

“Dual Carbon Goals + Digital Intelligence” Empowering the Intelligent Transformation of Post-National Games Sports Venues: Theoretical Framework, Practical Challenges, and Implementation Pathways

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Abstract. This study uses literature review, field surveys, and expert interviews to explore key issues and pathways in the intelligent operation of these venues. The research identifies four core challenges hindering sustainable utilization: technological integration difficulties, inefficient commercial operation models, policy coordination gaps, and multi-stakeholder benefit imbalances. In response, it constructs a theoretical framework for venue intelligent transformation—with "ternary theory" as guidance and "Dual Carbon Goals + Digital Intelligence" synergy to align with the "Five-sphere Integrated Plan". Four targeted implementation pathways are proposed: 1) enhancing technical empowerment to break data silos; 2) innovating business models to tap venue scenario value; 3) promoting cross-departmental policy coordination for institutional guarantees; 4) strengthening talent cultivation and organizational capacity to solidify transformation foundations. These pathways aim to provide theoretical guidance and practical references for intelligent transformation of similar post-mega-event venues.

Keywords: intelligent transformation; post-National Games; realistic dilemma; implementation path

1. Introduction

General Secretary Xi Jinping pointed out when inspecting the planning and construction of venues for the Beijing Winter Olympic Games that "the utilization of stadiums after the Games is a worldwide problem. Repeated utilization, comprehensive utilization and long-term utilization of stadiums are our experiences." Large stadiums are seriously idle after games, the utilization rate is not high, and resources are wasted[1], which has always been the key to restricting the sustainable development of stadiums after games, this phenomenon is called "global problem". In recent years, digital technology has developed rapidly, continuously promoting the intelligent transformation of stadiums, which provides a new direction for solving the problem of sustainable use of stadiums after the competition. In addition, China advocates green and low-carbon development and proposes a "dual carbon goals" strategy of "striving to achieve carbon peak by 2030 and carbon neutrality by 2060". Therefore, the intelligent transformation of stadiums is not only the key to promoting high-quality urban development, but also the requirement of responding to national policies[2].

How to leverage digital and intelligent technologies to empower the sustainable development of sports venues following the 15th National Games of the People's Republic of China is a practical challenge every host city must confront. However, at present, there are some problems in the intelligent transformation of stadiums in China, such as low intelligence degree, poor user experience, imperfect system mechanism and isolated data island, which restrict the efficient operation of stadiums[3,4]. Therefore, this study constructs a "The Five-sphere Integrated Plan" theoretical model for empowering the intelligent transformation of sports venues through "dual carbon goals+ digital intelligence" grounded in sustainability theory, urban renewal theory, and public space revitalization theory. It proposes a intelligent transformation pathway for post-National Games sports venues, providing theoretical support and practical reference for the sustainable post-event operation of future large-scale sports facilities.

2. Theoretical Construction of Intelligent Transformation of Sports Venues After The National Games

2.1 Foundation of "Ternary Theory"

The intelligent transformation of stadiums is not only a technical application problem, but also a topic of urban space utilization and sustainable development. Sustainable development theory, which focuses on economic growth and environmental conservation, provides crucial developmental guidance for the intelligent transformation of sports venues. In the post-National Games period, host cities must establish localised and distinctive venue operation models based on the geographical conditions and regional characteristics of the sports facilities[5]. Urban renewal theory focuses on urban space regeneration and function optimization, and revitalizes old facilities and venues through rational planning and management. As an integral part of urban public spaces, the intelligent transformation of sports venues should serve local residents, becoming a vehicle for enhancing their sense of well-being. The theory of public space activation refers to improving the vitality of public space through innovative methods and making it a carrier of urban development. In the process of intelligent transformation, stadiums can introduce intelligent management systems, innovate service management models, and enrich immersive scene experiences[6,7], realize the activation of sports space and enhance its social and economic value. These theories collectively lay a solid theoretical foundation for the intelligent transformation of post-National Games sports venues.

2.2 Driven Dual-Track Approach Driven by "Dual Carbon Goals" and "Digital Intelligence"

"Green and low carbon" is the goal constraint and value orientation of sustainable development of sports venues. Green and low carbon concept should run through the whole life cycle of intelligent transformation of sports venues. As a large public building, sports venues consume a lot of energy and emit a lot of carbon in the process of construction and operation. Technology application and low carbon standards should be used to lead the realization of energy saving and carbon reduction goals of sports venues. The functional design and operation mode of stadiums integrate green and low-carbon concepts, so that they can better meet market demand and improve operational efficiency after the games. Therefore, "green and low-carbon" is one of the goals of intelligent transformation of stadiums and is also the value orientation of intelligent transformation of stadiums.

"Digital intelligence" is the core driving force and technical support for the innovation and development of stadiums. As an important driving force for the intelligent transformation of stadiums, digital intelligence technology is widely used in stadium management, service optimization, consumption experience enhancement, etc. Big data, artificial intelligence, Internet of Things and other technologies applied to stadiums can promote refined operation of stadiums, improve management efficiency and service quality, and enable them to better adapt to market changes and expand diversified operation models. "Digital intelligence" not only provides strong technical support in the intelligent transformation process of stadiums, but also injects new impetus into the innovation and development of stadiums.

"Green and low carbon" and "digital intelligence" are interrelated and complementary, jointly promoting the intelligent transformation of sports venues after the National Games.

2.3 Construction of "The Five-sphere Integrated Plan" Model for Intelligent Transformation of Sports Venues

2.3.1 Intelligent Management: Data-driven Decisions and Operations

Intelligent management is the core of intelligent transformation of stadiums, mainly built by the integration of artificial intelligence technology and Internet of Things technology[8]. Its essence is to comprehensively collect people flow, environment, facilities and operation data, transform data

into insight, and drive intelligent decision-making and refined operation. The operation management of sports venues after the National Games needs to shift from traditional empirical management to data-driven precision management to improve operational efficiency, reduce costs and improve service quality. The key to intelligent management lies in building a perfect digital management system, collecting various types of data including venue internal data, business data and external environment data, extracting, processing and applying the data, realizing real-time monitoring, data analysis and intelligent decision-making of venue operation status. Data-driven intelligent management will ultimately solve the core problems of inefficiency, poor experience and security risks under the traditional management model, and realize the intelligent management transformation from passive response to active optimization.

2.3.2 Intelligent Experience: Personalized and Immersive Services for Users

Intelligent experience is a direct manifestation of the intelligent transformation of stadiums, emphasizing user-centered services. Intelligent experience is mainly based on advanced digital technologies such as artificial intelligence, virtual reality and augmented reality. Its goal is to enhance the user experience through digital means, making its activities in the stadium more convenient, comfortable and interactive. Sports stadiums enabled by digital technology can collect consumer data in advance, predict consumer consumption habits and preferences, and transform post-service into pre-service[9]. Consumers can further stimulate consumer motivation by participating in the process of innovation, design and production of services and products to achieve value creation with venues. Based on technology breakthrough physical limitations, it can amplify the fun of watching games and sports, and create immersive experiences of deep participation and interaction.

2.3.3 Intelligent Commerce: Intelligent Integration of Diversified Business Models Through "Sports+"

Intelligent commerce is an important extension of the intelligent transformation of stadiums. Through intelligent technology, stadiums will be built into a digital platform connecting multiple consumption and life scenarios, thus building a symbiotic ecology with sports as the core and radiating multiple industries. The core of intelligent business is to expand the functional boundaries of venues through the "sports +" mode and realize the deep integration of sports industry and other industries[10]. The realization of intelligent formats relies on the support of big data analysis, artificial intelligence, block chain and other digital technologies. Through the "sports +AI" approach, venues can build intelligent operation models to achieve precise marketing and efficient operation. Intelligent commerce is to open up sports and surrounding formats with data flow, realize flow mutual guidance and consumption closed loop, and make stadiums become intelligent sports complex space integrating sports, entertainment, education and commerce.

2.3.4 Intelligent Low Carbon: Synergy between Green Technology and Clean Energy

Intelligent low-carbon is the foundation for the intelligent transformation of stadiums. After the National Games, intelligent low-carbon development of stadiums needs to pay more attention to energy conservation and emission reduction, reduce carbon emissions by adopting new technologies and new energy sources, and improve resource utilization. Adhere to the new development concept and integrate the green and low-carbon concept into the whole process of construction, transformation and operation management of stadiums for the National Games[11]. Through the application of a series of green technologies such as intelligent lighting system, the energy consumption of stadiums is minimized to achieve win-win economic and ecological benefits. Meanwhile, intelligent low-carbon stadiums also need to be integrated into intelligent energy management systems.

2.3.5 Intelligent Governance: Policy and Mechanism Innovation of Multi-subject Coordination

Intelligent governance is an important guarantee for the intelligent transformation of stadiums. Based on the digital platform and coordination mechanism, through the collaborative cooperation of

government, market and social multiple subjects, a modern co-governance pattern of intelligent decision-making, data sharing, responsibility sharing and benefit sharing can be realized to ensure the smooth progress of intelligent transformation[12]. In the post-National Games period, the operation mode of sports venues needs to pay more attention to policy support and system innovation, so as to cope with various challenges that may arise in the process of intelligent transformation. Finally, the relationship between various subjects should be straightened out to maximize value. In addition, intelligent governance also includes the establishment of a data sharing mechanism. By building a unified data platform, we can realize the interconnection of venue operation data and improve management efficiency and scientific decision-making.

Table 1 Dual-Drive Intelligent Transformation of Sports Venues into “Five-sphere Integrated Plan” Post-Competition

Foundation of "ternary theory"	Driven Dual-track approach driven by “Dual Carbon Goals” and “Digital Intelligence”	The “Five-sphere Integrated Plan” Intelligent Transformation of Sports Venues	Core Content
The theory of sustainable development Urban renewal theory The theory of public space activation	Driven by green and low-carbon initiatives Driven by Digital Intelligence	Intelligent Management	Data Acquisition and Integration, Data Analysis and Insights, Intelligent Operations and Automated Execution, Safety and Risk Prevention and Control, etc.
		Intelligent Experience	Intelligent recommendations and personalization, streamlined user experience, customized personal environments, immersive viewing, interactive sports participation, and more.
		Intelligent Commerce	“Sports + Commerce”, “Sports + Cultural Tourism”, “Sports + Wellness”, “Sports + Education”, etc.
		Intelligent Low Carbon	Energy-saving control, energy efficiency diagnostics and optimisation, resource recycling, precise monitoring and management of carbon emissions, etc.
		Intelligent Governance	Data openness and sharing, innovative procurement and performance evaluation, collaborative command mechanisms, feedback and oversight mechanisms, etc.

3. The Realistic Dilemma of Intelligent Transformation of Sports Venues After The National Games

3.1 Technology Convergence Dilemma

In the process of intelligent transformation of stadiums, “data island” phenomenon is a common problem. Due to the lack of unified data standards and interface specifications among different systems, platforms and suppliers, it is difficult to realize interconnection of data within venues, forming information barriers. “Data islands” also limit accurate analysis of user behavior in venues, making it difficult to realize personalized services and intelligent decision-making. Secondly, the intelligent transformation of sports venues still relies heavily on external technology suppliers and lacks the independent innovation capabilities of core technologies[13]. Many venues have become technologically reliant on external providers in areas such as smart management systems, data analysis platforms, and intelligent security systems, hindering their ability to achieve genuine

independent innovation. Moreover, due to the rapid pace of technological advancement, if a supplier ceases technical support, the venue's smart systems may experience limited functionality or operational failures, posing significant risks to their daily operations.

3.2 Business Operation Dilemma

Traditional stadiums and gymnasiums are inefficient, costly and low-profit operation models, which are difficult to meet the multiple demands of modern consumers for efficient, convenient, personalized and immersive experiences. Many existing stadiums and gymnasiums are still in the traditional mode, relying too much on event revenue and venue leasing, lacking intelligent scenario exploration and business model innovation. The application of intelligent scenarios in stadiums and gymnasiums is still in its infancy, and no intelligent service system has been formed. The relative shortage of compound talents with digital skills and operation management ability is also an important reason for the slow transformation of stadiums. The digital literacy of stadium managers and operation teams is insufficient, and it is difficult to effectively use intelligent tools to improve operation efficiency. In addition, current consumers have low awareness of intelligent products and have not formed consumption habits. It takes a long time to cultivate the intelligent service market and develop user consumption habits.

3.3 Policy Synergy Dilemma

The intelligent transformation of stadiums needs to rely on a multifunctional mixed development model to enhance their operational efficiency and market competitiveness. However, the current land policy and urban planning system limit the multifunctional development of stadiums to a certain extent. The urban planning department is cautious about the use change of stadiums during the approval process, which makes it difficult for stadiums to flexibly adjust their functional layout during the post-competition stage. The fiscal and taxation support policies for the intelligent transformation of stadiums are also scattered, lacking long-term and systematic incentives. The intelligent transformation of stadiums also involves the balance between public welfare and marketization, but in practice, the boundary between the two is often not clear enough, resulting in deviation in the process of policy implementation.

3.4 Benefit Balance Dilemma

The balance between social equity and technical efficiency, the balance between short-term investment and long-term return, and the balance between strategic foresight and strategic implementation are the root causes of the dilemma of balancing the benefits of intelligent venues. First, the dilemma of balancing the social efficiency of intelligent venues excludes the elderly and the poor who are not good at operating intelligent technologies in the pursuit of high efficiency and deep experience, resulting in a "digital gap". Second, the essence of the economic benefit balance dilemma of venue intelligence is a game between high short-term investment and uncertain long-term return. Venue intelligence requires huge investment in hardware, etc., and such investment returns are long, uncertain and difficult to control. Third, the strategic positioning dilemma of venue intelligence is reflected in the profound contradiction between long-term vision and short-term performance, technical foresight and pragmatism. Intelligent transformation is a strategic slow investment with a long return cycle, but it is often squeezed by the "fast indicators" of annual financial reports and term achievements.

4. Implementation Path Of Intelligent Transformation Of Post-National Games Stadiums

4.1 Strengthen Technical Empowerment And Build An Integrated Intelligent Base

4.1.1 Build an intelligent infrastructure system of "cloud-edge-terminal" collaboration

Build a "cloud-edge-terminal" collaborative venue intelligent infrastructure system to realize intelligent operation and accurate management of stadiums. Cloud computing is the storage, calculation and analysis of big data, which uses artificial intelligence and big data to realize real-time detection and prediction analysis of venue operation status. Edge computing reduces the time difference and speed difference caused by transmission, and realizes intelligent security, energy consumption management and real-time decision-making with high real-time requirements. Terminal devices are intelligent sensors, Internet of Things, and user devices, which are used to collect and provide user consumption needs. Under the "cloud-edge-terminal" collaborative system, stadiums can achieve effective data transmission and intelligent decision-making, achieving high quality and efficient operation.

4.1.2 Building venue digital twins to realize full life cycle management

As an important guarantee for realizing the intelligent transformation and upgrading of stadiums, digital twin technology can realize the fine management of the whole process of stadium construction and operation. The digital twin of the stadium real-time perceives the operation status, equipment working conditions, environmental data, etc. of the stadium, synchronizes the physical structure, equipment operation, user activities and other information of the stadium to the digital twin of the stadium through the Internet of Things terminal and data acquisition system, and provides visual data perception and intelligent data analysis for the stadium manager. Venue digital twins can also provide predictive maintenance, machine learning on equipment operation information, and realize functions such as equipment failure prediction in advance, reducing potential failures and reducing maintenance costs.

4.1.3 Promoting data interoperability among venues in the Greater Bay Area, Building and sharing a smart platform

The Guangdong-Hong Kong-Macao Greater Bay Area has a large number of large-scale sports venues. Its intelligent transformation is not only a problem of individual venue operation, but also a coordinated development strategy of service areas. Promoting data interconnection and sharing of venues in the Greater Bay Area and building a shared intelligent platform are the core contents of sports resource sharing and intelligent management in the Greater Bay Area of Guangdong, Hong Kong and Macao. The interconnection of venue data not only promotes the improvement of venue operation capacity, but also forms resource sharing and innovation within the region, promoting the high-quality development of regional sports.

4.2 Highlight The Innovation Of Business Form And Cultivate The New Ecology Of "Sports +" Wisdom

4.2.1 Implement "one hall, one policy" after venue competition

The strategy of "one stadium, one policy" after the Games is promoted, and differentiated development and precise positioning of stadiums are the starting points for the intelligent transformation of stadiums. Make full use of big data, artificial intelligence and other technologies, grasp user needs, market demands and dynamics, implement precise operation, and adopt different operation modes for different stadiums. Large-scale and comprehensive stadiums develop sports, culture, commerce, leisure, entertainment and other industrial formats to create diversified sports complexes; Small and medium-sized stadiums are deeply involved in a sports event and provide precise services. Based on insight data, intelligent stadiums can optimize resources such as

personnel and venues, improve operation capabilities, and achieve more flexible stadium operation modes.

4.2.2 Vigorously develop new digital formats of venues

With the wide application of digital technology, intelligent e-sports, virtual sports, immersive cultural tourism and other new formats will become the new trend of intelligent construction of sports venues. Intelligent e-sports is supported by 5G, cloud computing, artificial intelligence and other technologies, providing content services such as HD live broadcast, interactive game experience, personalized event experience, etc., making sports venues the wind outlet of e-sports events. Virtual sports use virtual reality, augmented reality and other technologies as means to bring immersive sports experience to users and expand the experience space of stadiums [14]. With sports, culture and tourism as the core elements, immersive cultural tourism creates an immersive experience space integrating sports, entertainment, education and culture to enhance the cultural connotation and market appeal of stadiums.

4.2.3 Provide personalized and precise intelligent service products

In the process of intelligent transformation of stadiums, building digital portraits of users and providing personalized and accurate intelligent products have become an important way for stadiums to improve user experience. Through big data analysis and artificial intelligence technology, stadiums collect and analyze user behavior, preferences, habits, consumption and other information, and establish accurate user portraits to customize personalized sports fitness plans and event viewing experiences for users [15]. The intelligent construction of venues can also provide accurate demand push based on digital portraits, and provide different promotion programs according to user consumption behavior to enhance user loyalty and stickiness. The establishment of user portraits in stadiums can better create high-quality products and services for users and add new vitality to the intelligent transformation of stadiums.

4.3 Promote Policy Coordination And Optimize System Design And Governance Mechanism

4.3.1 Innovative land policy, pilot "sports +" mixed land use model

Land policy innovation is an important guarantee for the multi-functional mixed development of sports venues in the intelligent transformation. Traditional land use division limits the mixed development of sports venues and makes it difficult to adapt to the needs of intelligent transformation of sports venues. Innovate the top-level design of land policy, explore a new mixed land use model of "sports +", and allow sports venues to develop commercial, cultural and tourism functions after the National Games. Explore the combination of sports venues and commercial complexes, cultural stations, tourist spots, etc. to realize a spatial complex integrating sports, leisure and entertainment. Innovate land policy design, attract social funds into intelligent construction of sports venues, promote flexible operation of sports venues after the National Games, and support the intelligent transformation of sports venues.

4.3.2 Set up special funds to increase subsidies and tax incentives for green and intelligent transformation

Set up special funds, formulate green intelligent transformation subsidies and preferential tax policies, reduce venue operating costs, enhance development momentum, improve the intelligent development level of stadiums. Special funds can be used as subsidies for the construction of intelligent hardware facilities and the upgrading of intelligent management systems; preferential tax policies can reduce venue operating costs and encourage investment in intelligent venue construction. Through tax reduction or exemption for sports venues using green technology, intelligent management and energy-saving equipment, or subsidies for intelligent projects, we will support the intelligent construction and development of sports venues. Based on the support of special funds and preferential tax policies, sports venues will receive more policy support, and provide financial guarantee for intelligent development.

4.3.3 Establish comprehensive performance appraisal and dynamic subsidy mechanism

In the intelligent transformation of stadiums, the establishment of performance appraisal and dynamic subsidy mechanism based on comprehensive benefits is conducive to the intelligent transformation and sustainable development of stadiums. The establishment of scientific performance appraisal mechanism, economic, social and environmental benefits into the scope of performance appraisal, comprehensive assessment of the performance of intelligent transformation of stadiums. At the same time, dynamic subsidy mechanism can adjust subsidy policies according to the actual operation of stadiums to ensure the fairness and effectiveness of fund use. Performance appraisal and dynamic subsidy mechanism based on comprehensive benefits can enable stadiums to obtain more reasonable policy support and achieve balanced and sustainable development in the intelligent transformation of stadiums.

4.4 Speeding up Talent and Organization Guarantee

4.4.1 Introducing and Cultivating Compound Management Talents

The intelligent transformation of stadiums cannot be separated from compound management talents with sports feelings and digital technology, providing personnel support and guarantee for promoting the application and operation management of intelligent technology. Strengthen the introduction and training of talents, encourage universities and vocational colleges to open relevant majors or courses, and cultivate professionals with sports management, information technology, data analysis and other compound abilities. Sports venues are encouraged to cooperate with universities and scientific research institutes to establish talent training bases, provide systematic training and practical training for employees, improve the digital skills literacy of sports management talents and the intelligent operation ability of sports venues. Improve the talent compensation incentive mechanism, attract talents to participate in the intelligent construction of sports venues, and make a good talent reserve for the intelligent transformation and upgrading of sports venues.

4.4.2 Promote "separation of management and execution" and introduce professional venue operation organizations

Promoting "separation of management and office" is an important means to improve the operational efficiency and competitiveness of stadiums. Promoting "separation of management and execution" and actively introducing professional market operation companies to undertake the management and intelligent operation of stadiums. Market operation companies flexibly allocate and optimize resources based on market operation to improve the operational efficiency of stadiums. Through advanced venue management concepts and technological innovation, the level of venue intelligent construction will be promoted; through rich experience in sports event operation, the level of event organization and management will be improved; intelligent management system suppliers will be introduced to optimize the intelligent management mode of venues. "Separation of management and execution" can promote the development of venue intelligent construction in a more flexible direction.

4.4.3 Establish a "political-industrial-learning-research" collaborative innovation platform to provide intellectual support

The government plays a policy guiding role, formulates relevant planning and supporting policies for intelligent transformation, and provides institutional guarantee for venues. Enterprises play a leading role in the market to promote the application of intelligent technology and innovation of business models. Universities and scientific research institutions play a leading role in scientific research to carry out intelligent technology research and talent cultivation. Industry associations and think tanks play a bridge role to promote information exchange and resource integration among all parties. Through the establishment of the "political-industrial-learning-research" collaborative innovation platform, stadiums can gather resources from various parties to form a multi-party joint

force to jointly promote the intelligent transformation and in-depth development of stadiums. In addition, the platform can also promote cooperation between stadiums and scientific and technological enterprises, financial institutions, etc., and realize the sustainable development of intelligent construction.

5. Conclusion

This paper systematically explores the theoretical foundations, practical challenges, and implementation pathways for the intelligent transformation of sports venues in the post-National Games era, against the backdrop of integrating the dual carbon goals with digital and intelligent technologies. Supported by theories of sustainable development, urban renewal, and public space revitalisation, the study constructs a "The Five-sphere Integrated Plan" intelligent transformation framework driven by the dual engines of "dual carbon goals" and "digital intelligence". This framework encompasses five dimensions: intelligent management, intelligent experience, intelligent business models, intelligent low-carbon operations, and intelligent governance, providing theoretical underpinnings and practical guidance for the sustainable post-event operation of sports venues.

Addressing current challenges in stadium intelligent transformation—including technical integration difficulties, weak business model operations, insufficient policy coordination, and profit-loss balancing dilemmas—this paper proposes systematic advancement through: enhanced technological empowerment, prioritised business innovation, strengthened policy synergy, and reinforced talent and organisational safeguards. Particularly against the backdrop of the Guangdong-Hong Kong-Macao Greater Bay Area hosting the 15th National Games, greater emphasis should be placed on regional coordination and resource sharing to drive the integrated development of digital, green and intelligent facilities.

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