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ESG, OPEN INNOVATION, AND FIRM PERFORMANCE IN CONSTRUCTION FIRMS: EXPLORING THE MEDIATING ROLE OF DIGITAL TRANSFORMATION

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Abstract. The construction industry faces growing pressure to reconcile financial performance with Environmental, Social, and Governance (ESG) commitments and open innovation strategies. Although ESG and open innovation are recognized as drivers of long-term corporate value, their impact mechanisms on firm performance, particularly the mediating role of digital transformation and the moderating role of financing constraints, remain insufficiently understood. This study addresses this gap by empirically analyzing Chinese listed construction firms from 2013 to 2021. Using multiple regression, bootstrap mediation, and moderation analysis, we examine how ESG performance and open innovation affect firm performance, and how digital transformation and financing constraints shape these relationships. The results reveal that both ESG performance and open innovation negatively affect firm performance in the short term, while open innovation improves ESG performance. Digital transformation partially mediates the relationships between ESG performance, open innovation, and firm performance. Financing constraints strengthen the positive effect of ESG on digital transformation and weaken the negative effect of open innovation on firm performance. Notably, all these relationships are significant only in state-owned enterprises, not in non-state-owned enterprises. These findings illuminate the complex interplay among ESG, open innovation, digital transformation, and financing constraints, providing actionable implications for construction enterprise.

Keywords: ESG, open innovation, digital transformation, financing constraints, firm performance.

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1. Introduction

The construction industry serves as a fundamental pillar of the global economy. However, against the backdrop of accelerated globalization, technological advancement, resource depletion, environmental pollution and labor shortages, it is confronted with unprecedented challenges and opportunities. In 2006, the United Nations Principles for Responsible Investment officially incorporated environmental, social and governance (ESG) factors into investment practices, which further established ESG as a key driver of sustainable growth and stakeholder value (Chen et al., 2023; Gong et al., 2024). Research on sustainable development reporting has experienced rapid growth since 2015, and future research should focus on the impacts of digital transformation and practices in emerging markets

(Benameur et al., 2024, 2025). To achieve sustainable development, enterprises must strike a balance between traditional economic objectives and environmental protection, social responsibility as well as governance transparency (Li et al., 2025; Zhang, 2025). Meanwhile, open innovation has become an important model for integrating internal and external knowledge (Hodson, 2016), and digital transformation has been proven to significantly improve operational efficiency (Chen et al., 2024a; Hassanein & Tharwat, 2024; Zareie et al., 2024). Both are closely associated with the long-term sustainable development of enterprises. In contrast, financing constraints are widely recognized as a major obstacle to the implementation of strategic initiatives (Ju et al., 2020; Zhang, 2022).

While the relationships among ESG performance, open innovation, and firm performance have been extensively examined in the manufacturing and financial sectors, research remains severely limited in the construction industry. Theoretically, existing literature neither incorporates the unique characteristics of high environmental impact and inflexible financing structure in the construction industry nor integrates core factors into a unified analytical framework. In particular, prior studies have overlooked the mediating role of digital transformation between ESG and performance, as well as the moderating effect of financing constraints on this mechanism, leading to a fragmented understanding of their complex interdependencies. Practically, construction firms are plagued by high capital intensity and fragmented supply chains, yet lack industry-specific guidance to leverage these factors to address financing challenges and improve sustainable performance.

To address existing research gaps, this study utilizes a sample of Chinese listed construction firms from 2013 to 2021 and employs a panel data regression model to test the proposed hypotheses. Specifically, regression analysis is first conducted to assess the direct effects of ESG performance and open innovation on corporate financial performance. Subsequently, by combining the causal steps approach with the Bootstrap method for mediation effect testing, it separately identifies the mediating role of digital transformation in the impact of ESG performance and open innovation on corporate performance. Furthermore, interaction terms are introduced to test whether financing constraints moderate the strength of the identified mediation pathways. Through this analytical framework, the study systematically elucidates the interplay among ESG performance, open innovation, digital transformation, financing constraints, and corporate performance, offering theoretical insights and practical guidance for construction firms pursuing sustainable development via ESG practices and innovation-driven strategies.

The remainder of this paper is structured as follows: Section 2 elaborates on the theoretical analysis and research hypotheses. Section 3 outlines the data sources and research methods. Section 4 discusses the empirical results. Section 5 presents further analyses, including robustness, endogeneity and heterogeneity tests. Section 6 deliberates on the research findings. Finally, Section 7 draws the conclusions of this study.

2. Theoretical analyses and hypotheses

2.1. ESG and firm performance

The core academic debate on the relationship between ESG and corporate performance focuses on the inherent conflict between firms short-term resource allocation and long-term value creation. Proactive ESG investment can shape corporate image, boost employee motivation and reduce turnover (Babajee et al., 2021), whereas overinvestment will crowd out resources for core businesses (Gafni et al., 2024). The construction industry serves as a typical research context for exploring the ESG-corporate performance nexus. Its characteristics of high investment demand and long payback cycle result in distinct short-term and long-term effects in the relationship between ESG and corporate performance in this sector. In the short term, the resource crowding-out effect and value conversion barriers caused by ESG investment exert a significant negative impact on corporate performance. Through a comparative case study in California, Greer et al. (2019) identified a disconnect between LEED certification scores and actual environmental performance, which hinders the timely conversion of ESG investment into market-recognized value and indicates industry-specific barriers to ESG performance value conversion in construction. In the long term, a significant positive correlation will emerge between the two with the continuous advancement of ESG practices and gradual breakthrough of value conversion barriers. Adewumi et al. (2024) examined the value and role of the UK's BREEAM system in local construction enterprises achievement of ESG goals.

Several theories offer a framework for analyzing ESG and firm performance in the construction industry. Stakeholder theory argues that firms must integrate core competencies like stakeholder management and strategic formulation to address ESG-related issues effectively (Gan et al., 2018). The resource-based view (RBV) regards ESG as a vital intangible asset that drives long-term performance improvement by influencing stakeholders resource exchange willingness, but it fails to explain the short-term performance decline caused by ESG input (Surroca et al., 2009). Institutional theory compensates for RBVs deficiencies from an external perspective, illustrating how the institutional environment (policies, norms, cognitive beliefs) shapes construction firms ESG practices (Elmaghrabi et al., 2025; Hassanein et al., 2024; Hassanein & Elmaghrabi, 2024; Nimer et al., 2025) and digital transformation decisions. Martiny et al. (2024) pointed out that mandatory pressures such as environmental regulations force construction enterprises to make early ESG investments, which leads to a mismatch between short-term costs and long-term benefits due to insufficient market recognition of ESG value. Tahat and Hassanein (2024) argued that to improve the quality of ESG performance reporting and align corporate practices with sustainable development goals, policymakers should actively promote gender diversity within firms and encourage the establishment of dedicated sustainability committees. Goubran et al. (2023) further analyzed the alignment of three major green building standards, namely LEED, BOMA BEST and GRESB, with the 2030 Agenda for Sustainable Development. Considering the characteristics of the construction industry such as high investment and long payback cycles, as well as the existence of short-term and long-term effects in the relationship between ESG performance and the performance of construction enterprises, we propose the following hypothesis:

H1: In the short term, ESG performance has a significant negative impact on the performance of construction enterprises.

2.2. Open innovation and firm performance

Existing literature widely acknowledges that open innovation plays a vital role in enhancing innovation performance and overall firm competitiveness. Sun et al. (2025) contributed a fresh perspective for objectively evaluating and enhancing corporate innovation by demonstrating how the interactions among innovation vitality, persistence, and volatility drive the expansion of innovation inputs and outputs. Tang et al. (2021) found that an open innovation strategy improves technological performance on market performance in terms of market performance, open innovation strategies are most effective when the diversity of team roles is high. However, not all studies paint a positive and intuitive picture of the relationship between open innovation and firm performance. Faems et al. (2010) noted that in the short term, the cost-increasing effects of open innovation may outweigh its value-creating benefits, leading to an overall negative impact on financial performance. Furthermore, Schper et al. (2023) pointed out in their research that there is an S-shaped relationship between open innovation and financial performance, and its optimal range is jointly moderated by the industrial institutional environment (e.g., knowledge accessibility) and environmental dynamism.

In construction enterprises, open innovation remains an important factor affecting firm performance. Wang et al. (2018) indicated that small and medium-sized construction companies can ensure their performance through innovation activities. Greco et al. (2021) examined how open innovation can improve productivity in the construction industry and proposed strategies such as sharing the risks and costs of investment in innovations through cross-organizational collaboration. Aliasghar et al. (2019) noted that firms can facilitate process innovation by accessing the knowledge of their value chain partners, rather than relying solely on universities or research organizations. The construction industry is on the cusp of a new era of innovation. The convergence of emerging technologies with physical structures is seen as the next frontier of innovation in the construction industry (Akanmu et al., 2021). In the short term, open innovation negatively affects construction firms' performance owing to inter-organizational collaboration and knowledge integration costs, turning positive in the medium term with the maturation of collaboration mechanisms. This effect is subject to the collaborative complexity (multi-stage, interdisciplinary collaboration), where greater complexity leads to a more pronounced short-term negative effect. Based on this, we propose the following hypotheses:

H2: In the short term, open innovation exerts a significant negative impact on corporate performance.

2.3. ESG and open innovation

With the deepening of the concept of sustainable development, the relationship between ESG goals and open innovation has received increasing attention. This trend is reflected not only in corporate practices but also widely validated in academic research. PepsiCo's Open Innovation Platform facilitates collaboration with small-scale partners and suppliers to drive new innovations that are aligned with ESG priorities. Additionally, Singapore's Open Innovation Network (OIN) serves as a gateway to an open innovation ecosystem, characterized by challenges organized by firms or institutions to engage innovators, startups, and corporations in tackling ESG-related issues. Luan and Wang (2023) suggested that open innovation is not only effective in increasing firm value but also enhances firms' ESG performance. Further research by Strazzullo et al. (2023) shows that open innovation helps firms to improve their CSR performance. By collaborating with different stakeholders, firms can contribute to the achievement of the SDGs. Luan and Wang (2024) also argued that open innovation improves firms' overseas revenues as well as their environmental and social performance and considers environmental and social performance as a key mediating channel through which innovation affects international revenues. It is worth noting that corporate governance does not exhibit mediating effects in their study. The integration of open innovation with ESG is crucial to drive innovation and sustainable development in the construction industry. Greco et al. (2021) viewed open innovation as a means to increase the productivity of the construction ecosystem. Strong implementation of innovation strategies has become an important way for construction firms to move away from outdated construction and management models, transform how they fulfill their social responsibilities, and improve efficiency (Shen et al., 2017).

Based on the above analysis, we propose the following hypothesis:

H3: Open innovation positively affects ESG performance.

2.4. The mediating role of the degree of digital transformation

2.4.1. Degree of digital transformation and ESG

Digital transformation has a dual attribute: it is both an enterprise's strategic and organizational dynamic capability and a quantifiable outcome of digital investment. As a dynamic capability, its core lies in the systematic optimization of enterprises' business processes, stakeholder relationships and governance systems through digitalization.

Cai et al. (2023) confirmed that digital transformation can enhance corporate ESG performance by improving operational efficiency, strengthening information transparency and stakeholder participation, and optimizing governance structures. As an investment outcome, it refers to the perceptible and measurable tangible and intangible outputs generated by enterprises through inputting capital, technology and talents in the layout of digital technology. Wang and Esperana (2023) provided evidence for this: digital technology improves corporate ESG performance from multiple dimensions including energy management, emission and waste reduction, employee welfare, community development, information transparency and risk management, which is a direct embodiment of such investment outcome. Notably, the impact of digital transformation on ESG varies by enterprise type and scale. A study found that the carbon reduction effect of digitalization is heterogeneous. Driven by strict regulation and resource advantages, it significantly inhibits carbon intensity in state-owned and large enterprises. However, the effect is insignificant in non-state-owned and small enterprises due to resource and technical constraints. In addition, digitalization and ESG have a two-way promoting relationship (Wang et al., 2024). Khurram et al. (2024) demonstrated that strong ESG performance facilitates the smooth advancement of digital transformation for enterprises. Examples include easier access to capital and talent, enhanced reputation to attract stakeholders, accelerated innovation in green technologies, and better management of transformation challenges through robust risk management systems.

2.4.2. Degree of digital transformation and open innovation

Digital transformation plays a pivotal role in enhancing open innovation within organizations. Tsou and Chen (2021) argued that digital technologies provide enterprises with innovative tools and methods, which not only drive the development of new products, services and business models but also further boost firms' overall performance. Urbinati et al. (2020) focused on the core contribution of digital technologies to open innovation, pointing out that by facilitating knowledge flow, accelerating the innovation process and driving the shift in innovation paradigms, digital technologies help enterprises build an open collaborative ecosystem and realize the joint development of technologies and co-creation of solutions with external partners. Li et al. (2023b) verified the significant positive impact of corporate digitalization on innovation performance and meanwhile emphasizes the importance for enterprises to formulate digital transformation strategies tailored to their own development. They also find that enterprises in regions with a high level of innovation in the digital industry tend to rely on existing technologies, and such reliance will reduce marginal innovation efficiency and inhibit the long-term innovation growth of enterprises.

Existing studies have all highlighted the close correlation between digital transformation and open innovation, and the dynamic capability perspective provides a more insightful and novel analytical dimension for researching the relationship between the two and corporate innovation. From the dynamic capability perspective, digital transformation is not merely resource integration as viewed from the RBV, but a dynamic capability building process in which enterprises restructure their operational processes by absorbing external knowledge. Taking the process industry as the research object, Chirumalla (2021) explored in depth the construction path of digital-driven process innovation and ultimately proposed a systematic analytical framework comprising 19 specific dynamic capabilities. This framework accurately captures the core capability demands of digital transformation in the industry. Focusing on the low-carbon development needs of the manufacturing industry, Yang et al. (2023) conducted an empirical study, which further revealed that dynamic capabilities play a key mediating role between digital transformation and corporate innovation. This finding has greatly enriched the application scenarios of the dynamic capability theory in the fields of digitalization and innovation.

2.4.3. Degree of digital transformation and firm performance

A large body of literature confirms the positive impact of digital transformation on firm performance. Zareie et al. (2024) demonstrated that digital transformation exerts a lagged positive effect on financial performance, though its benefits are contingent upon enterprises enhancing organizational capital, strengthening corporate governance, and improving information quality. Wang et al. (2017) proposed a conceptual cost estimation model for construction projects that integrates component ratio, Fuzzy Adaptive Learning Control Network (FALCON), fast messy genetic algorithm (fmGA), regression, and multi-factor evaluation methods. A case study demonstrates that the model can more accurately reflect project characteristics, improve estimation accuracy, and reduce rework costs. Zhang et al. (2023), in their study in the manufacturing industry, found that digital transformation improves efficiency, reduces costs, and strengthens the market by optimizing products and processes while driving innovation, helping firms to develop new markets, and creating a differentiated competitive advantage improves firm performance. Jardak and Ben Hamad (2022) noted that the impact of digital maturity on financial performance is dynamic and that large investments may have negative financial impacts in the short term, but in the long term, digital transformation enhances firm competitiveness, creates new value and improves financial performance. According to Tsou and Chen (2021), digital transformation positively impacts business performance by increasing operational efficiency, enabling data-driven decision-making, improving customer experience and driving organizational change, enhancing customer satisfaction and loyalty while promoting changes in organizational structure and culture, increasing flexibility and adaptability, and further contributing to improved business performance. Based on this analysis, it becomes evident that ESG performance and open innovation influence firm performance through the degree of digital transformation. Digital transformation acts as a mediator, channeling the effects of ESG initiatives and open innovation practices into tangible performance outcomes. Therefore, we propose the following hypotheses:

H4a: The degree of digital transformation mediates the relationship between ESG performance and firm performance.

H4b: The degree of digital transformation mediates the relationship between open innovation and firm performance.

2.5. Moderating effects of financing constraints

2.5.1. Financing constraints and ESG

The relationship between financing constraints and ESG performance is both complex and impactful, carrying significant consequences for corporate strategy and investment decisions. According to information asymmetry theory, investors tend to prefer firms that actively fulfill their ESG responsibilities in capital markets where information transparency is limited. Firms with strong ESG performance mitigate information asymmetry by disclosing detailed information about their ESG activities. This increased transparency allows investors to more accurately assess the risks and potential value of these firms, thereby lowering financing constraints by facilitating easier access to external funding (Bai et al., 2022; Hao & Wu, 2024). Zhang and Lucey (2022) showed that by signaling high quality to the credit market, ESG-performing firms can access more trade credit, which eases financing constraints and promotes better firm performance. Interestingly, Zhang (2022) provided evidence that the study suggested that firms facing severe financing constraints are more likely to engage in greenwashing, i.e., misrepresenting their ESG performance, in order to increase their attractiveness to investors. This suggested that financial pressures can motivate firms to engage in unethical practices that undermine genuine ESG endeavours. In sum, effective ESG performance can reduce financing constraints by increasing transparency, attracting institutional investors and improving access to external finance. However, when firms are under financial pressure, they may resort to practices such as greenwashing, which can negatively affect their credibility and overall ESG objectives.

2.5.2. Financing constraints and open innovation

Financing constraints play a critical role in influencing a firm's ability to engage in open innovation. Savignac (2008) pointed out that firms facing financial constraints find it more difficult to obtain external financial support. These constraints may compel companies to reduce the scope of their innovation efforts or choose less risky projects, thereby affecting the overall effectiveness of their innovation activities. Similarly, Cecere et al. (2020) identified financial constraints as a significant barrier to eco-innovation among SMEs. They found that public funding can effectively complement private financing and facilitate the development of eco-innovation. The authors recommended that policymakers take measures to simplify the process for firms to access public funds and encourage co-operation between firms to promote eco-innovation. Yu et al. (2022) pointed out that financing constraints as a key driver of increased pollution emission intensity, arguing that this occurs primarily by impeding technological progress and suppressing improvements in total factor productivity (TFP). Yu et al. (2021) emphasized that financing constraints are a key factor limiting green innovation in Chinese enterprises. They advocated for firms to actively disclose environmental information and improve their credit ratings through green assessments to secure more green financing support.

2.5.3. Financing constraints and firm performance

Financing constraints significantly affect firm performance by reducing financial liquidity and limiting access to external capital, which in turn restricts operational capacity. Musso and Schiavo (2008) argued that financial constraints limit the ability of firms to expand production, increase market share, and improve competitiveness, thereby negatively affecting firm growth. However, they also find a paradoxical positive relationship between financial constraints and productivity growth. This counter-intuitive finding suggests that when faced with limited finance, firms may have to cut costs and increase efficiency to compensate for the lack of finance. Ferrando and Ruggieri (2018) conducted a study in several European countries and found that financial constraints significantly reduce labor productivity, especially for innovative firms. Their study highlights the importance of easing financial constraints (especially for SMEs) to increase labor productivity and stimulate economic growth. In addition, Baos-Caballero et al. (2014) explored the finding that the degree of financial constraints affects the optimal level of working capital for maximizing firm value, specifically firms facing stronger financing constraints tend to have lower optimal levels of working capital investment. Wu and Huang (2022) demonstrated that the presence of financing constraints can limit the effectiveness of digital financial innovation, thereby indirectly affecting corporate performance. The authors argued that digital financial transformation requires substantial additional investments in technology, talent, and platform development, which exacerbates financial pressure on firms. Moreover, financially constrained enterprises lack the necessary resources to address the novel risks associated with digital finance, such as data security vulnerabilities and technological dependency issues. These studies emphasize that the impact of financing constraints on firm performance is multifaceted and complex.

2.5.4. Financing constraints and degree of digital transformation

Financing constraints and digital transformation closely interact to shape corporate investment efficiency and firm performance. He et al. (2023) found that financing constraints can hinder the effectiveness of digital transformation. Digitization also reduces transaction costs and improves risk management through online negotiation and smart contracts, thereby increasing the authenticity and reliability of contractual agreements. By optimizing business processes and reducing administrative and transaction costs, digital transformation improves firm performance and creates more value. Xu et al. (2023) suggested that inefficient investments negatively impact firms' digital transformation efforts, and these adverse effects are exacerbated by financing constraints. Both state-owned and privately-owned enterprises face more pronounced challenges in implementing digital transformation when financial resources are limited. Li et al. (2023a) observed that digital technologies improve the transparency of corporate disclosures and reduce information asymmetry, helping firms secure financing at lower costs. The development of digital finance offers enterprises – especially small, medium, and micro-sized firms – additional financing channels. Based on the above analysis, we propose the following hypotheses:

H5a: Financing constraints moderate the direct effect of ESG performance on firm performance.

H5b: Financing constraints moderate the mediating role of digital transformation between ESG performance and firm performance.

H6a: Financing constraints moderate the direct effect of open innovation on firm performance.

H6b: Financing constraints moderate the mediating role of digital transformation between open innovation and firm performance.

In summary, the theoretical research framework constructed in this study is shown in Figure 1, which examines the relationship between ESG, open innovation, and firm performance, while exploring the mediating role of the degree of digital transformation and the moderating role of financing constraints.

3. Data and research methodology

To empirically test the above research hypotheses and verify the constructed theoretical framework, this section details the research design, including sample selection, variable definition and model setting.

3.1. Sample selection and data sources

This paper takes Chinese listed construction enterprises as the research sample and selects the research data after 2013. In view of the availability of data, the construction companies listed in China's Shanghai and Shenzhen exchanges from 2013 to 2021 are used as the initial sample. The original sample is screened according to the following criteria: (1) excluding samples with incomplete financial data and outliers; (2) excluding ST and ST* enterprises; and (3) excluding missing data values for all variables. According to the above screening requirements, 530 valid samples of 100 listed construction enterprises were finally obtained. Among them, the financial data of construction enterprises mainly come from professional databases such as Wande Financial Information Software (Wind) and Cathay Pacific (CSMAR); ESG data are sourced from Huazheng ESG Rating; patent data come from National China Research Data Service Platform (CNRDS).

3.2. Variable

3.2.1. Dependent variable

In 1969, economist James Tobin proposed the Tobin's Q theory. Since then, the Tobin's Q value has become a key indicator for measuring firm performance or market value. However, scholars have also used other accounting-based metrics such as ROI and ROA, but these are not forward-looking, meaning that they do not provide information about the future value of the firm (Geyskens et al., 2002) and are not comparable across firms and industries due to factors such as risk adjustment. Given the applicability of

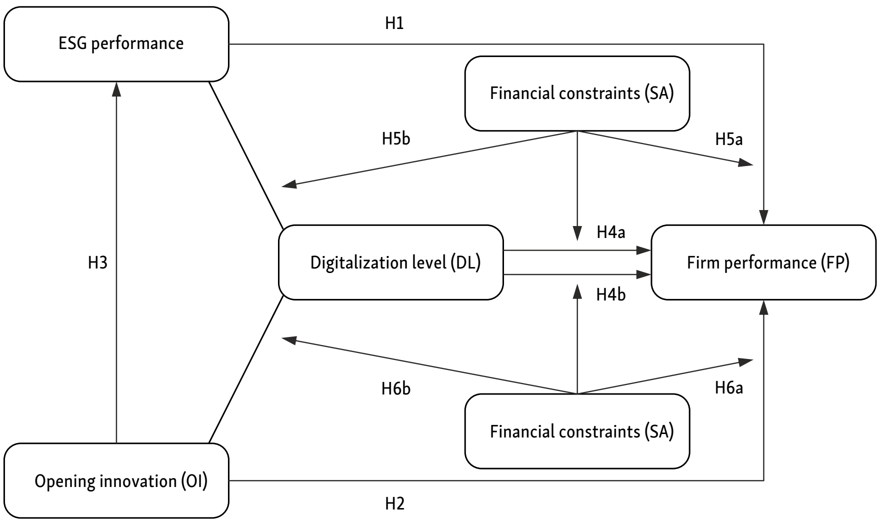

Figure 1. Theoretical research framework

Tobin's Q as an indicator for evaluating firm performance according to many scholars, this paper adopts Tobin's Q to describe firm performance.

3.2.2. Independent variable

The explanatory variables in this paper include open innovation (OI) and ESG performance. Referring to the measurement approach proposed by Brockman et al. (2018), the number of jointly obtained patents is used as a measure of open innovation, reflecting the intellectual property rights acquired by firms through joint R&D with external partners. Joint patents are used as the sole proxy for open innovation because they objectively measure collaborative activities with external partners and provide tangible evidence of knowledge integration across organizational boundaries. This approach aligns with established methodologies in the literature while offering concrete, verifiable data that reduces subjectivity in measuring open innovation activities. Although this measure doesn't capture non-patent-based innovation forms, joint patents serve as a reliable indicator of successful collaborative innovation outcomes that have been formally recognized and protected through the patent system. ESG performance is measured using the Huazheng ESG Rating. This rating draws on international mainstream methodologies and practical experience, integrates the core elements of global ESG frameworks, and combines Chinas national conditions and capital market characteristics to construct the Huazheng ESG Rating System. Specifically, the system conducts a comprehensive assessment of enterprises ESG performance based on a multi-level indicator framework, including 3 first-level indicators (Environment, Social, and Corporate Governance), 16 second-level indicators, 44 third-level indicators, and over 70 fourth-level indicator dimensions. The Huazheng ESG Rating adopts 9 grades, namely C, CC, CCC, B, BB, BBB, A, AA, and AAA. Consistent with mainstream academic and industry practices, this paper assigns numerical values to the ESG ratings of listed companies: 1 for the lowest grade (C) and 9 for the highest grade (AAA).

3.2.3. Mediator variable

The degree of digital transformation (DL) is the mediator variable in this paper. Due to the lack of firm-level digital data, we refer to existing studies and use the provincial-level digital economy-related index as a proxy variable (Eliwa et al., 2021; Xiong et al., 2023). Specifically, based on the registered location of listed companies, it is matched with the fifth issue of the Peking University Digital Financial Inclusion Index of China, and the provincial digital inclusion index digitalization degree sub-index is selected to measure the degree of digital transformation of enterprises. The provincial digital inclusion index digitalization degree sub-index is an important tool for studying digital transformation, providing data-based quantitative indicators that can visually demonstrate the progress made by regions in the process of digital transformation. By comparing data from different regions and different years, the speed and effectiveness of digital transformation can be objectively assessed. In addition, digital transformation is a multidimensional phenomenon that goes far beyond the financial sector, covering areas such as education, healthcare and manufacturing. This feature makes the Index uniquely positioned to provide a more comprehensive assessment of digital transformation.

3.2.4. Moderator variable

Hadlock and Pierce (2010) questioned the KZ index originally used to measure financing constraints. Based on this critical assessment, they turned their attention to firm size and age (denoted as Size and Age respectively) as potential predictors of the effectiveness of financing constraints. After intensive research, they proposed the SA Index and confirmed its validity in measuring financing constraints. Specifically, smaller and shorter established firms have higher values of the SA index, implying that they face more severe financing constraints (Hadlock & Pierce, 2010). In this paper, we choose the SA index as a moderator variable to measure the degree of financing constraints faced by firms.

3.2.5. Control variable

Referring to the studies of Gaglio et al. (2022), Ding et al. (2024) and Li et al. (2024), given that the gearing ratio (Lev), the proportion of shares held by the first largest shareholder (Top 1), the proportion of shares held by institutional investors (INST), the number of years of listing of the firms (Age), and the two positions in one (Dual) have a significant effect on corporate performance, so the above variables are selected as control variables in this paper. In order to avoid the situation of zero-value of the enterprise's listed years, this paper treats all listed years as plus one. With the continuous growth of the enterprise's operation time, the enterprise will accumulate more practical experience and relatively better risk-taking ability. The gearing ratio (Lev) states that the higher the value, the more the enterprise borrows, which means that the enterprise faces greater financial risk, inhibiting the enterprise's ability to create value. Shareholding of the largest shareholder (Top1), the higher the value, the stronger the control over the company, the larger the shareholder may push for the optimization of the corporate governance structure and the development of clearer strategic objectives. Combination of two positions (Dual): Combining positions can reduce the number of decision-making layers and improve decision-making efficiency, enabling the company to respond in a timely manner in a rapidly changing market environment. Institutional investor shareholding ratio (INST), the number of shares held by institutional investors divided by the total number of shares. All variables are described as shown in Table 1.

The descriptive statistics of the variables are shown in Table 2. From the descriptive statistics of the variables, it can be seen that the average ESG score of China's listed construction companies from 2013 to 2021 is 4.090, which indicates that the general situation of ESG performance of China's construction companies is in the middle to lower range, meanwhile, the standard deviation (SD) of ESG is 1.049 and the lowest value is 1.000, which suggests that some companies perform poorly in terms of ESG. For Open Innovation (OI), the mean value is 1.718, indicating that construction firms in the sample perform relatively poorly in general in terms of open innovation. The large standard deviation (1.988) suggests that there are significant differences in the implementation of open innovation strategies, with some firms (e.g., the maximum value of 7.907) excelling in utilizing external resources for innovation, while others do not engage in open innovation at all (e.g., the minimum value of 0.000). This implies that some companies may rely more on internal resources for innovation, which may lead to limited innovation outcomes. The mean value of digitalization level (DL) is 367.951 with a relatively small standard deviation (69.822), suggesting that there are limited differences in digitalization levels between firms, which may imply that the majority of firms are struggling with digital transformation. The mean value of financing constraints (SA) is –3.721, a negative value that may imply that construction firms in the sample generally face some degree of financing constraints, which may affect their investment in open innovation and digitalization.

3.3. Model

Based on the theoretical analysis and research hypotheses of this paper, the following empirical models are constructed using pooled OLS to explore the relationship between ESG performance, open innovation and corporate performance, as well as the moderating role of financing constraints and the mediating role of digitalization. This study employs pooled OLS instead of fixed effects regression, a choice dependent on the sample nature, characteristics of the construction industry, theoretical framework and variable attributes. The sample of Chinese listed construction enterprises exhibits low heterogeneity, which is captured by control variables; the homogeneous institutional environment reduces unobserved firm-specific factors, and the slow changes in core variables render fixed effects regression prone to biases. The Hausman test (χ^2 = 2.0596, p = 0.3571) and BP test (χ^2 = 2.1709, p = 0.3377) confirm the applicability of pooled OLS.

Table 1. Variable description table

Variable Category	Variable Name	Variable Symbol	Variable Definition
Dependent Variable	firm performance	FP	Tobin's Q value
Independent Variable	ESG performance	ESG	ESG ratings are assigned values from 1 to 9 on a scale from low to high
	Open Innovation	OI	Add one to the number of jointly granted patents and then take the logarithm
Moderator Variable	Financing constraint	SA	SA = −0.737*Size + 0.043*Size2 − 0.040*Age
Mediator Variable	Degree of digital transformation	DL	Selecting the provincial digital inclusion index digitalization degree sub-index to measure the degree of digital transformation of enterprises
Control Variable	Debt to asset ratio	Lev	Total liabilities divided by total assets
	Whether the chairman and general manager are concurrently appointed	Dual	Chairman and General Manager is 1 if the two positions are combined, and 0 otherwise.
	Shareholding ratio of the largest shareholder	Top1	Number of shares held by the largest shareholder divided by total number of shares
	Number of years the company has been listed	Age	Number of years the company has been listed plus one
	Institutional investor shareholding	INST	Number of shares held by institutional investors divided by total number of shares

Table 2. Descriptive statistics of variables

Variable	Mean	Standard deviation	Minimum	Maximum	Number of observations
FP	1.285	0.450	0.834	5.333	530
ESG	4.090	1.049	1.000	7.000	530
OI	1.718	1.988	0.000	7.907	530
Lev	0.656	0.162	0.158	0.907	530
Dual	0.170	0.376	0.000	1.000	530
Top1	0.378	0.158	0.045	0.786	530
INST	0.398	0.249	0.000	0.949	530
Age	10.404	6.771	1.000	29.000	530
DL	367.951	69.822	222.120	462.228	530
SA	–3.721	0.499	–4.565	–2.109	530

Considering the time lag effect of relevant variables on firm performance and digital transformation, this paper uses values of all dependent variables in the models that are lagged by one period relative to the explanatory variables, so as to better verify the theoretical hypotheses. Model 1 is the basic model, which mainly includes control variables; Model 2.1 and Model 2.2 mainly verify the effects of ESG performance and open innovation on the performance of construction firms. Model 3 tests the relationship between open innovation and ESG performance. Models 4.1.1–4.1.2 and 4.2.1–4.2.2 test the mediating effect of digitalization in the relationship between ESG performance, open innovation and firm performance. Models 5.1.1–5.1.2 and Models 5.2.1–5.2.2 test whether financing constraints have a direct or indirect moderating effect. Where i denotes the individual, t denotes the time period, β_0 is the intercept term, β_1–β_6 are the coefficients of each explanatory variable, and ε denotes the residual term.

$$FP_{i,t+1} = \beta_0 + \beta_1 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (1)$$

$$FP_{i,t+1} = \beta_0 + \beta_1 ESG_{i,t} + \beta_2 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (2.1)$$

$$FP_{i,t+1} = \beta_0 + \beta_1 OI_{i,t} + \beta_2 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (2.2)$$

$$ESG_{i,t} = \beta_0 + \beta_1 OI_{i,t} + \beta_2 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (3)$$

$$DL_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \beta_2 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (4.1.1)$$

$$FP_{i,t+1} = \beta_0 + \beta_1 ESG_{i,t} + \beta_3 DL_{i,t} + \beta_3 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (4.1.2)$$

$$DL_{i,t} = \beta_0 + \beta_1 OI_{i,t} + \beta_2 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (4.2.1)$$

$$FP_{i,t+1} = \beta_0 + \beta_1 OI_{i,t} + \beta_3 DL_{i,t} + \beta_3 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (4.2.2)$$

$$DL_{i,t} = \beta_0 + \beta_1 ESG_{i,t} + \beta_2 SA_{i,t} + \beta_3 ESG_{i,t} \times SA_{i,t} + \beta_4 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (5.1.1)$$

$$FP_{i,t+1} = \beta_0 + \beta_1 ESG_{i,t} + \beta_2 SA_{i,t} + \beta_3 DL_{i,t} + \beta_4 ESG_{i,t} \times SA_{i,t} + \beta_5 SA_{i,t} \times DL_{i,t} + \beta_6 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (5.1.2)$$

$$DL_{i,t} = \beta_0 + \beta_1 OI_{i,t} + \beta_2 SA_{i,t} + \beta_3 OI_{i,t} \times SA_{i,t} + \beta_4 CONTROLS_{i,t} + \varepsilon_{i,t}; \quad (5.2.1)$$

$$FP_{i,t+1} = \beta_0 + \beta_1 OI_{i,t} + \beta_2 SA_{i,t} + \beta_3 DL_{i,t} + \beta_4 OI_{i,t} \times SA_{i,t} + \beta_5 SA_{i,t} \times DL_{i,t} + \beta_6 CONTROLS_{i,t} + \varepsilon_{i,t}. \quad (5.2.2)$$

4. Results

Building on the research design outlined above, we now present the empirical results. Before doing the regression analysis in this paper, correlation analysis was done (Table A1 in Appendix) and the table of correlation results shows that firm performance is significantly correlated with ESG and OI, SA at the 1% level and with DL at the 5% level. It is significantly correlated with the rest of the control variables at 1% level. Also, ESG is significantly correlated with OI at 1% level. In addition, we calculated the variance expansion factor (VIF) for each variable, and the VIF values were all between 1 and 4, with multicollinearity within the acceptable range. The regression results are shown in Table 3.

The results of the main effects (Model 2.1) show that ESG exerts a significantly negative impact on firm performance (FP) ($B = -0.083^{***}$, $\beta = -0.193^{***}$), thereby supporting Hypotheses H1. In the short term, for each one-standard-deviation increase in ESG level, firm performance decreases by 0.193 standard deviations accordingly; for each one-unit increase in ESG level, firm performance drops by approximately 6.46% in the short term. Open innovation (OI) also has a significantly negative impact on FP ($B = -0.056^{***}$, $\beta = -0.247^{***}$, supporting Hypotheses H2). In the short term, for each one-standard-deviation increase in OI level, firm performance decreases by 0.247 standard deviations accordingly; for each one-unit increase in OI level, firm performance declines by about 4.36% in the short term. These findings indicate that both ESG and open innovation squeeze firm performance in the short run. In Model 3, open innovation exhibits a significantly positive impact on firm performance (supporting Hypothesis H3): for each one-unit increase in OI, firm performance increases significantly by 0.214 units, which is equivalent to a performance improvement of approximately 16.6%. For each one-standard-deviation increase in OI, firm performance increases by 0.405 standard deviations (Table 3).

In order to verify whether hypotheses H4a and H4b are valid to establish models 4.1.1–4.2.2. The results of Model 4.1.1–4.2.2 and the Bootstrap mediation effect test show that digital transformation (DL) plays a significant mediating role in both the ESG-FP and OI-FP pathways. The coefficient of ESG-DL is 12.033^{***}, and that of DL-FP is -0.001^{***}; the total mediating effect is -0.027^{***} (Bootstrap 95% CI [−0.047, −0.008]), meaning that for each one-unit increase in ESG, FP decreases by 0.027 through the mediating effect of DL, corresponding to a performance decline of 2.10%. The coefficient of OI-DL is 6.386^{***}, and that of DL-FP is -0.001^{***}; the total mediating effect is -0.028^{***} (Bootstrap 95% CI [−0.049, −0.008]), meaning that for each one-unit increase in OI, FP decreases by 0.028 through the mediating effect of DL, corresponding to a performance decline of 2.18% (Table 4 and Table 5).

Based on the above results, the mediating effect of DL is significant. Is the moderating effect of SA significant? The results are shown in Table 6. The results of the moderating effects (Model 5.1.1-5.2.2) show that financing constraints (SA) positively moderate the ESG-DL pathway ($B = 9.885^{**}$, $\beta = 0.142^{***}$). For each one-standard-deviation increase in SA, the positive promoting effect of ESG on digital transformation (DL) is strengthened by 4.93, leading to a 1.34% increase in the level of digital transformation. Financing constraints negatively moderate the OI-FP pathway ($B = -0.037^{**}$, $\beta = -0.083^{***}$). For each one-standard-deviation increase in SA, the negative impact of OI on FP is weakened by 0.018, reducing the negative effect of OI by approximately 32.14%.

Table 3. Regression results

	Model 1		Model 2.1		Model 2.2		Model 3	
	B	β	B	β	B	β	B	β
ESG			–0.083***	–0.193***				
			(0.028)	(0.065)				
OI					–0.056***	–0.247***	0.214***	0.405***
					(0.013)	(0.055)	(0.051)	(0.096)
Lev	–0.839***	–0.302***	–0.953***	–0.343***	–0.693***	–0.250***	–1.928***	–0.298***
	(0.196)	(0.070)	(0.172)	(0.062)	(0.216)	(0.078)	(0.559)	(0.086)
Dual	0.144**	0.120**	0.137*	0.114*	0.133*	0.111*	–0.048	–0.017
	(0.072)	(0.060)	(0.072)	(0.060)	(0.070)	(0.058)	(0.172)	(0.062)
Top1	–0.442**	–0.155**	–0.394**	–0.138**	–0.289	–0.101	–0.007	–0.001
	(0.199)	(0.070)	(0.179)	(0.063)	(0.196)	(0.069)	(0.731)	(0.110)
Age	–0.009***	–0.140***	–0.009***	–0.135***	–0.009***	–0.140***	0.004	0.027
	(0.003)	(0.051)	(0.003)	(0.050)	(0.003)	(0.049)	(0.013)	(0.087)
INST	0.147	0.081	0.207	0.115	0.309**	0.171**	0.109	0.026
	(0.128)	(0.071)	(0.129)	(0.071)	(0.128)	(0.071)	(0.332)	(0.079)
Constant	2.016***	0.000	2.385***	0.000	1.896***	0.000	4.913***	0.000
	(0.135)	(0.059)	(0.185)	(0.057)	(0.153)	(0.055)	(0.334)	(0.080)
F	13.18		16.15		24.63		7.05	
R^2	0.201		0.236		0.238		0.156	

Notes: standard errors in parentheses, *** indicates significant at the 1% level, ** indicates significant at the 5% level, and * indicates significant at the 10% level. Unless otherwise specified, the same applies to all tables in this paper.

Table 4. Results of the mediation effect test

	Model 4.1.1		Model 4.1.2		Model 4.2.1		Model 4.2.2	
	B	β	B	β	B	β	B	β
ESG	12.033***	0.181***	–0.071**	–0.166**				
	(3.455)	(0.052)	(0.031)	(0.072)				
OI					6.386***	0.182***	–0.049***	–0.219***
					(1.934)	(0.055)	(0.013)	(0.056)
DL			–0.001***	–0.152***			–0.001***	–0.156***
			(0.000)	(0.055)			(0.000)	(0.047)
Lev	–75.277***	–0.175***	–1.026***	–0.370***	–108.453***	–0.251***	–0.802***	–0.289***
	(28.341)	(0.066)	(0.179)	(0.064)	(29.802)	(0.069)	(0.220)	(0.079)
Dual	16.847*	0.091*	0.153**	0.128**	17.028*	0.092*	0.150**	0.125**
	(9.140)	(0.049)	(0.070)	(0.059)	(8.674)	(0.047)	(0.069)	(0.057)
Top1	–16.538	–0.037	–0.410**	–0.144**	–27.045	–0.061	–0.316	–0.111
	(29.870)	(0.067)	(0.177)	(0.062)	(28.810)	(0.065)	(0.194)	(0.068)
Age	2.472***	0.240***	–0.007*	–0.098*	2.524***	0.245***	–0.007**	–0.102**
	(0.552)	(0.054)	(0.003)	(0.051)	(0.585)	(0.057)	(0.003)	(0.051)
INST	20.012	0.071	0.227*	0.125*	10.268	0.037	0.319**	0.177**
	(19.106)	(0.068)	(0.123)	(0.068)	(19.574)	(0.070)	(0.125)	(0.069)
Constant	337.850***	0.000	2.715***	0.000	405.158***	0.000	2.303***	0.000
	(22.907)	(0.047)	(0.186)	(0.057)	(18.466)	(0.047)	(0.197)	(0.055)
F	7.72		19.58		6.26		24.02	
R^2	0.105		0.257		0.095		0.26	

Table 5. (Bootstrap) results of the mediation effect test

Path	Observed coef	Bootstrap std. err.	LLCI	ULCI
ESG–DL–FP	–0.027***	0.010	–0.047	–0.008
ESG–FP	–0.166***	0.051	–0.266	–0.066
OI–DL–FP	–0.028 ***	0.011	–0.049	–0.008
OI–FP	–0.219 ***	0.044	–0.304	–0.133

Table 6. Mediation effect test results with moderation

	Model 5.1.1		Model 5.1.2		Model 5.2.1		Model 5.2.2	
	B	β	B	β	B	β	B	β
ESG	15.952***	0.240***	–0.05	–0.116				
	(3.468)	(0.052)	(0.034)	(0.079)				
OI					14.974***	0.426***	–0.023	–0.100
					(2.732)	(0.078)	(0.020)	(0.090)
SA	–44.677***	–0.319***	–0.150*	–0.166*	–90.138***	–0.644***	–0.037	–0.041
	(10.551)	(0.075)	(0.077)	(0.086)	(14.039)	(0.100)	(0.105)	(0.116)
OI*SA					11.873***	0.170***	–0.037**	–0.083**
					(2.965)	(0.042)	(0.016)	(0.037)
ESG*SA	9.885***	0.142***	–0.003	–0.007				
	(2.982)	(0.043)	(0.031)	(0.069)				
DL			–0.001***	–0.180***			–0.001***	–0.167***
			(0.000)	(0.057)			(0.000)	(0.048)
DL*SA			0.013	0.030			0.016	0.036
			(0.015)	(0.034)			(0.013)	(0.028)
Lev	–50.356*	–0.117*	–0.914***	–0.329***	–85.673***	–0.199***	–0.816***	–0.294***
	(28.846)	(0.067)	(0.202)	(0.073)	(28.668)	(0.066)	(0.224)	(0.081)
Dual	16.236*	0.087*	0.160**	0.134**	18.592**	0.100**	0.162**	0.136**
	(9.517)	(0.051)	(0.071)	(0.060)	(8.537)	(0.046)	(0.070)	(0.058)
Top1	6.235	0.014	–0.322*	–0.113*	–19.453	–0.044	–0.279	–0.098
	(28.798)	(0.065)	(0.171)	(0.060)	(29.351)	(0.066)	(0.194)	(0.068)
Age	1.612***	0.156***	–0.010**	–0.146**	0.981*	0.095*	–0.009**	–0.135**
	(0.611)	(0.059)	(0.004)	(0.064)	(0.586)	(0.057)	(0.005)	(0.068)
INST	38.212*	0.136*	0.334**	0.184**	23.641	0.084	0.369***	0.204***
	(20.989)	(0.075)	(0.146)	(0.081)	(17.572)	(0.063)	(0.139)	(0.077)
Constant	129.268**	–0.045	2.023***	0.007	38.656	–0.128*	2.175***	0.068
	(58.673)	(0.049)	(0.405)	(0.051)	(60.850)	(0.068)	(0.465)	(0.062)
F	12.56		18.27		8.33		18.79	
R^2	0.153		0.272		0.197		0.273	

5. Further analysis

5.1. Robustness tests

Using the provincial digital sub-index to measure firm-level digital transformation risks ecological fallacy. This macro-level proxy masks firm-level heterogeneity in digital investment, potentially underestimating the mediating role of digital transformation. To mitigate this problem, the frequency of relevant keywords in the annual reports of listed enterprises is used as an alternative variable for digital transformation in this paper. In the meantime, to test the robustness of the research conclusions, the core explanatory variables are replaced: the composite ESG score is employed as an alternative indicator of ESG performance, and open innovation efficiency is used as an alternative indicator of open innovation, where open innovation efficiency is calculated as OI / ln (RD) (RD denotes corporate research and development expenditure). All models are re-estimated using the replaced variables, and the results are basically consistent with those of the benchmark analysis. Detailed estimation results are presented in Appendix, Tables A2–A4.

5.2. Endogeneity test

This study employs the instrumental variable (IV) method to mitigate the endogeneity issue between ESG performance, open innovation, and firm performance, using lagged one-period ESG (*ESG_IV*) and lagged one-period open innovation (*OI_IV*) as the instrumental variables for ESG and open innovation, respectively. First, we test the validity of the instrumental variables: in the weak instrumental variable test, the *F*-statistics are 685.805 and 1683.643 with *p*-values of 0.000 in both cases, indicating that the selected instrumental variables are strong, while the LM statistics are 262.138 and 337.268 with *p*-values of 0.000, confirming no underidentification problem. The two-stage least squares (2SLS) regression results (Appendix, Table A5) show that in the first stage, the instrumental variables *ESG_IV* and *OI_IV* are significantly positively correlated with ESG and OI, respectively, and in the second stage, ESG and OI are significantly negatively correlated with firm performance (FP) at the 1% significance level, which is consistent with the baseline regression results of the main effect reported earlier, confirming the robustness of the study's conclusions.

5.3. Heterogeneity test

Considering that the nature of different enterprises is affected differently by the institutional environment, State-owned enterprises are generally subject to strict government regulation and bear considerable social responsibility, thus having both economic and political attributes. With the growing demand for sustainable development, SOEs have also gradually become a key tool for the government to promote high-quality development. Therefore, this paper continues to explore the relationship between corporate ownership attributes on ESG, open innovation, and firm performance, as well as the effects of the mediating role of digitalization degree and the moderating role of financing constraints. This paper conducts a heterogeneity test for SOEs and non-SOEs (see Appendix, Tables A6–A10). The results show that in non-state-owned firms, the direct effects of ESG and open innovation on firm performance are insignificant. The mediating role of the degree of digitalization does not exist, while open innovation has no effect on ESG performance. While in state-owned enterprises, the direct effect of ESG, open innovation on firm performance, and the indirect effect through the degree of digitalization are significant, but financing constraints do not exert a statistically significant moderating effect on the ESG–firm performance relationship. Meanwhile, in the relationship between open innovation and firm performance, the moderating effect of financing constraints on the mediating effect of digitalization is reflected in the first half of the path, while there is no moderating effect on the direct effect.

6. Discussion

The empirical results presented above verify the validity of our research hypotheses. Against the context of the construction industry, this section further discusses these empirical findings.

In the short term, both ESG performance and open innovation exert a significantly negative impact on firm performance (supporting H1 and H2). This is primarily because the market requires time to digest ESG information, and the short-term cost increase is difficult to offset by value enhancement (Rojo-Suárez & Alonso-Conde, 2023). Meanwhile, the upfront investment, collaboration costs, and management burden associated with open innovation are particularly prominent in the construction industry (Greco et al., 2021; Lu & Chesbrough, 2022). However, there is a synergistic effect between the two: open innovation can significantly improve ESG performance (supporting H3), which is expected to generate positive returns in the long run Abdelbaky et al. (2025).

Digital transformation plays a partial mediating role between ESG/open innovation and firm performance (supporting H4a and H4b). ESG practices can broaden the investor base, reduce capital costs, and provide financial impetus for digital transformation (Zhai et al., 2022); open innovation accelerates the digital process by acquiring external knowledge and technologies (Chen et al., 2024b; Wang et al., 2025). Although short-term investments in digital transformation exacerbate performance pressure (Jardak & Ben Hamad, 2022), in the long run, it can improve firm performance through cost reduction and efficiency enhancement (Fang & Liu, 2024).

Financing constraints exhibit heterogeneous moderating effects: they strengthen the positive effect of ESG on digital transformation (supporting H5b), as financial pressure forces firms to use digitalization to improve efficiency; at the same time, they weaken the negative impact of open innovation on performance (supporting H6a), as firms under financing constraints select innovation projects more cautiously to avoid blind investment (Ali et al., 2025). The nature of firm ownership further amplifies these effect differences: in state-owned enterprises (SOEs), both the direct and indirect effects of ESG and open innovation are significant, and financing constraints exert a moderating effect on the OI-DL path; in non-state-owned enterprises (non-SOEs), none of the relevant paths are significant, reflecting that they have not yet established a systematic ESG and innovation operation mechanism. This heterogeneity stems from SOEs' policy orientation, stronger digital transformation drive and financing advantages, as well as non-SOEs' focus on short-term benefits (Shu & Tan, 2023; Yan et al., 2023).

7. Conclusions

This study analyzes a sample of Chinese listed construction firms from 2013 to 2021 to examine how ESG and open innovation affect firm performance. In addition, it investigates the mediating role of digital transformation in the above relationships and the moderating role of financing constraints. Our results show that in the short term, both ESG and open innovation suppress financial performance, while open innovation promotes ESG. Digital transformation partially mediates the effects of ESG and open innovation on performance. Financing constraints strengthen the positive effect of ESG on digital transformation and mitigate the negative impact of open innovation. These relationships are only significant in state-owned enterprises, highlighting the role of institutional logic. This paper contributes to the literature on sustainable development in construction firms and carries important implications.

7.1. Contributions

7.1.1. Theoretical contributions

This study advances theoretical understanding by integrating institutional theory, the dynamic capability view, and the resource-based view into a unified analytical framework, constructing an "institutional pressure – capability building – performance output" framework. This framework clarifies how multiple theoretical perspectives complement one another to explain the sustainable innovation pathways of construction firms and bridges the gap between external pressures, internal capabilities, and strategic outcomes.

7.1.2. Empirical contributions

By testing the mediating role of digital transformation and the moderating role of financing constraints in the construction industry, this study provides new evidence. It deepens the understanding of boundary conditions in the transmission process of the "ESG/open innovation – digitalization – performance" nexus and uses ownership-based heterogeneity analysis to reveal institutional differences in the effects of sustainable innovation.

7.1.3. Practical and policy contributions

This study provides strategic guidance for enterprises on the synergistic development of ESG and digitalization, and offers references for policymakers on targeted incentives to accelerate the sustainable transformation of capital-intensive, policy-sensitive industries.

7.2. Managerial implications

- Optimize investment priorities and implement the phased "ESG – Digitalization – Open Innovation" strategy. ESG practices and open innovation both drive digital transformation, a key mediating variable for firm performance. Construction enterprises should first consolidate ESG foundations to gain policy and financing support, then focus on digital transformation to reduce collaboration costs, and finally conduct open innovation via digital platforms to maximize innovation efficiency.
- Adopt differentiated strategies. SOEs should leverage policy and resource advantages to integrate ESG, digitalization and open innovation, maintaining reasonable ESG investment even in financial strain. Non-SOEs should avoid blind large-scale investment, focus on market-oriented, short-cycle and high-return innovation, and use financing tools like green credit to alleviate financing constraints.

7.3. Policy implications

- Implement a differentiated policy support system. For SOEs, increase the weight of ESG and digital transformation performance in assessments and incorporate them into leaders performance appraisals. For non-SOEs, reduce transformation costs via green technology subsidies, open innovation tax incentives and digital special funds.
- Improve the green finance system. Establish a "Special Loan for the Digital Transformation of Green Buildings" to provide low-interest support. Promote diversified financing tools (e.g., green bonds, ESG-themed funds) to expand financing channels for construction enterprises, especially non-SOEs, and alleviate the inhibitory effect of financing constraints.

7.4. Limitations and further research

Although this paper has achieved certain results, it has limitations in terms of samples and research cycles: the samples only focus on listed companies in China's construction industry and do not cover overseas samples or industry segments, which affects the universality of the conclusions; the research only reveals the short-term relationship between variables and cannot capture their dynamic evolution and long-term effects. In this regard, future research can supplement data through multiple channels and include samples from other countries, construction industry segments, and non-listed small and medium-sized enterprises; extend the research cycle, track and quantify the long-term effects of core variables through panel data, and verify the conditions for the transformation of short-term and long-term effects.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

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APPENDIX

Table A1. Correlation matrix

	FP	ESG	OI	Lev	Dual	Top1	INST	Age	DL	SA
FP	1									
ESG	–0.157 ***	1								
OI	–0.345 ***	0.301	1							
		***								
Lev	–0.397 ***	–0.103	0.421	1						
		*	***							
Dual	0.214 ***	–0.041	–0.194	–0.217	1					
			***	***						
Top1	–0.210 ***	0.101 *	0.438	0.288	–0.139	1				
			***	***	**					
INST	–0.154 ***	0.142	0.544	0.381	–0.221	0.427	1			
		**	***	***	***	***				
Age	–0.249 ***	–0.027	0.139	0.396	–0.175	–0.101	0.197	1		
			**	***	***	*	***			
DL	–0.138 **	0.195	0.085 *	–0.101	0.069	–0.076	0.042	0.168	1	
		***		*				***		
SA	–0.223 ***	0.318	0.757	0.288	–0.091	0.451	0.492	–0.165	–0.147	1
		***	***	***	*	***	***	***	***	

Note: *** indicates significant correlation at the 1 per cent level, ** indicates significant correlation at the 5 per cent level and * indicates significant correlation at the 10 per cent level.

Table A2. Regression results

	Model 2.1		Model 2.2		Model 3	
	B	β	B	β	B	β
ESG	–0.015***	–0.195***				
	(0.005)	(0.060)				
OI			–1.077***	–0.217***	23.736***	0.376***
			(0.281)	(0.057)	(5.658)	(0.090)
Lev	–0.938***	–0.338***	–0.699***	–0.252***	–9.510***	–0.269***
	(0.172)	(0.062)	(0.217)	(0.078)	(3.189)	(0.090)
Dual	0.140*	0.117*	0.133*	0.111*	–0.024	–0.002
	(0.072)	(0.060)	(0.070)	(0.059)	(0.865)	(0.057)
Top1	–0.376**	–0.132**	–0.312	–0.109	1.413	0.039
	(0.175)	(0.061)	(0.199)	(0.070)	(4.103)	(0.113)
Age	–0.008**	–0.124**	–0.009***	–0.139***	0.067	0.079
	(0.003)	(0.050)	(0.003)	(0.049)	(0.077)	(0.091)
INST	0.203	0.112	0.275**	0.152**	0.845	0.037
	(0.128)	(0.071)	(0.125)	(0.069)	(1.655)	(0.072)
Constant	3.137***	0.000	1.916***	0.000	75.521***	0.000
	(0.370)	(0.057)	(0.153)	(0.055)	(1.706)	(0.081)
F	16.28		20.99		6.21	
R^2	0.237		0.231		0.143	

Table A3. Results of the mediation effect test

	Model 4.1.1		Model 4.1.2		Model 4.2.1		Model 4.2.1	
	B	β	B	β	B	β	B	β
ESG	2.048***	11.739***	–0.013**	–0.076**				
	(0.706)	(4.049)	(0.005)	(0.030)				
OI					121.403***	11.019***	–0.951***	–0.086***
					(43.115)	(3.913)	(0.281)	(0.026)
DL			–0.001***	–0.001***			–0.001***	–0.001***
			(0.000)	(0.000)			(0.000)	(0.000)
Lev	–78.591***	–12.724***	–1.015***	–0.164***	–107.528***	–17.409***	–0.811***	–0.131***
	(27.812)	(4.503)	(0.178)	(0.029)	(29.787)	(4.823)	(0.221)	(0.036)
Dual	16.322*	6.134*	0.156**	0.059**	17.037*	6.403*	0.150**	0.057**
	(9.094)	(3.418)	(0.070)	(0.026)	(8.754)	(3.290)	(0.069)	(0.026)
Top1	–18.359	–2.893	–0.394**	–0.062**	–24.258	–3.822	–0.337*	–0.053*
	(30.128)	(4.747)	(0.173)	(0.027)	(28.745)	(4.529)	(0.198)	(0.031)
Age	2.381***	16.124***	–0.006*	–0.040*	2.513***	17.015***	–0.007*	–0.045*
	(0.551)	(3.728)	(0.003)	(0.023)	(0.580)	(3.925)	(0.003)	(0.023)
INST	21.282	5.290	0.224*	0.056*	14.353	3.567	0.290**	0.072**
	(18.728)	(4.655)	(0.122)	(0.030)	(19.293)	(4.795)	(0.122)	(0.030)
Constant	241.297***	367.951***	3.375***	1.648***	402.697***	367.951***	2.335***	1.667***
	(53.158)	(3.272)	(0.349)	(0.128)	(18.333)	(3.220)	(0.195)	(0.109)
F	6.16		21.84		5.76		20.84	
R^2	0.101		0.258		0.090		0.254	

Table A4. Mediation effect test results with moderation

	Model 5.1.1		Model 5.1.2		Model 5.2.1		Model 5.2.1	
	B	β	B	β	B	β	B	β
ESG	2.806***	0.230***	–0.010*	–0.122*				
	(0.656)	(0.054)	(0.006)	(0.072)				
OI					258.546***	0.336***	–0.401	–0.081
					(51.784)	(0.067)	(0.396)	(0.080)
SA	–47.829***	–0.342***	–0.148*	–0.165*	–77.812***	–0.556***	–0.046	–0.051
	(9.776)	(0.07)	(0.076)	(0.085)	(12.628)	(0.090)	(0.095)	(0.105)
OI*SA					12.879***	0.184***	–0.044**	–0.099**
					(3.207)	(0.046)	(0.017)	(0.038)
ESG*SA	13.466***	0.193***	–0.002	–0.005				
	(3.061)	(0.044)	(0.029)	(0.064)				
DL			–0.001***	–0.181***			–0.001***	–0.171***
			(0.000)	(0.056)			(0.000)	(0.048)
DL*SA			0.016	0.035			0.013	0.029
			(0.015)	(0.033)			(0.012)	(0.027)
Lev	–55.439**	–0.129**	–0.909***	–0.327***	–88.825***	–0.206***	–0.814***	–0.293***
	(27.818)	(0.065)	(0.200)	(0.072)	(28.874)	(0.067)	(0.223)	(0.080)
Dual	15.243	0.082	0.162**	0.135**	18.303**	0.099**	0.163**	0.136**
	(9.301)	(0.050)	(0.071)	(0.059)	(8.518)	(0.046)	(0.069)	(0.058)
Top 1	5.800	0.013	–0.310*	–0.109*	–18.122	–0.041	–0.279	–0.098
	(28.809)	(0.065)	(0.167)	(0.058)	(29.307)	(0.066)	(0.193)	(0.068)
Age	1.541**	0.149**	–0.009**	–0.138**	1.277**	0.124**	–0.009**	–0.141**
	(0.593)	(0.057)	(0.004)	(0.064)	(0.578)	(0.056)	(0.004)	(0.067)
INST	36.380*	0.130*	0.330**	0.182**	27.137	0.097	0.368***	0.204***
	(20.519)	(0.073)	(0.146)	(0.081)	(17.994)	(0.064)	(0.140)	(0.077)
Constant	–17.792	–0.064	2.514***	0.007	85.474	–0.129**	2.150***	0.074
	(79.725)	(0.048)	(0.544)	(0.051)	(56.201)	(0.065)	(0.436)	(0.062)
F	12.77		21.19		7.71		17.66	
R^2	0.165		0.273		0.173		0.274	

Table A5. Two-Stage Regression Results (IV Analysis)

	First	Second	First	Second
	ESG	FP	OI	FP
ESG_IV	0.760***			
	(26.409)			
OI_IV			0.919***	
			(41.378)	
ESG		–0.244***		
		(–4.466)		
OI				–0.289***
				(–4.889)
Lev	–0.046	–0.336***	0.027	–0.221***
	(–1.225)	(–6.157)	(1.188)	(–4.022)
Dual	0.010	0.053	–0.022	0.057
	(0.312)	(1.109)	(–1.132)	(1.187)
Top 1	0.063*	–0.073	0.043**	–0.045
	(1.731)	(–1.373)	(1.971)	(–0.827)
Age	0.027	–0.109**	0.044**	–0.119**
	(0.808)	(–2.235)	(2.199)	(–2.455)
INST	0.023	0.041	0.045*	0.123**
	(0.624)	(0.761)	(1.933)	(2.104)
Constant	0.048	–0.038	0.074***	–0.034
	(1.606)	(–0.885)	(4.225)	(–0.793)
R^2	0.647	0.193	0.884	0.190

Table A6. Regression results (non-state-owned enterprises)

	Model 2.1		Model 2.2		Model 3	
	B	β	B	β	B	β
ESG	0.012	0.029				
	(0.052)	(0.121)				
OI			–0.004	–0.020	–0.031	–0.058
			(0.051)	(0.226)	(0.076)	(0.144)
Lev	–0.963***	–0.347***	–0.971***	–0.350***	–0.848	–0.131
	(0.281)	(0.101)	(0.267)	(0.096)	(0.517)	(0.080)
Dual	0.147	0.123	0.146	0.122	–0.059	–0.021
	(0.098)	(0.082)	(0.097)	(0.081)	(0.165)	(0.059)
Top 1	–0.223	–0.078	–0.233	–0.082	–0.49	–0.074
	(0.350)	(0.123)	(0.340)	(0.119)	(0.915)	(0.137)
Age	–0.014	–0.212	–0.014	–0.208	0.014	0.091
	(0.012)	(0.186)	(0.012)	(0.181)	(0.019)	(0.126)
INST	0.646**	0.357**	0.634**	0.351**	–1.039**	–0.246**
	(0.261)	(0.145)	(0.243)	(0.134)	(0.439)	(0.104)
Constant	1.887***	0.162	1.949***	0.144	4.842***	–0.306*
	(0.359)	(0.135)	(0.204)	(0.195)	(0.449)	(0.165)
F	6.06		6.13		2.00	
R^2	0.157		0.156		0.100	

Table A7. Results of the mediation effect test (non-state-owned enterprises)

	Model 4.1.1		Model 4.1.2		Model 4.2.1		Model 4.2.2	
	B	β	B	β	B	β	B	β
ESG	7.081	0.106	0.023	0.053				
	(6.255)	(0.094)	(0.053)	(0.124)				
OI					1.051	0.030	–0.003	–0.013
					(4.245)	(0.121)	(0.049)	(0.217)
DL			–0.001***	–0.222***			–0.001**	–0.218**
			(0.001)	(0.083)			(0.001)	(0.083)
Lev	–101.678**	–0.236**	–1.108***	–0.399***	–108.450***	–0.251***	–1.123***	–0.404***
	(39.275)	(0.091)	(0.277)	(0.100)	(40.429)	(0.094)	(0.260)	(0.094)
Dual	24.398**	0.131**	0.182*	0.152*	23.980*	0.129*	0.180*	0.151*
	(12.006)	(0.065)	(0.097)	(0.081)	(12.509)	(0.067)	(0.096)	(0.080)
Top 1	28.324	0.064	–0.183	–0.064	25.899	0.058	–0.196	–0.069
	(48.825)	(0.110)	(0.344)	(0.121)	(46.362)	(0.105)	(0.330)	(0.116)
Age	3.685**	0.357**	–0.009	–0.132	3.764***	0.365***	–0.009	–0.129
	(1.399)	(0.136)	(0.012)	(0.180)	(1.391)	(0.135)	(0.012)	(0.177)
INST	8.675	0.031	0.659**	0.364**	1.055	0.004	0.636**	0.352**
	(29.666)	(0.106)	(0.258)	(0.142)	(28.900)	(0.103)	(0.240)	(0.133)
Constant	351.838***	0.039	2.390***	0.170	385.591***	0.024	2.489***	0.149
	(36.457)	(0.127)	(0.376)	(0.128)	(26.275)	(0.127)	(0.252)	(0.184)
F	2.7		11.82		2.49		11.24	
R^2	0.089		0.189		0.081		0.188	

Table A8. Regression results (state-owned enterprises)

	Model 2.1		Model 2.2		Model 3	
	B	β	B	β	B	β
ESG	–0.106***	–0.247***				
	(0.036)	(0.084)				
OI			–0.058***	–0.257***	0.228***	0.432***
			(0.016)	(0.069)	(0.062)	(0.118)
Lev	–0.756**	–0.272**	–0.202	–0.073	–3.542***	–0.547***
	(0.283)	(0.102)	(0.303)	(0.109)	(1.000)	(0.154)
Dual	0.157*	0.131*	0.154**	0.128**	–0.234	–0.084
	(0.081)	(0.068)	(0.071)	(0.059)	(0.315)	(0.113)
Top 1	–0.295	–0.103	–0.177	–0.062	–0.266	–0.040
	(0.191)	(0.067)	(0.258)	(0.090)	(0.927)	(0.139)
Age	–0.006*	–0.088*	–0.006*	–0.094*	–0.001	–0.006
	(0.003)	(0.050)	(0.004)	(0.054)	(0.017)	(0.110)
INST	0.060	0.033	0.135	0.074	0.777*	0.184*
	(0.105)	(0.058)	(0.127)	(0.070)	(0.405)	(0.096)
Constant	2.308***	–0.060	1.526***	–0.096	5.953***	0.084
	(0.314)	(0.115)	(0.242)	(0.116)	(0.668)	(0.146)
F	7.44		11.94		11.35	
R^2	0.263		0.235		0.306	

Table A9. Results of the mediation effect test (state-owned enterprises)

	Model 4.1.1		Model 4.1.2		Model 4.2.1		Model 4.2.2	
	B	β	B	β	B	β	B	β
ESG	14.914***	0.224***	–0.099**	–0.231**				
	(4.488)	(0.067)	(0.040)	(0.094)				
OI					8.029***	0.229***	–0.054***	–0.238***
					(2.638)	(0.075)	(0.015)	(0.066)
DL			0.000	–0.070			–0.001*	–0.084*
			(0.000)	(0.059)			(0.000)	(0.044)
Lev	–30.903	–0.072	–0.771**	–0.277**	–108.204*	–0.251*	–0.261	–0.094
	(55.270)	(0.128)	(0.293)	(0.106)	(59.728)	(0.138)	(0.322)	(0.116)
Dual	7.837	0.042	0.161**	0.134**	8.198	0.044	0.158**	0.132**
	(15.979)	(0.086)	(0.077)	(0.065)	(11.461)	(0.062)	(0.070)	(0.058)
Top 1	–47.489	–0.107	–0.316*	–0.111*	–63.650	–0.144	–0.211	–0.074
	(43.701)	(0.099)	(0.180)	(0.063)	(42.652)	(0.096)	(0.244)	(0.086)
Age	2.351***	0.228***	–0.005	–0.072	2.405***	0.233***	–0.005	–0.074
	(0.852)	(0.083)	(0.004)	(0.058)	(0.896)	(0.087)	(0.004)	(0.059)
INST	32.616	0.116	0.075	0.042	22.881	0.081	0.147	0.081
	(32.889)	(0.117)	(0.102)	(0.057)	(36.060)	(0.128)	(0.129)	(0.071)
Constant	301.665***	–0.068	2.445***	–0.065	411.260***	–0.035	1.748***	–0.099
	(58.747)	(0.141)	(0.310)	(0.119)	(56.168)	(0.146)	(0.256)	(0.120)
F	4.91		10.01		4.03		12.95	
R^2	0.141		0.273		0.129		0.248	

Table A10. Mediation effect test results with moderation (state-owned enterprises)

	Model 5.1.1		Model 5.1.2		Model 5.2.1		Model 5.2.2	
	B	β	B	β	B	β	B	β
ESG	17.114***	0.257***	–0.083*	–0.193*				
	(5.090)	(0.076)	(0.044)	(0.103)				
OI					18.788***	0.535***	–0.017	–0.074
					(3.874)	(0.110)	(0.021)	(0.093)
SA	–31.197**	–0.223**	–0.265***	–0.294***	–92.558***	–0.661***	–0.296*	–0.329*
	(15.321)	(0.109)	(0.086)	(0.096)	(23.062)	(0.165)	(0.168	(0.187)
OI*SA					8.375*	0.120*	0.026	0.059
					(4.362)	(0.062)	(0.024)	(0.054)
ESG*SA	4.933	0.071	0.053	0.118				
	(4.126)	(0.059)	(0.038)	(0.085)				
DL			–0.001	–0.089			–0.001***	–0.129***
			(0.000)	(0.073)			(0.000)	(0.045)
DL*SA			–0.012	–0.026			0.000	0.000
			(0.019)	(0.042)			(0.015)	(0.033)
Lev	–0.807	–0.002	–0.561**	–0.202**	–72.715	–0.169	–0.179	–0.065
	(62.111)	(0.144)	(0.254)	(0.091)	(52.946)	(0.123)	(0.336)	(0.121)
Dual	7.148	0.038	0.149**	0.125**	16.907	0.091	0.189**	0.158**
	(18.793)	(0.101)	(0.067)	(0.056)	(11.822)	(0.064)	(0.074)	(0.062)
Top 1	–25.395	–0.057	–0.140	–0.049	–43.481	–0.098	–0.166	–0.058
	(44.591)	(0.101)	(0.160)	(0.056)	(44.446)	(0.100)	(0.213)	(0.075)
Age	1.501	0.146	–0.011**	–0.170**	0.170	0.016	–0.011*	–0.172*
	(0.996)	(0.097)	(0.005)	(0.074)	(0.853)	(0.083)	(0.007)	(0.101)
INST	51.725	0.184	0.235*	0.130*	35.784	0.127	0.196	0.108
	(34.167)	(0.122)	(0.132)	(0.073)	(31.611)	(0.113)	(0.130)	(0.072)
Constant	148.677	–0.084	1.224***	–0.097	31.148	–0.077	0.651	–0.121
	(100.521)	(0.133)	(0.375)	(0.101)	(105.678)	(0.142)	(0.761)	(0.101)
F	6.85		10.04		5.91		9.39	
R^2	0.162		0.358		0.208		0.288	