to address the complex demands of urban environments as low-altitude technology enters the field of smart tourism.

1.3. Research progress on the integration of smart city construction and low-altitude technology

The literature widely acknowledges the significant potential of low-altitude technology in smart cities, particularly in traffic management, environmental monitoring, and public safety (Huang et al., 2024). Studies have shown that low-altitude technology can significantly enhance the efficiency of traffic flow monitoring, especially in large urban areas. UAVs can collect real-time traffic data, enabling transportation management departments to quickly identify traffic bottlenecks and accidents, which helps in optimising traffic signals and resource allocation (Wang et al., 2020). In environmental monitoring, UAVs have been successfully applied for air quality monitoring, pollution source tracking, and assessing urban environmental health. These capabilities provide city managers with efficient tools for monitoring and responding to urban sustainability challenges (Madden et al., 2022; Wang et al., 2013).

However, despite the clear advantages demonstrated in these application areas, existing research often suffers from inadequate integration of technology. Most studies focus on low-altitude technology's application in single-use cases, such as traffic monitoring or pollution surveillance, while largely neglecting how these technologies can be integrated with other urban management systems, such as intelligent transportation systems (ITS) and urban safety networks (Boes et al., 2016; Li et al., 2017; Floreano & Wood, 2015). This lack of integration limits the overall effectiveness of low-altitude technology and prevents it from reaching its full potential in addressing the multifaceted needs of modern smart cities.

In the context of smart tourism cities, the application of low-altitude technology remains underexplored. While existing literature acknowledges the role of low-altitude technology in various urban sectors, it has given limited attention to its integration into tourism management systems. Smart tourism cities require more than just efficient traffic and environmental management; they also need enhanced tourist experiences and smarter service delivery. Low-altitude technology can play a crucial role in real-time tourist flow monitoring, panoramic sightseeing experiences, and emergency response services. However, most studies focus on the application of UAVs in isolated tourism settings, such as monitoring visitor flows in specific tourist spots or offering aerial tours. These studies fail to explore how low-altitude technology can contribute to broader resource optimisation, visitor management, and emergency services within a smart tourism city (Baggio et al., 2020). There is a significant gap in the research regarding how low-altitude technology can integrate with the overall tourism management system to optimise resource allocation, enhance emergency response capabilities, and improve overall visitor satisfaction.

The methodological approaches in existing research further exacerbate these gaps. Most studies rely heavily on case studies and qualitative analysis, which provide valuable insights into specific applications but lack the capacity for comprehensive, generalised assessments of technology effectiveness across different urban environments (Suanpang et al., 2022). Although case studies are useful for providing detailed accounts of low-altitude technology applications in particular cities or scenarios, they often fail to offer scalable conclusions that can be applied across multiple urban settings. Furthermore, qualitative analyses, such as expert interviews or surveys, often lack empirical data to substantiate the actual effectiveness of these technologies in large-scale applications. These studies typically highlight the potential benefits of low-altitude technology but fail to provide systematic evaluations of its real-world impacts, particularly in terms of cost-effectiveness, scalability, and social acceptance (Ilkhanizadeh et al., 2020).

The empirical research conducted to date has primarily focused on validating the technological feasibility of low-altitude technology in specific urban services, such as traffic management and environmental monitoring. However, these studies often lack cross-functional assessments of how low-altitude technology can interact with other systems across smart cities (Jiang et al., 2025). Most studies focus on the effectiveness of low-altitude technology in isolated domains without investigating how it could be integrated with other urban systems like intelligent traffic management, public safety networks, or urban resource management (Důbravová et al., 2024). This limitation makes it difficult to assess the full impact of low-altitude technology across smart city infrastructures.

Moreover, the current empirical studies tend to concentrate on single-use applications without exploring the holistic integration of low-altitude technology across urban sectors. For example, UAVs have been shown to improve monitoring in specific tourism areas, such as tracking visitor numbers at tourist spots, but there has been limited research on how low-altitude technology can work in synergy with other smart tourism management systems to create a seamless tourist experience (Mohamed et al., 2020). The lack of systematic empirical data on low-altitude technology's impact on overall tourism resource management and optimisation further limits our understanding of its true value in smart tourism cities (Madden et al., 2022).

While some research has contributed insights into the practical applications of low-altitude technology, there is a distinct lack of quantitative evaluations and scalability assessments. Most studies rely on case studies or qualitative analyses, which, while offering valuable contextual information, fail to provide comprehensive data on the long-term sustainability, cost-effectiveness, and social impact of UAVs in smart city applications (He et al., 2022). Additionally, limited exploration exists of how policy and regulatory challenges may influence the widespread adoption of low-altitude technology, which is essential for understanding the real-world barriers to its implementation.

1.4. Research gaps

Two key research gaps were identified in the current literature on the application of low-altitude technology in smart tourism cities. First, empirical analysis of low-altitude technology is lacking. Many studies focus on the technical feasibility of low-altitude technology in isolated domains or specific applications but lack comprehensive empirical research on its effects in smart tourism cities, especially in areas like resource optimisation and tourism management. While some studies have explored the potential of low-altitude technology in tourist flow monitoring and panoramic sightseeing, these studies often focus on specific scenarios or projects and do not systematically analyse how low-altitude technology can function in multiple contexts and scenarios within smart tourism cities. Therefore, this research will fill this gap by providing an empirical analysis of the real-world application of low-altitude technology in Guangzhou, focusing on its effectiveness in improving resource management, optimising visitor experiences, and enhancing emergency response.

The second research gap is the integration of low-altitude technology with other urban management systems. While existing research has explored low-altitude technology in areas like traffic and environmental monitoring, few studies have systematically examined how low-altitude technology can collaborate with other management systems in smart tourism cities, such as intelligent transportation, public safety, and tourism resource management. Existing studies tend to focus on the independent application of low-altitude technology without delving into the synergistic effects between different technologies, which limits the overall impact of low-altitude technology. This study will address this gap by proposing a framework for integrating low-altitude technology with other systems in Guangzhou's smart tourism city. It will also analyse the effectiveness of cross-technology collaboration using empirical data, filling this important gap in the literature.

By focusing on the case of Guangzhou's smart tourism city, this study aims to address both of these research gaps. First, it will provide a comprehensive empirical assessment of the impact of low-altitude technology on resource management, visitor experience, and emergency management in Guangzhou's smart tourism city. Second, the study will explore how low-altitude technology can be effectively integrated with other smart city management systems in Guangzhou, offering a cross-technology integration model that is supported by empirical data. This research will provide new theoretical insights and practical guidance for the broader application of low-altitude technology in smart tourism cities.

2. Research methods

2.1. Study location

This study's research object is Guangzhou, a representative city known for its thriving tourism industry and leading smart city development. Guangzhou is one of China's key tourist destinations, boasting diverse cultural and natural resources, such as the Canton Tower, the Pearl River, and numerous historical sites, attracting millions of tourists annually. However, the rapid growth of the tourism industry has introduced challenges in managing tourist flows, optimising service quality, and ensuring sustainable development.

In recent years, Guangzhou has made significant progress in building smart city infrastructure and introducing innovative solutions to urban governance, including smart tourism. Guangzhou's tourism development strategy emphasises digital transformation, integrating technologies such as big data, IoT, and AI to upgrade tourism management and service delivery (Liu et al., 2023). However, current smart tourism practices in Guangzhou face limitations in real-time data collection, dynamic resource allocation, and immersive tourist experiences. These challenges highlight the necessity of introducing advanced technologies like low-altitude drones to further enhance the city's smart tourism model.

2.2. Selection of the research methods

In selecting the research methods for this study, several considerations were made to ensure that the analysis would provide a comprehensive and accurate understanding of the potential integration of low-altitude technology into Guangzhou's smart tourism framework. The primary rationale behind the choice of methods is to address both the technical feasibility and the broader socio-economic impacts of drone technology within the specific context of Guangzhou.

First, the textual analysis of policy documents was chosen because it offers a clear understanding of the existing policy support and institutional framework surrounding the integration of low-altitude technology. By focusing on key policy documents, such as the Smart City Development Plan and the Five-Year Tourism Development Plan, this study can identify potential gaps in current policy and suggest areas for improvement. This method is essential for providing insight into how well low-altitude technology aligns with the city's long-term development goals.

Second, quantitative methods, such as technical feasibility analysis, economic benefit analysis, and social impact analysis, were chosen to provide a data-driven approach to assess the actual performance and impact of low-altitude technology. These methods allow the study to evaluate the technical capabilities of drone systems and quantify their potential economic contribution and social acceptance. This multi-dimensional approach ensures that the study goes beyond theoretical assumptions and provides a well-rounded, evidence-based analysis.

The combination of qualitative policy analysis and quantitative evaluation allows for a holistic understanding of the challenges and opportunities in integrating low-altitude technology into Guangzhou's smart tourism initiatives. By using these methods in tandem, the study can provide actionable recommendations grounded in the technical feasibility and the broader institutional and societal context.

2.3. Textual analysis based on policy texts

This study conducts a quantitative analysis of relevant policy texts to understand the policy support and institutional environment for integrating low-altitude technology into Guangzhou's tourism sector. This approach identifies the priorities and potential gaps within the existing policy framework to assess the feasibility of integrating drone technology with smart tourism development. The analysis includes the following steps:

1. Data collection

Collect key policy documents related to smart tourism, low-altitude technology, and smart-city development from national, provincial, and municipal levels, including Guangzhou's Smart City Development Plan and 14th Five-Year Tourism Development Plan.

2. Content analysis

Apply text-mining techniques to extract keywords and themes related to smart tourism, low-altitude technology, and tourism management. Quantitative metrics, such as term frequency and co-occurrence analysis, are used to identify key policy focuses and the relationships between drone technology and tourism development.

3. Gap analysis

Compare Guangzhou's current policy environment with international best practices to identify gaps in policy support and areas for improvement. This helps determine how to better facilitate the integration of low-altitude technology into tourism management.

2.4. Quantitative analysis methods

To systematically evaluate the potential of low-altitude technology in Guangzhou's smart tourism development, this study adopts the following three quantitative analysis methods:

1. Technical feasibility analysis

Objective — to evaluate the technical readiness and feasibility of low-altitude technology applications in Guangzhou's tourism sector.

Data source — technical reports, case studies from pilot projects in Guangzhou, and performance specifications of drone systems.

Methodology — analysis of navigation accuracy, battery endurance, payload capacity, and adaptability in complex urban environments; a comparative analysis of expected versus actual performance benchmarks conducted to identify gaps and improvement areas.

2. Economic benefit analysis

Objective — to quantify the economic impact of low-altitude technology in Guangzhou's tourism industry.

Data source — financial data from pilot projects, market analysis reports, and Guangzhou's tourism revenue statistics.

Methodology — constructing a cost-benefit model to evaluate equipment costs, operational expenses, and direct (e.g., ticket revenue) and indirect (e.g., tourist spending, city branding) economic contributions. ROI calculations are performed to determine the financial feasibility of integrating drone technology.

3. Social impact analysis

Objective — to analyse public acceptance and behavioural patterns related to drone-based tourism services.

Data source — social media platforms, online travel reviews, and tourist flow data from Guangzhou.

Methodology — natural language processing (NLP), which is used to conduct sentiment analysis of public feedback regarding drone-assisted services, categorising responses into positive, neutral, and negative sentiments. Behavioural data, such as participation rates in drone sightseeing projects, is analysed to assess user preferences and levels of acceptance.

2.5. Research process

The research process includes the following steps:

1. Policy and context analysis — conducting a detailed review of Guangzhou's tourism development needs and smart city planning, examining the relationship between policy support and technology applications.

2. Data collection — gathering technical, economic, and social data from pilot projects, government reports, and big data platforms.

3. Quantitative evaluation — using the above methods to systematically analyse the technical feasibility, economic impact, and social effects of integrating low-altitude technology into smart tourism.

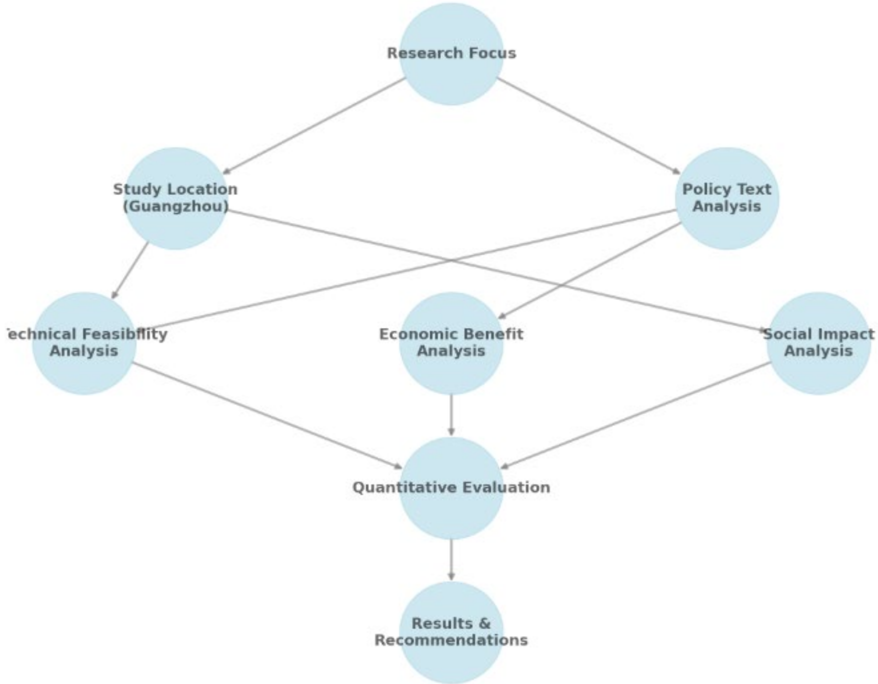

Fig. 1. Research framework

4. Results and recommendations — synthesise the findings to propose actionable recommendations for optimising Guangzhou's smart tourism model using low-altitude technology.

Fig. 1 shows the flow chart of this study's methodology. This integrated research approach ensures that the analysis is rooted in Guangzhou's specific needs, providing a comprehensive understanding of the potential for integrating low-altitude technology with smart tourism. The inclusion of policy analysis adds depth to the institutional context, supporting a well-rounded evaluation.

3. Research results and analysis

The data collection for this study was conducted primarily during October and November 2024, covering the necessary data for policy text analysis, technical feasibility analysis, economic benefit analysis, and social impact analysis. The data was sourced from policy documents published by the Guangzhou government, technical reports, market analysis, and social media and tourist flow data, ensuring the timeliness and reliability of the research results.

3.1. Results of policy text analysis

This study conducted a textual analysis of 57 policy documents related to smart tourism, low-altitude technology, and urban development in Guangzhou. These policy documents cover the period from 2010 to 2023, a timeframe chosen because 2010 marked the beginning of systematic planning for smart city construction in China, while low-altitude technology (e.g., drones) began expanding from military and research applications to civilian and commercial use during this period. This time range comprehensively captures the evolution of Guangzhou's policy initiatives in integrating smart tourism with low-altitude technology.

The analysed documents were sourced from the following channels: official Guangzhou government websites, policy announcement platforms, municipal planning reports, legislative documents, and research publications related to smart cities and low-altitude technology. These sources ensure the authority and comprehensiveness of the policy data. By applying text mining techniques, this study extracted key terms and themes from the policy texts, followed by frequency analysis, co-occurrence analysis, and gap analysis. The findings reveal key trends, policy gaps, and development priorities in Guangzhou's policy framework. This analysis provides empirical evidence and data-based recommendations to further refine the policy structure and promote the application of low-altitude technology in the field of smart tourism.

The frequency analysis of policy keywords, as shown in Fig. 2, highlights the areas of emphasis on Guangzhou's policy framework on smart tourism and low-altitude technology. The most frequently mentioned keyword is "Smart Tourism" (50 occurrences), indicating its prominence in Guangzhou's strategic development agenda. "Tourism Experience" (40 occurrences) and "Low-Altitude Technology" (35 occurrences) follow closely, suggesting a strong focus on improving visitor satisfaction and leveraging emerging technologies like drones.

However, keywords like "Safety Standards" (15 occurrences) and "Data Sharing" (25 occurrences) appear less frequently, reflecting potential gaps in the current policy framework. These aspects are crucial for ensuring the safe and efficient integration of low-altitude technology into tourism operations. For example, insufficient emphasis on safety standards could delay drone deployment in crowded urban areas, while limited data-sharing mechanisms may hinder cross-departmental coordination in implementing drone-based services.

Fig. 3 presents the co-occurrence matrix of policy keywords, demonstrating the interrelationships between key terms. The strongest co-occurrence is observed between "Smart Tourism" and "Tourism Experience" (0.9), underscoring the close linkage

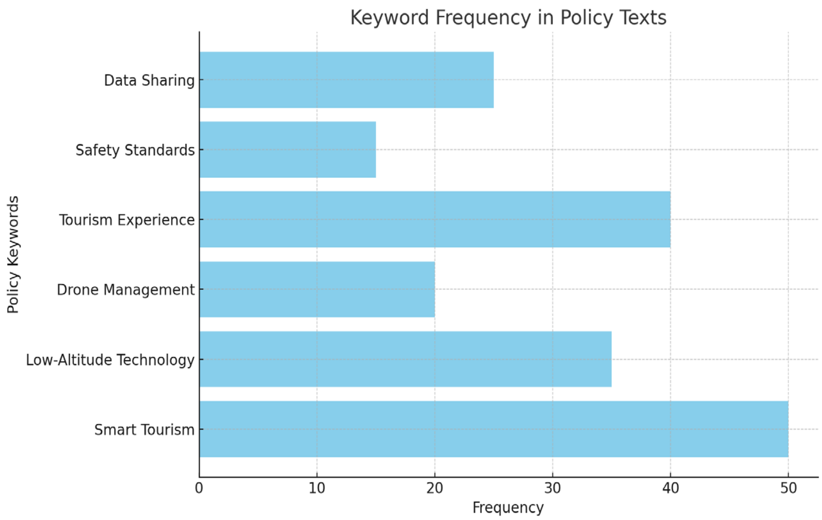

Fig. 2. Keyword frequency in policy texts

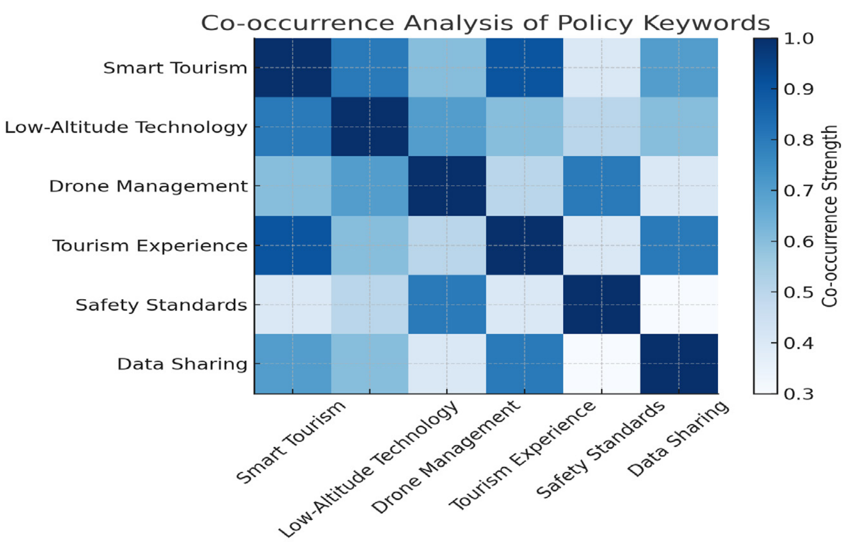

Fig. 3. Co-occurrence analysis of policy keywords

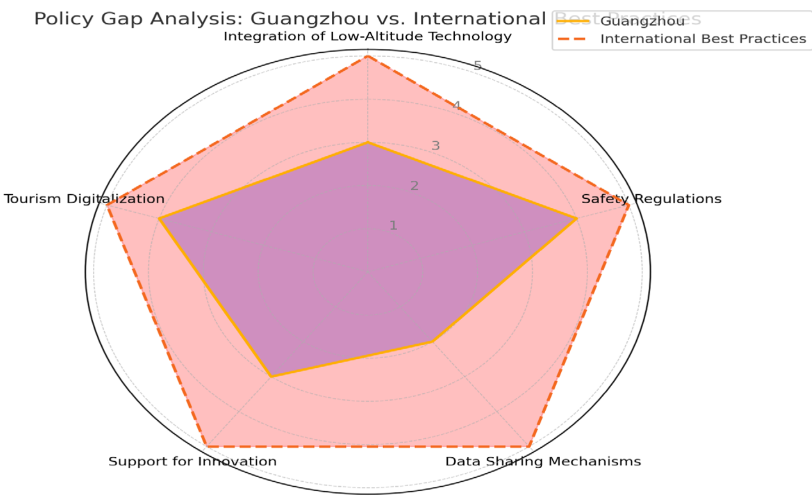

Fig. 4. Policy gap analysis

between enhancing visitor satisfaction and the adoption of smart technologies. This suggests that policy efforts are heavily focused on improving the overall tourist experience through digital transformation initiatives.

"Low-Altitude Technology" exhibits moderate co-occurrences with "Drone Management" (0.7) and "Data Sharing" (0.6), reflecting a growing policy interest in operational and technical aspects of drone deployment. However, weaker correlations are noted between "Safety Standards" and other keywords (e.g., 0.4 with "Smart Tourism" and "Data Sharing"), indicating a fragmented approach to regulatory oversight. This lack of integration could result in operational inefficiencies or public resistance to drone applications.

The radar chart in Fig. 4 compares Guangzhou's policy environment with international best practices across five key aspects. While Guangzhou demonstrates relatively strong support for "Tourism Digitalization" (4/5) and "Safety Regulations" (4/5), significant gaps remain in "Integration of Low-Altitude Technology" (3/5) and "Data Sharing Mechanisms" (2/5). For example, international benchmarks emphasise well-established frameworks for sharing operational data across agencies, ensuring seamless integration of low-altitude technology into urban tourism management. Guangzhou's lower scores in these areas highlight the need for targeted improvements to enhance its institutional support and technological readiness for low-altitude drone applications.

The analysis results indicate that Guangzhou's policy framework places significant emphasis on smart tourism and improving visitor experiences, showing notable strengths in tourism digitalisation and basic safety regulations. However, there are clear policy gaps in areas such as data-sharing mechanisms and innovation support, where Guangzhou lags behind international best practices. Additionally, the integration of low-altitude technology and safety regulation remains fragmented, lacking a systematic and cohesive framework. Overall, while Guangzhou's policy foundation is solid, further improvements in data collaboration and innovation-driven policies are essential to fully leverage the potential of low-altitude technology in smart tourism.

3.2. Quantitative analysis results

The data for the technical feasibility analysis (as shown in Fig. 5 and Table 1) are primarily sourced from technical reports on the application of low-altitude technology in Guangzhou, performance specifications of drone systems, and case studies from several pilot projects. These data points cover the key application areas of low-altitude technology in smart tourism scenarios. By comparing actual performance with industry-standard expectations, the analysis identifies gaps in technical maturity and application potential. Eight critical performance metrics, including navigation accuracy, battery endurance, payload capacity, and stability in complex environments, were selected to provide a comprehensive technical diag-

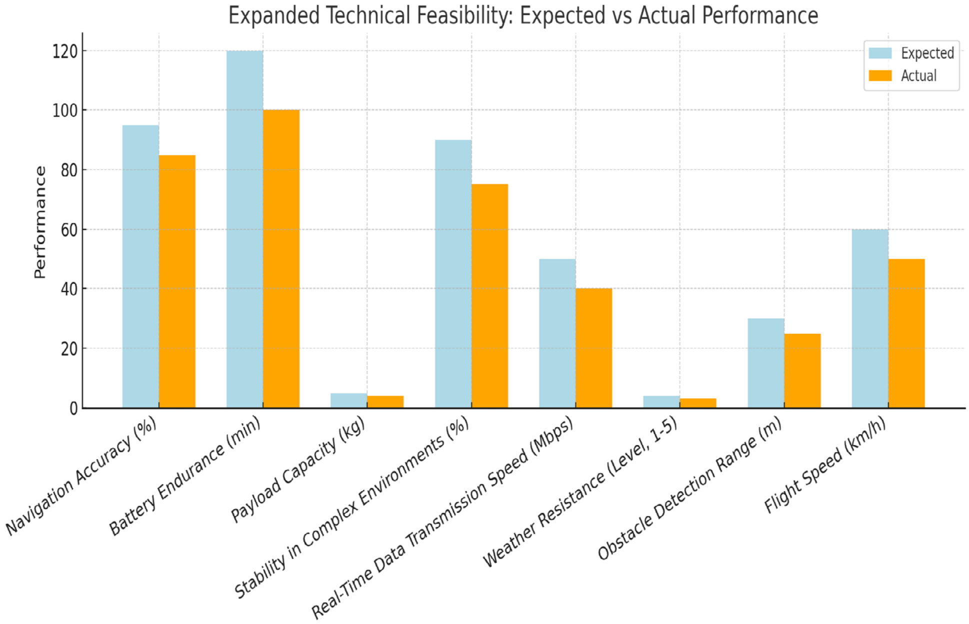

Fig. 5. Expanded technical feasibility

Tab. 1. Performance metrics

Performance Metrics	Expected Value	Actual Value	Gap (%)
Navigation accuracy (%)	95	85	10
Battery endurance (min)	120	100	20
Payload capacity (kg)	5	4	20
Stability in complex environments (%)	90	75	15
Real-time data transmission speed (Mbps)	50	40	20
Weather resistance (Level, 1–5)	4	3	25
Obstacle detection range (m)	30	25	16.7
Flight speed (km/h)	60	50	16.7

nosis. The aim is to pinpoint current shortcomings, offer actionable recommendations for improvement, and provide robust data support for integrating low-altitude technology into Guangzhou's smart tourism framework.

Fig. 5 and Table 1 reveal that low-altitude technology in Guangzhou's tourism sector demonstrates performance gaps across multiple key metrics compared to expected standards. First, in terms of navigation accuracy and stability in complex environments, the actual navigation accuracy of drones reaches 85 %, which is relatively close to the expected 95 %. However, stability in urban environments performs at only 75 %, falling short of the 90 % target. This indicates the need for enhanced anti-interference capabilities to ensure reliable operations in densely populated areas with complex signals. Additionally, optimising navigation accuracy is essential for delivering precise services across diverse urban scenarios.

Second, significant gaps are observed in battery endurance and payload capacity. The actual battery endurance is 100 minutes, 20 % lower than the expected 120 minutes, while payload capacity stands at 4 kg, also 20 % below the expected 5 kg. These shortcomings limit the ability of drones to undertake longer operations and carry heavier equipment or materials. Furthermore, the real-time data transmission speed of 40 Mbps falls 20 % short of the expected 50 Mbps, potentially affecting the drones' ability to process real-time data effectively, thereby reducing responsiveness and operational efficiency in dynamic scenarios. These gaps underscore the urgent need for advancements in battery technology and communication systems to support more complex and diverse tasks.

Finally, the data shows deficiencies in weather resistance and obstacle detection range, which are crucial for environmental adaptability. The weather resistance is rated at Level 3 (on a scale of 1–5), below the expected Level 4, limiting drone deployment under adverse weather conditions. The obstacle detection range is 25 meters, 16.7 % less than the expected 30 meters, reflecting reduced effectiveness in crowded urban environments. Additionally, the flight speed is 50 km/h, below the expected 60 km/h, indicating inefficiencies in covering larger areas. Collectively, these metrics highlight the need for improvements in battery performance, environmental adaptability, and real-time communication capabilities. This analysis provides a clear roadmap for optimising low-altitude technology and ensuring its effective integration into Guangzhou's smart tourism framework.

The economic benefit analysis in this study is based on actual statistical data for Guangzhou's low-altitude technology applications in smart tourism from 2020 to 2024, combined with market trend projections and growth models for 2025 to 2029. The actual data was sourced from official Guangzhou government tourism statistics, operational reports from low-altitude technology companies, and publicly available policy documents and academic research. The future five-year projections are calculated using the Compound Annual Growth Rate (CAGR) formula, considering technological advancements, policy support, and market demand. The CAGR formula is as follows:

$$\mathrm{CAGR} = \frac{\text{Final Value}}{\text{Initial Value}}^{\frac{1}{\text{Number of Years}}} \text{-1}$$

With an observed growth rate of 25 %, the projections were benchmarked against historical growth trends of similar technologies in the industry. The data analysis shows that the economic output of low-altitude technology in 2020 was approximately USD 1 million, growing to USD 10 million by 2024, reflecting rapid development in this field. By 2029, its economic benefits are expected to surpass USD 200 million, demonstrating the critical role and vast growth potential of drone technology in smart tourism cities.

Between 2020 and 2024, the economic output of Guangzhou's low-altitude technology experienced rapid growth, increasing from an initial USD 1 million to USD 10 million. This growth was driven by the widespread application of drones in smart tourism services in Guangzhou, including real-time tourist flow monitoring, aerial promotional imagery for urban attractions, and enhanced emergency response and resource management. In 2020, low-altitude technology was primarily in its pilot stage, with limited service coverage. However, as the development of smart cities accelerated and drone technologies matured, their integration into urban tourism management expanded steadily. By 2023 and 2024, drones contributed significantly to Guangzhou's international tourism branding by providing high-quality aerial imagery and improving visitor experiences, which directly boosted related economic benefits. Meanwhile, policy initiatives supporting smart tourism created a favourable environment for this technological growth.

From 2025 to 2029, economic benefits are expected to grow exponentially, reaching USD 25 million by 2025 and surpassing USD 200 million by 2029. This projection is based on several factors, including technological advancements, policy support, and expanding market demand. First, drone applications in Guangzhou's smart tourism sector are expected to deepen, covering more scenic spots and introducing intelligent panoramic tours and drone-guided services, further increasing tourist spending and tourism revenue. Second, policy support will continue to play a critical role; with the improvement of cross-departmental data-sharing mechanisms and operational standardisation, the large-scale application of drones will significantly improve efficiency. Additionally, declining costs of low-altitude technology, increasing market demand, and continuous upgrades in smart hardware and software will provide the foundation for rapid growth in economic benefits.

Despite the promising projections, several challenges must be addressed to realise the anticipated economic growth. Currently, Guangzhou faces deficiencies in operational standardisation and policy support for low-altitude technology, such as limited coordination in safety regulations and data-sharing mechanisms, which may hinder the full deployment of drones. On the technical side, further optimisation is required, particularly in such areas as drone battery endurance and environmental adaptability, to handle complex urban environments and adverse weather conditions. Moreover, efficient data transmission capabilities are essential to achieving real-time monitoring and dynamic response. To address these challenges, Guangzhou must increase investment in R&D, promote technological innovation, and collaborate with enterprises and research institutions. At the same time, policy reforms, such as improving regula-

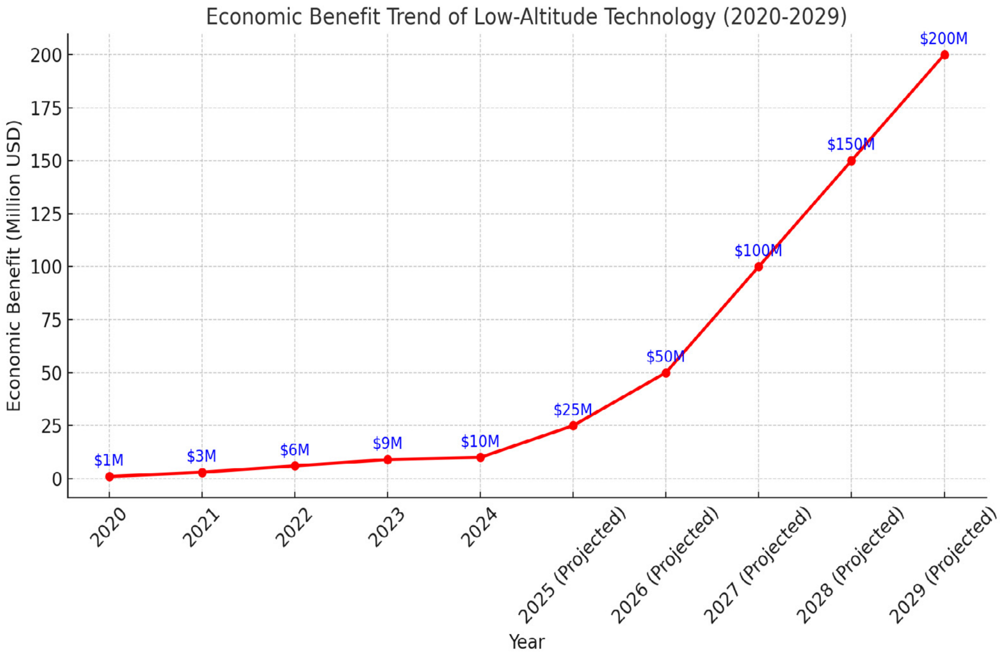

Fig. 6. Economic benefit trend of low-altitude technology (2020–2029)

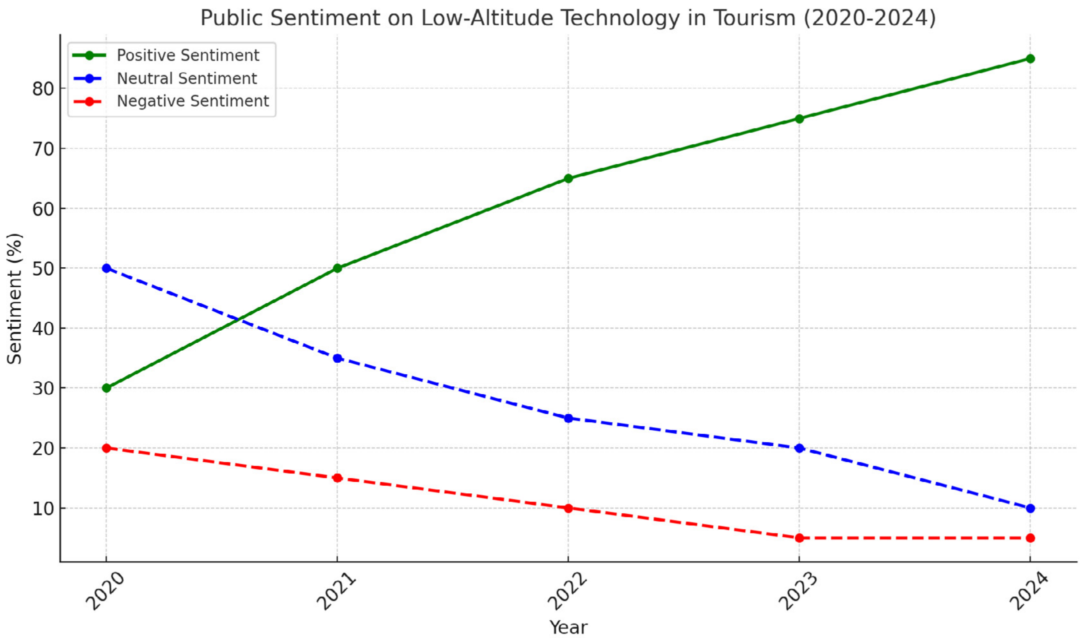

Fig. 7. Public sentiment on low-altitude technology in tourism (2020–2024)

tory frameworks and fostering cross-departmental cooperation, will be critical for realising the projected economic benefits.

The social impact of low-altitude technology on Guangzhou's smart tourism sector has been evaluated through public sentiment analysis and public engagement trends from 2020 to 2024. The analysis utilises big data derived from social media platforms, online travel reviews, and participation rates in drone-enabled tourism projects. The findings are illustrated through two key metrics: sentiment trends and public participation growth.

From the sentiment analysis, as shown in Fig. 7, public perception of drone technology in tourism has shown significant improvement over the past five years. Positive sentiment increased from 30 % in 2020

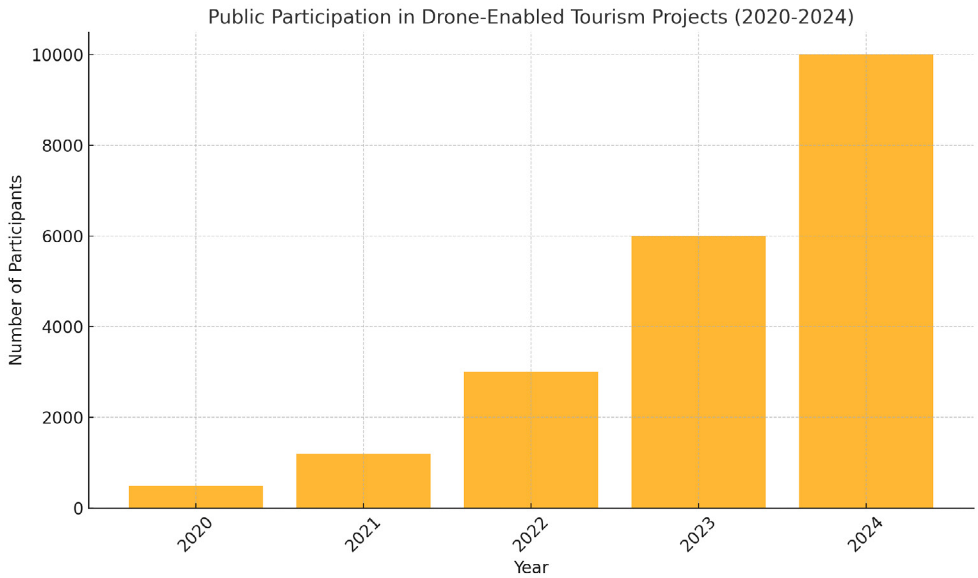

Fig. 8. Public sentiment regarding low-altitude technology in tourism (2020–2024)

to 85 % in 2024, reflecting growing acceptance and enthusiasm for drone-based applications in tourism. Initially, public scepticism was driven by concerns about privacy, safety, and noise pollution, as evidenced by the 20 % negative sentiment in 2020. However, sustained efforts in addressing safety standards and improving operational transparency, combined with the enhanced user experience offered by drone services, have drastically reduced negative sentiment to 5 % by 2024. Meanwhile, neutral feedback has also declined from 50 % in 2020 to 10 % in 2024 as more users shifted their perceptions toward a positive stance.

Public participation in drone-enabled tourism projects has grown exponentially, as shown in Fig. 8. The number of participants increased from 500 in 2020 to 10,000 in 2024, demonstrating widespread public interest in immersive drone-assisted tourism services, such as panoramic drone tours, real-time virtual guided tours, and interactive aerial displays. This growth can be attributed to the increasing integration of drone applications in iconic tourist attractions, such as the Canton Tower and Pearl River Night Cruise. Drone-assisted virtual experiences have also gained popularity among tech-savvy tourists, enhancing the diversity and accessibility of tourism services.

The interplay between improving public sentiment and increasing participation highlights the successful integration of low-altitude technology into Guangzhou's tourism sector. However, the findings also underscore the importance of sustained efforts in addressing social concerns related to privacy and regulatory oversight. As Guangzhou continues to expand its drone applications in tourism, efforts to engage the public through education campaigns and transparent communication about safety and privacy measures will be critical to maintaining positive perceptions.

In a nutshell, the social impact analysis demonstrates that low-altitude technology has been well-received by the public and has driven substantial engagement in smart tourism initiatives. The combined rise in positive sentiment and participation highlights the potential of drones to enhance tourism experiences and strengthen public trust in innovative technologies. Moving forward, addressing residual social concerns and fostering inclusive participation will be pivotal to maximising the social benefits of low-altitude technology in smart tourism.

4. Discussion

The integration of low-altitude technology into Guangzhou's smart tourism framework represents a significant advancement in urban tourism management and service innovation. The findings of this study reveal that low-altitude technology, primarily through drones, has become an indispensable tool for enhancing visitor experiences, optimising resource management, and addressing complex urban tourism challenges. By analysing its economic, social, and technical impacts, this research builds upon prior studies, such as Důbravová et al. (2024), which emphasise the transformative potential of digital technologies in shaping smarter and more sustainable tourism systems. However, while the economic growth trajectory and social acceptance of drones in Guangzhou have been remarkable, several underlying challenges demand attention to fully realise their long-term potential.

Economically, the exponential growth from USD 1 million in 2020 to USD 10 million in 2024 reflects the increasing integration of drones into various aspects of urban tourism, ranging from real-time monitoring to aerial tourism branding. This aligns with observations by Hossein Motlagh et al. (2016) that low-altitude technology's economic impact grows with diversification into new service areas. Yet, the technical constraints identified in this study, such as limitations in battery endurance, payload capacity, and operational stability in complex urban environments, remain significant barriers to scaling these services. Moreover, the projected economic benefits of over USD 200 million by 2029 depend on stakeholders' ability to address these challenges through targeted investments in R&D and the development of standardised operational frameworks. Therefore, while the financial prospects are promising, the success of future applications will rely heavily on advancing core drone technologies and fostering public-private collaborations to drive both innovation and market adoption.

The social impact analysis highlights a critical shift in public attitudes toward low-altitude technology. Building on findings by Wang et al. (2023), which underline the importance of public trust in urban drone applications, this study demonstrates that positive sentiment toward drones in tourism grew from 30 % in 2020 to 85 % in 2024. This growth reflects not only the improved user experience provided by drones but also the effectiveness of safety and transparency measures implemented in Guangzhou's urban management. However, residual concerns about privacy and safety remain a challenge, as indicated by lingering negative sentiments, albeit at a reduced level. These findings suggest that stakeholders must prioritise transparent communication about operational protocols and further engage the public through education campaigns. Demonstrating the tangible benefits of drone-enabled services, such as improved emergency response and sustainable tourism practices, will be crucial to fostering long-term public acceptance.

From a governance and policy perspective, the findings also echo Shafiee et al. (2019), who argue that the success of smart tourism initiatives depends on the integration of diverse technologies into a cohesive urban system. Although Guangzhou has made commendable progress in leveraging low-altitude technology, this study reveals gaps in data-sharing mechanisms and cross-departmental collaboration. For instance, while drones have proven effective in monitoring tourist flows and providing immersive experiences, the lack of a unified framework for coordinating data across municipal departments hinders their full potential. Stakeholders must, therefore, focus on developing standardised protocols for data integration and governance. Learning from international best practices, such as Amsterdam's robust urban technology frameworks, could provide valuable insights for Guangzhou in creating seamless interoperability between low-altitude technology and other smart city systems.

Several strategic recommendations emerge to address these challenges. First, investing in technological advancements remains a priority. Enhancements in drone hardware, such as extended battery life and improved weather resistance, combined with advancements in AI-based navigation and real-time data processing, will enable drones to operate more effectively in complex urban environments. Such investments should be supported by public funding and incentivised private-sector partnerships, as suggested by Giones and Brem (2017), who emphasise the role of collaborative ecosystems in driving innovation in emerging technologies.

Second, regulatory frameworks must evolve to keep pace with technological advancements and market expansion. This includes updating safety standards, streamlining licensing processes, and establishing clear guidelines for data privacy and security. The development of drone-specific urban airspace policies akin to those implemented in Shenzhen could serve as a model for Guangzhou to ensure safe and efficient drone operations in densely populated areas.

Finally, engaging key stakeholders, including tourists, local communities, and businesses, is essential for sustaining the momentum of drone adoption in smart tourism. As Muhmad Kamarulzaman et al. (2023) highlight, fostering stakeholder collaboration is critical to overcoming implementation barriers and ensuring equitable benefits from new technologies. In Guangzhou's case, creating participatory platforms where stakeholders can provide feedback, share concerns, and contribute to policy development would enhance both public trust and operational efficiency.

The proposed Low-Altitude Technology-Based Smart Tourism Service Model (Fig. 9) for Guangzhou

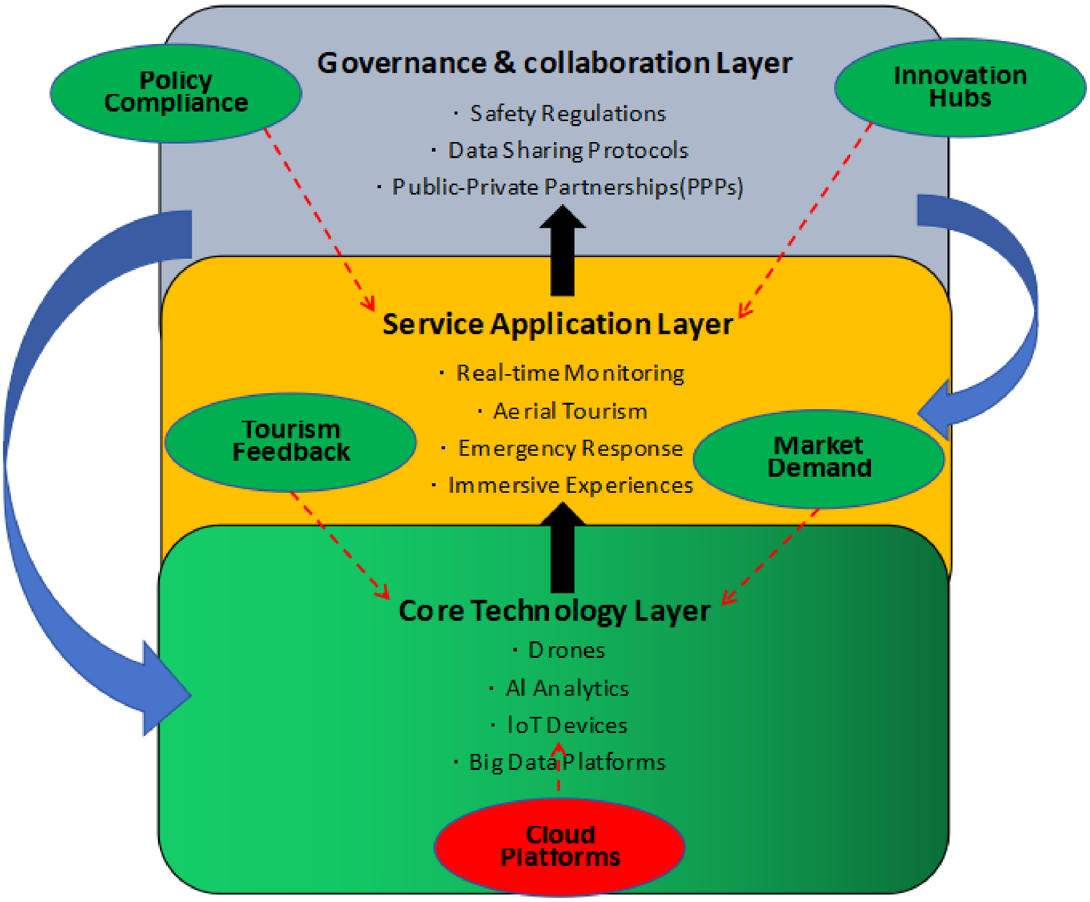

Fig. 9. Low-altitude Technology-based Smart Tourism City Service Model

integrates three interconnected core layers: Core Technology, Service Application, and Governance and Collaboration, creating a cohesive and efficient system that addresses critical technological, operational, and governance elements. At its foundation, the Core Technology Layer serves as the backbone, incorporating drones, AI algorithms, IoT devices, and big data platforms to enable real-time data collection, processing, and actionable insights. These technologies support operational efficiency and enhance tourist services, such as real-time monitoring of tourist flows, panoramic sightseeing, and emergency responses. Building on this infrastructure, the Service Application Layer operationalises these capabilities to deliver diverse tourism services, including live crowd monitoring, immersive aerial tourism experiences, emergency response capabilities, and virtual or augmented reality tours, improving both visitor satisfaction and city-level management. The Governance and Collaboration Layer ensures the system operates within a robust regulatory framework, addressing safety, data sharing, and stakeholder coordination through safety regulations, data integration protocols, and public-private partnerships. These layers are interconnected through seamless communication and workflows, with data from the Core Technology Layer directly feeding into the Service Application Layer, while the Governance Layer ensures security and collaboration. This model provides a strategic, scalable framework for integrating low-altitude technology into Guangzhou's smart tourism ecosystem, offering policymakers, businesses, and researchers a guide to align technological advancements with practical applications and governance structures to enhance urban tourism sustainability and efficiency.

The integration of low-altitude technology into Guangzhou's smart tourism sector represents a promising frontier for innovation and growth. While the economic and social benefits are evident, addressing technical constraints, regulatory gaps, and public concerns will be crucial to unlocking its full potential. By aligning technological advancements with stakeholder interests and adopting a collaborative governance approach, Guangzhou can set a benchmark for other cities seeking to leverage drones for smarter, more sustainable urban tourism systems. This study contributes to the growing body of knowledge on the application of low-altitude technology in smart tourism cities and provides actionable insights for policymakers, industry leaders, and researchers aiming to drive the next wave of urban innovation.

Recent studies have emphasised the transformative potential of low-altitude technology in urban tourism management, particularly in optimising operational efficiency and enhancing visitor experiences. For example, Sevilla-Sevilla et al. (2024) highlighted how drones are increasingly being utilised for real-time crowd monitoring and emergency response, aligning with this study's findings on the critical role of low-altitude technology in improving tourism safety and resource management. However, while previous research primarily focuses on individual case studies, this study extends the discussion by providing a comprehensive evaluation framework that integrates technical feasibility, economic viability, and social impact. This multi-dimensional approach ensures that the deployment of drones is not only technologically feasible but also economically sustainable and socially acceptable. Furthermore, the research introduced in this article supports the conclusions of Madden et al. (2022), who argue that while drones contribute to tourism enhancement, their large-scale integration requires regulatory refinement and stronger public-private collaborations, both of which are identified as key priorities in Guangzhou's smart tourism strategy.

Moreover, the governance challenges associated with integrating drones into smart city frameworks have been widely discussed in recent literature. Studies such as Mohamed et al. (2023) emphasised the need for cross-sectoral coordination and robust data-sharing mechanisms to maximise the efficiency of drone-based tourism services. The findings of this study corroborate this perspective, as the policy gap analysis indicates that while Guangzhou has made strides in digitalising its tourism sector, significant deficiencies remain in regulatory frameworks, particularly regarding data integration and safety standards. By addressing these challenges through an improved governance model, as proposed in the Low-Altitude Technology-Based Smart Tourism Service Model (Fig. 9), Guangzhou can serve as a reference for other urban centres seeking to implement drone technology in tourism management. Furthermore, this study builds upon the work of Ayamga et al. (2021), who stressed that regulatory bottlenecks often hinder the scalability of drone applications. By proposing an integrated framework that aligns regulatory oversight with technological innovation, this study provides practical solutions for overcoming implementation barriers and ensuring the long-term sustainability of low-altitude tourism services.

Conclusions

This study proposed a comprehensive service model for integrating low-altitude technology into Guangzhou's smart tourism ecosystem, addressing the critical technological, operational, and governance elements needed for sustainable urban tourism development. The three-layered model, including the Core Technology Layer, the Service Application Layer, and the Governance and Collaboration Layer, illustrates how cutting-edge technologies, such as drones, AI, IoT devices, and big data platforms, can be systematically leveraged to enhance tourism services, improve operational efficiency, and ensure secure and collaborative management. By aligning technological advancements with practical applications and governance frameworks, the model provides a scalable and adaptable strategy for addressing the complexities of modern tourism cities.

The significance of this research lies in its interdisciplinary approach, combining low-altitude technology and smart tourism concepts to propose an innovative and actionable framework. From a theoretical perspective, it advances the understanding of how low-altitude technology can be integrated into urban tourism systems, enriching the academic discourse on smart tourism cities. Practically, the proposed service model offers policymakers, businesses, and researchers a structured guide for implementing low-altitude technology, enabling efficient resource management, improving visitor experiences, and fostering public-private collaboration. Furthermore, the model contributes to bridging the gap between technical feasibility and real-world applications by addressing the challenges of safety, regulatory oversight, and data sharing.

Despite its contributions, this study is not without limitations. First, the research primarily focuses on Guangzhou, which, while representative of rapidly urbanising cities, may limit the generalisability of the findings to other cities with differing tourism infrastructures, regulatory environments, or technological capabilities. Second, the proposed model remains theoretical, and its practical implementation has not yet been empirically tested, leaving room for uncertainty regarding its scalability and adaptability in real-world scenarios. Lastly, the analysis of external influencing factors, such as social acceptance of drones and cost-benefit trade-offs, requires further empirical validation to understand their broader implications in diverse urban contexts.

Future research should focus on addressing these limitations to enhance the applicability and robustness of the proposed service model. First, empirical studies should be conducted to validate the model through pilot projects in Guangzhou and other cities with varying urban and tourism characteristics. This would provide valuable insights into the model's scalability and adaptability across different contexts. Second, further exploration of advanced technologies, such as drone swarms, 5G-enabled communication, and blockchain for data security, could refine the technological foundation of the Core Technology Layer. Third, interdisciplinary studies should examine the social and economic impacts of integrating low-altitude technology into smart tourism, particularly regarding public acceptance, privacy concerns, and cost-effectiveness. Finally, future research should explore collaborative frameworks between cities, fostering knowledge sharing and best practices to accelerate the global adoption of low-altitude technology in smart tourism ecosystems.

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