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Research on the Integration and Innovation Path of Digital Cultural and Creative Industry Clusters in Guangdong, Hong Kong, and Macao Based on Grey Relational Analysis

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Abstract: The digital cultural and creative industry has become an important engine for high-quality economic development in the Guangdong-Hong Kong-Macao Greater Bay Area. This paper constructs an evaluation index system covering five dimensions: industrial scale, digital infrastructure, innovation capacity, market consumption, and open linkage. Using grey relational analysis, it quantitatively measures the core influencing factors of the digital cultural and creative industry clusters in the three regions from 2020 to 2024. The empirical results show that market consumption is the primary factor driving cluster integration, the correlation of open linkage factors exceeds expectations, and the correlation of workforce factors is the lowest, reflecting the substitution effect of digital technology on labor. Based on this, this paper proposes a path design for integration and innovation from four dimensions: technological empowerment, spatial synergy, institutional breakthrough, and market co-cultivation.

Keywords: Guangdong-Hong Kong-Macao Greater Bay Area; Digital cultural and creative industry; Industrial cluster integration; Grey relational analysis; Innovation path

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1. Introduction

The wave of the digital economy is profoundly reshaping the organizational form and value logic of the cultural and creative industry. In 2023, cultural and related industry enterprises above a designated size in Guangdong achieved operating revenue of RMB 2,248.3 billion, ranking first in the country for twenty consecutive years; the value-added of Hong Kong's cultural and creative industry was approximately HKD 134.5 billion; Macao's cultural industry service revenue increased by 12.7% year-on-year to MOP 9.73 billion. The superposition of the continuous expansion of the industries in the three regions and digital transformation has led to a clustered development trend in the digital cultural and creative industry in the Greater Bay Area. The suggestions for Guangdong's "14th Five-Year Plan" explicitly propose cultivating a digital creative industry cluster in the Guangdong-Hong Kong-Macao Greater Bay Area. The intensive release

of policy signals marks that the digital cultural and creative industry has entered the in-depth realm of national strategic deployment.

From an academic perspective, the theory of industrial clusters has undergone multiple iterations, from Porter's "Diamond Model" to Florida's Creative Class Theory [1]. Since its introduction by Professor Deng Julong, Grey System Theory has been widely applied in the field of industrial analysis [2]. Cao Jinyang (2019) once used grey relational analysis to study the influencing factors of cultural and creative industry clusters in the Greater Bay Area, but the data ended in 2016 and did not involve the digital dimension [3]. Currently, institutional differences and cross-border data barriers among the three regions still pose obstacles to cluster integration. How to quantitatively identify and rank the core driving factors for the integration of digital cultural and creative industry clusters is an urgent research question. This paper intends to conduct an empirical study using grey relational analysis based on data from 2020 to 2024.

2. Current situation of digital cultural and creative industry clusters and integrated development in Guangdong, Hong Kong, and Macao

2.1. Evolution of digital cultural and creative industries in Guangdong, Hong Kong, and Macao

The digital cultural and creative industries in Guangdong, Hong Kong, and Macao each have their own institutional contexts and market logics, but they are converging under the wave of digitalization. Guangdong relies on the cluster of internet enterprises in Shenzhen and the digital content production capacity in Guangzhou to form an industrial system centered on games, animation, digital music, and online audio-visual. Xia Jiechang et al. (2024) pointed out that digital industry clusters emerge from the integration practice of the digital economy and the real economy, and the interaction between the policy environment and leading enterprises constitutes the core mechanism of their innovation network [4]. In 2023, the operating revenue of Guangdong's digital creative industry cluster exceeded RMB 600 billion, with a growth rate of 16.1%, ranking first among the province's strategic industrial clusters.

Hong Kong's digital cultural and creative industry is built on the foundation of international finance and professional services. In 2024, it released the "Blueprint for the Development of the Cultural and Creative Industry," aiming to increase the value-added of the cultural and creative industry to HKD 200 billion by 2034. Macao, on the other hand, relies on the gaming and tourism industry to develop cultural IP, with performing arts economy, world heritage activation, and digital media as the main industries. Although the evolutionary paths of the three regions have their own focuses, the common logic of digital technology empowering cultural content production and consumption is driving the industry from independent development to collaborative clustering.

2.2. Scale and structural characteristics of digital cultural and creative industry clusters in the three regions

The digital cultural and creative industries in Guangdong, Hong Kong, and Macao exhibit significant gradient differences and complementary characteristics. In 2024, Guangdong had 12,198 legal entities in cultural and related industries above the designated size, with operating revenue of approximately RMB 2,497.2 billion. Shenzhen's game industry revenue accounted for more than 80% of the national total. The value-added of Hong Kong's eight major creative industries totaled approximately HKD 66.05 billion, with digital entertainment (HKD 17.18 billion) being the largest sector. Macao's cultural industry had 2,868 institutions, with the "digital media" sector accounting for 42.3% of service revenue. **Table 1** comprehensively presents the key scale indicators of the three regions.

Table 1. Key scale indicators of digital cultural and creative industries in Guangdong, Hong Kong, and Macao (2023/2024)

Indicator	Guangdong (2024)	Hong Kong (2023)	Macau (2024)
Number of Above-scale Cultural Enterprises/Institutions	12,198 enterprises	Approx. 42,000 enterprises	2,868 establishments
Number of Employees	1.3716 million persons	226,000 persons	14,900 persons
Revenue / Service Income	2,497.2 billion RMB	66.05 billion HKD (eight creative sectors)	9.73 billion MOP
Core Digital Content Proportion	Games account for > 80% of national total	Digital entertainment accounts for 26.0%	Digital media accounts for 42.3%

Data sources: Guangdong Provincial Bureau of Statistics, CCIDAHK, and the Statistics and Census Service of Macao. Note: There are differences in statistical criteria among the three regions, and the data in the table are provided solely for comparative reference.

2.3. Practical challenges facing the cross-regional integration of the digital cultural and creative industries in Guangdong, Hong Kong, and Macao

Despite the complementary resource endowments of the industries in the three regions, cross-regional integration remains constrained by multiple structural barriers. The three regions fall under different legal systems and regulatory frameworks, with substantial differences in intellectual property protection standards and rules governing cross-border data flows. Cai Chimeng (2017) pointed out that the construction of the Guangdong-Hong Kong-Macao Greater Bay Area urban agglomeration faces challenges in aligning rules under the "One Country, Two Systems" framework [5]. Inconsistencies in industrial statistical criteria pose another layer of obstacles, fundamentally limiting the comparability of data across the three regions. The deep-seated challenges facing the integration of the digital cultural and creative industries in Guangdong, Hong Kong, and Macao lie in the systemic mismatches between institutional rules, statistical standards, and market access.

3. Construction of an evaluation index system for industrial cluster integration and innovative development

3.1. Design logic and selection principles of the evaluation index system

The evaluation index system must address a preliminary question: what framework should be used to encompass the multidimensional characteristics of the integration of digital cultural and creative industry clusters across the three regions? The clustering logic of the digital cultural and creative industries has undergone substantial changes, with digital platforms alleviating some spatial constraints, data elements becoming a new force for agglomeration, and cross-border institutional arrangements becoming a key variable affecting cluster efficiency.

Based on this, the author designed the index system within a five-dimensional framework encompassing industrial scale, digital infrastructure, innovation capacity, market consumption, and open collaboration. The selection of indicators adheres to three criteria: data availability, cross-regional comparability, and dynamic sensitivity.

3.2. Construction of the evaluation index system framework

This paper constructs an evaluation framework consisting of five primary dimensions and eight specific indicators. For the industrial scale dimension, the added value of the digital cultural and creative industry (X1) and the number of employees (X2) are selected; for the digital infrastructure dimension, the internet penetration rate (X3) serves as a proxy variable;

for the innovation capacity dimension, the intensity of R&D expenditure (X4) and the number of patents granted (X5) are chosen; for the market consumption dimension, per capita cultural and recreational consumption expenditure (X6) is used as an indicator; and for the open collaboration dimension, the import and export volume of cultural services (X7) and the number of cross-border cooperation projects (X8) are included. **Table 2** presents the complete evaluation index system.

Table 2. Evaluation index system for the integration of digital cultural and creative industry clusters in Guangdong, Hong Kong, and Macao

First-level Dimension	Code	Specific Indicator	Data Source
Industry Scale Y1	X1	Added Value of Digital Cultural and Creative Industry (100 million yuan)	Statistical Bureaus of the Three Regions / Statistics and Census Service (Macao)
	X2	Number of Employees in Cultural Industry (10,000 persons)	Same as above
Digital Infrastructure Y2	X3	Internet Penetration Rate (%)	Ministry of Industry and Information Technology / Communications Authorities of Hong Kong and Macao
Innovation Capability Y3	X4	R&D Expenditure Intensity (% of GDP)	Statistical Yearbooks of the Three Regions
	X5	Number of Patents Granted Related to Cultural Industry (pieces)	China National Intellectual Property Administration / Patent Data of Hong Kong and Macao
Market Consumption Y4	X6	Per Capita Cultural and Entertainment Consumption Expenditure (yuan)	Statistical Bureaus of the Three Regions
Openness and Linkage Y5	X7	Import and Export Value of Cultural Services (100 million yuan)	Customs / Trade Development Council / Macao Economic Bureau
	X8	Number of Cross-border Cultural and Creative Cooperation Projects (items)	Bulletins of Culture and Tourism Departments of the Three Regions

Note: The currency units of each indicator have been converted into RMB based on the average annual exchange rate for unified processing.

3.3. Variable explanation, data sources, and standardization processing

The data in this paper covers the period from 2020 to 2024. Data for Guangdong is sourced from the Guangdong Provincial Bureau of Statistics, data for Hong Kong is sourced from the Hong Kong Census and Statistics Department and CCIDAHK, and data for Macao is sourced from the Statistics and Census Service. Currency units have been converted into RMB based on the average annual exchange rate. Due to differences in statistical standards across the three regions, this paper employs the initial value method for dimensionless processing, normalizing the base period values of each indicator to 1:

$$x_i'(k)=\frac{x_i(k)}{x_i(1)} \tag{1}$$

where x_i' (1) represents the base period value for each series in 2020. The initial value method preserves the relative trends of change within each series and avoids interference from differences in absolute magnitudes [2].

4. Empirical analysis based on the grey quantitative model

4.1. Setting and calculation mechanism of the Grey Relational Analysis (GRA) quantitative model

Grey Relational Analysis (GRA) was proposed by Professor Deng Julong in the early 1980s (Deng, 1989) [6]. It evaluates the closeness of relationships between factors by comparing the geometric similarity of system behavior sequences. Due to

its low computational requirements and minimal data demands, GRA has been widely applied in fields such as economic management [2]. This paper selects the classic Deng's grey relational degree model, with the calculation mechanism outlined as follows:

(1) Determine the reference sequence and comparison sequences. Let the reference sequence (system characteristic sequence) be:

$$x_0=\{x_0(1),x_0(2),\ldots,x_0(n)\} \tag{2}$$

The comparison sequences (influencing factor sequences) are:

$$x_i=x_i(1),x_i(2),\ldots,x_i(n)\ \ i=1,2,\ldots,m \tag{3}$$

In this paper, the added value of the digital cultural and creative industry (X_1) is used as the reference sequence , while the remaining seven indicators (X_2—X_8) serve as the comparison sequences.

(2) Dimensionless processing. Standardize all sequences using the initial value method:

$$x_i'(k)=\frac{x_i(k)}{x_i(1)},\ k=1,2,\ldots,n;i=0,1,\ldots,m \tag{4}$$

(3) Calculate the difference sequence and the maximum and minimum differences. The difference sequence is $\Delta_i(k)=|x_0'(k)-x_i'(k)|$. The maximum difference $M=\max\max\Delta_i(k)$, and the minimum difference $m=\min\min\Delta_i(k)$.

(4) Calculate the grey relational coefficient:

$$\xi_i(k)=\frac{m+\rho M}{\Delta_i(k)+\rho M} \tag{5}$$

where ρ is the resolution coefficient, with a value range of (0, 1), and it is customary in academia to set $\rho=0.5$.

(5) Calculate the grey relational degree:

$$\gamma_{0i}=\frac{1}{n}\sum\xi_i(k),\ k=1,2,\ldots,n \tag{6}$$

The larger the value of the relational degree γ_{0i}, the higher the degree of correlation between the comparison sequence x_i and the reference sequence x_0, indicating that the factor has a more significant impact on the added value of the digital cultural and creative industry.

4.2. Absolute and relative evaluation of the development level of the digital cultural and creative industry cluster in Guangdong, Hong Kong, and Macao

Table 3 presents the raw data for the core indicators of the digital cultural and creative industry in the three regions from 2020 to 2024 (currency units have been converted to RMB 100 million).

Table 3. Core indicator data for the digital cultural and creative industry in Guangdong, Hong Kong, and Macao (2020–2024)

Indicator / Year	2020	2021	2022	2023	2024
X1 Value Added (Guangdong, 100 million yuan)	5212	5983	6070	6504	7180
X2 Employed Persons (10,000 persons)	183.5	189.7	177.0	172.4	174.8
X3 Internet Penetration Rate (%)	77.4	80.2	83.0	85.7	87.5
X4 R&D Intensity (%)	3.14	3.22	3.26	3.40	3.54
X5 Patents Granted (1,000 pieces)	58.3	67.1	72.4	81.6	89.2
X6 Per Capita Cultural & Entertainment Consumption (yuan)	2430	2756	2580	2890	3235

Indicator / Year	2020	2021	2022	2023	2024
X7 Cultural Services Imports and Exports (100 million yuan)	342	418	397	465	538
X8 Cross-border Cooperation Projects (items)	126	148	135	167	192

Data sources: Guangdong Provincial Bureau of Statistics, Hong Kong Census and Statistics Department, Statistics and Census Service of Macao, etc. Note: X1 represents the added value of the digital and creative industries based on Guangdong's calculation method; X2-X8 are the aggregated or weighted average values of the three regions; some data for 2024 are preliminary figures.

4.3. Measurement and ranking of grey relational degrees among core influencing factors of cluster integration and innovation-driven development

Following the approach outlined in Section 3.1, with X1 (the added value of the digital and cultural creative industries) as the reference sequence x0, and X2-X8 as the comparison sequences x1-x7, an initial-value dimensionless treatment is conducted to obtain standardized sequences (**Table 4**).

Table 4. Results of Initial-Value Dimensionless Treatment

Sequence/Year	2020	2021	2022	2023	2024
x0' (X1)	1.0000	1.1479	1.1646	1.2479	1.3776
x1' (X2)	1.0000	1.0338	0.9646	0.9395	0.9526
x2' (X3)	1.0000	1.0362	1.0724	1.1073	1.1305
x3' (X4)	1.0000	1.0255	1.0382	1.0828	1.1274
x4' (X5)	1.0000	1.1509	1.2419	1.3996	1.5300
x5' (X6)	1.0000	1.1342	1.0617	1.1893	1.3313
x6' (X7)	1.0000	1.2222	1.1608	1.3596	1.5731
x7' (X8)	1.0000	1.1746	1.0714	1.3254	1.5238

Note: $x_i'(k)=\frac{x_i(k)}{x_i(1)}(1)$, with the base period set as 2020.

After calculating the difference sequence and the range between the maximum and minimum differences, the maximum difference M is found to be 0.4250, and the minimum difference m is 0.0000. Taking the resolution coefficient ρ as 0.5, the grey relational coefficients for each year are calculated (**Table 5**).

Table 5. Grey relational coefficients of various factors

Correlation Coefficient / Year	2020	2021	2022	2023	2024
ξ1 (X1)	1.0000	0.6506	0.5155	0.4081	0.3333
ξ2 (X2)	1.0000	0.6556	0.6975	0.6018	0.4625
ξ3 (X3)	1.0000	0.6349	0.6270	0.5628	0.4593
ξ4 (X4)	1.0000	1.0000	0.7339	0.5836	0.5825
ξ5 (X5)	1.0000	0.9399	0.6735	0.7843	0.8202
ξ6 (X6)	1.0000	0.7407	1.0000	0.6556	0.5213
ξ7 (X7)	1.0000	0.8885	0.6946	0.7339	0.5930

Based on the grey relational grade formula $\gamma_{0i}=\frac{1}{5}\sum\xi_i(k)$, the grey relational grades of various factors and their ranking

results are calculated (**Table 6**).

Table 6. Grey Relational Grades and ranking of various factors

Influencing Factor	Grey Relational Degree γ0i	Rank
X6 Per capita cultural and entertainment consumption expenditure	0.8436	1
X7 Import and export volume of cultural services	0.7835	2
X8 Number of cross-border cultural and creative cooperation projects	0.7820	3
X5 Number of patents granted related to cultural industry	0.7800	4
X3 Internet penetration rate	0.6835	5
X4 R&D expenditure intensity	0.6568	6
X2 Number of employees in cultural industry	0.5815	7

Note: The degrees of correlation are ranked in descending order. The resolution coefficient ρ = 0.5.

4.4. In-depth analysis of empirical results and comparative evaluation of the three regions

The gray relational degree ranking reveals that market consumption factors (X6, γ = 0.8436) hold a significant lead, ranking first, which aligns with the logic of demand-side driving industrial upgrading. The Guangdong-Hong Kong-Macao Greater Bay Area, with a permanent population of approximately 86 million, saw a 12% year-on-year increase in per capita cultural and entertainment consumption expenditure in 2024, providing ample demand-side momentum for the digital cultural and creative industries. The number of cross-border cooperation projects (X8, γ = 0.7820) and the import and export volume of cultural services (X7, γ = 0.7835) rank second and third, respectively, indicating that open collaboration has become a key force driving cluster integration. The number of patent grants (X5, γ = 0.7800) ranks fourth, with a stable annual correlation coefficient, suggesting sustained support from innovative outputs. The correlation degrees of internet penetration rate and R&D intensity are at intermediate levels, reflecting a gradual flattening of the pulling effect of marginal improvements. The number of employees (X2, γ = 0.5815) ranks last and shows a decreasing trend, reflecting the substitution effect of digital technologies on labor. Compared with Cao Jinyang's (2019) analysis using data from 2014 to 2016 [3], consumption indicators remain at the forefront, while fiscal indicators have been replaced by open collaboration indicators, reflecting a structural shift in the driving model from government fiscal-led to market-oriented and internationalization-oriented.

5. Path design for integration and innovation of the Guangdong-Hong Kong-Macao Digital Cultural and Creative Industry Cluster

5.1. Technological empowerment: Driving the integration and reconstruction of the upstream and downstream of the cultural and creative industry chain with digital elements

There is still room for improvement in the correlation degree of innovation capacity, indicating that the dividends of technological empowerment are far from being fully realized. Currently, the industrial chains in the three regions exhibit a "segmented" characteristic. Guangdong holds advantages in content production and terminal manufacturing, Hong Kong possesses international design capabilities, and Macao has accumulated unique experience in performing arts IP development. However, technological collaboration among the three remains at a loose cooperation level. The core path lies in constructing a digital collaborative infrastructure that spans upstream and downstream, covering functional modules such as AIGC content generation, digital IP copyright confirmation, and cross-border digital content distribution, enabling full-chain collaboration among cultural and creative enterprises in the three regions on the same technological foundation.

5.2. Spatial collaboration: Building a functionally complementary digital cultural and creative collaboration circle among the three regions

The correlation degree of the internet penetration rate is at an intermediate level, indicating that digital infrastructure connectivity no longer poses a bottleneck, but there is still room for optimizing collaborative mechanisms at the functional division level. Spatial collaboration can follow a circular structure consisting of a core layer (Shenzhen and Guangzhou undertaking technological R&D and content production), an intermediate layer (Hong Kong undertaking international brand operation and intellectual property transactions), and an outer layer (Macao and other cities in the Pearl River Delta undertaking cultural and tourism scenario transformation). Standardization of data element circulation should be accelerated to enable secure sharing of creative data and copyright asset data among cultural and creative enterprises in the three regions within a compliant framework.

5.3. Institutional breakthrough: Promoting rule alignment and the free flow of innovative elements across borders

The open collaboration indicators ranking among the top three inversely confirms the constraining effect of institutional barriers — given the high marginal returns of cross-border cooperation, if barriers are further reduced, contributions will significantly increase. The key to institutional breakthrough lies in prioritizing standard coordination, promoting the alignment of statistical standards for the digital cultural and creative industries in Guangdong, Hong Kong, and Macao, and formulating statistical standards applicable to the Greater Bay Area with reference to the UNESCO Framework for Cultural Statistics. Meanwhile, fully leverage the four platforms of Hengqin, Qianhai, Nansha, and Hetao to take the lead in trialing institutional arrangements such as mutual recognition of intellectual property rights and interchangeability of content review filings, and solidify pilot results into normalized institutions.

5.4. Market co-cultivation: Building a global Guangdong-Hong Kong-Macao digital cultural and creative brand ecosystem community

The top ranking of market consumption reveals the foundational role of demand in industrial development. Digital cultural and creative products exhibit non-rivalrous consumption characteristics, with marginal replication costs approaching zero, and market expansion can bring about geometric growth in revenue. The construction of a brand ecosystem community should advance from the content layer (collaborative IP development around shared resources such as Lingnan culture to form a “Guangdong-Hong Kong-Macao Digital Culture IP Matrix”), the channel layer (building a global distribution platform relying on Hong Kong’s international communication network and Guangdong’s digital trade infrastructure), and the ecosystem layer (establishing a Guangdong-Hong Kong-Macao Digital Cultural and Creative Industry Investment Fund), jointly building brands for the global market.

6. Conclusion and outlook

This paper constructs an evaluation index system covering five dimensions and employs gray relational analysis to quantitatively measure the core influencing factors from 2020 to 2024. The results indicate that market consumption factors are the primary force driving the growth of industrial added value, open collaboration factors have surged to the forefront in terms of correlation degree, innovation capacity maintains stable support, digital infrastructure exhibits a threshold effect of marginal decline, and the correlation degree of employees is the lowest and shows a decreasing trend. Compared with previous studies, this paper reveals a structural shift in the driving model from fiscal input-led to market-oriented and internationalization-oriented. Based on this, path designs in four dimensions, technological empowerment, spatial collaboration, institutional breakthrough, and market co-cultivation, are proposed.

This paper is limited by differences in statistical standards among the three regions, resulting in insufficient cross-domain comparability of some indicators; the linear assumption of gray relational analysis may not fully capture nonlinear

interaction effects. Future research can employ a combined weighting method to more precisely determine dimensional weights and track the improvement process of statistical systems in the three regions to conduct more accurate empirical tests.

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