

Article

Digital Capability Configurations and ESG Performance in International Megaprojects: An fsQCA Approach

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Highlights

How does this work contribute to systems science through systems practice, theory, and/or methodology?

- Digital capabilities are conceptualized as an interdependent project-level capability system comprising five dimensions.
- A configurational fsQCA perspective is adopted to identify multiple sufficient capability configurations and capture equifinality rather than static single-dimensional effects.

What are the main findings and/or implications of the main findings?

- Eleven sufficient configurations are identified for high environmental, social, or governance performance; environmental configurations are more analysis-oriented, social configurations emphasize sensing, and governance configurations rely more on connecting capability and agility.
- Practical suggestions, such as aligning digital investment with ESG priorities, developing complementary capability configurations, and strengthening digital information sharing and adaptive response, can help practitioners improve project-level ESG performance in megaprojects.

Abstract

Environmental, social, and governance (ESG) performance is vital for international megaprojects, but current firm-level research ignores the role of digital capabilities in project delivery. Based on dynamic capability theory, this paper examines how the combinations of digital capabilities (sensing, analysis, connecting, integration, and agility) jointly shape the project-level ESG performance of megaprojects. By combining fuzzy-set qualitative comparative analysis (fsQCA) and case study methods and using multi-source text data from 35 Belt and Road Initiative (BRI) megaprojects, an evaluation framework is developed to investigate effective causal paths. The results show that no single digital capability constitutes a necessary condition for high ESG performance. Instead, high performance is achieved through equifinality driven by non-redundant capability combinations. Specifically, analysis-oriented configurations support environmental performance through evidence-based decision-making. Sensing-oriented configurations are the basis of social performance to identify stakeholder risks. Connecting- and agility-oriented configurations improve governance performance by helping cross-organizational coordination. Suggestions are provided for practitioners, including aligning digital investment with specific ESG priorities, developing complementary capability configurations that match project governance priorities, and strengthening digital information sharing and adaptive response.



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This study helps researchers and practitioners understand the configurational effects of digital capabilities on the ESG of international megaprojects.

Keywords: digital capabilities; international megaprojects; ESG performance; fuzzy-set qualitative comparative analysis (fsQCA)

1. Introduction

In the construction industry, ESG has become an important standard for responsible development. As increasing attention is paid to project-level ESG implementation and evaluation [1], the practical focus is shifting from broad corporate commitments to concrete project actions. This shift is particularly significant for international megaprojects, where conflicting stakeholder interests, environmental sensitivity, and governance uncertainty are often concentrated. In such contexts, project-level ESG performance can directly affect contractors' social license to operate and institutional legitimacy in host countries [2,3]. Therefore, improving the ESG performance of international megaprojects has become a key challenge for the construction industry.

Digital transformation has increasingly been regarded as an important enabler of project-level ESG performance [4]. Through digital twins, the Internet of Things (IoT), and big data analytics platforms, contractors can monitor environmental changes at project sites in real time and improve resource coordination across complex project environments [5]. However, a growing body of research has also pointed to a "digitalization paradox" [3], whereby heavy investment in digital infrastructure does not necessarily translate into high project-level ESG performance. This suggests that high project-level ESG performance is not simply a product of digital investment or IT asset accumulation. Rather, it is more closely related to an organization's ability to mobilize, combine, and reconfigure digital resources under conditions of uncertainty. Such an ability is reflected in digital capability [6]. It is therefore important to examine how digital capabilities are associated with project-level ESG performance.

Research on ESG performance in construction has mainly relied on macro-level data from parent companies, offering limited insight into how ESG is managed at international project sites [1]. Prior studies have also tended to adopt a linear analytical logic, treating potential drivers as independent and additive factors. Such an approach overlooks the multidimensional and heterogeneous nature of digital capabilities and fails to capture the combined effects through which different capability dimensions may shape project outcomes [7]. In volatile multinational institutional environments, the effect of any single capability dimension is unlikely to provide a sufficient explanation of high project-level ESG performance. International megaprojects can therefore be viewed as complex socio-technical systems in which digital capabilities, project actors, and ESG governance processes are interdependent [8].

To address these gaps, this study draws on Dynamic Capability Theory and a configurational perspective to examine how different dimensions of digital capability combine to support high project-level ESG performance. In doing so, the study makes two main contributions. First, it shifts the focus of ESG evaluation from the corporate level to the project level. Second, it advances understanding of the causal complexity of digital enablement in ESG. The findings also offer practical implications for international contractors seeking to improve project sustainability through more effective digital resource orchestration. Accordingly, this study addresses the following research questions:

RQ1: How do multiple digital capabilities combine to support high project-level ESG performance in international megaprojects?

RQ2: How do configurational pathways to high environmental, social, and governance performance differ across the three dimensions?

2. Literature Review

2.1. ESG in the Construction Industry

Research on ESG in the construction industry has increasingly moved beyond corporate disclosure and reputational concerns toward the practical conditions under which sustainability is implemented in construction activities [1]. Existing studies generally suggest that ESG issues in this industry are shaped by three structural features: high environmental intensity, strong stakeholder dependence, and complex governance arrangements [1,9]. Compared with many other sectors, construction activities are more directly associated with resource consumption, emissions, community disturbance, labor management, and multi-actor coordination. As a result, ESG in the construction industry is not only a matter of corporate commitment but also a matter of how environmental, social, and governance objectives are translated into operational practice.

Within the environmental dimension, prior research has consistently shown that construction activities generate substantial pressures in terms of carbon emissions, energy use, material consumption, and waste generation [10]. Related studies further suggest that environmental performance is closely associated with life-cycle thinking, resource efficiency, and the ability to monitor and manage environmental impacts throughout project delivery [5]. In other words, environmental issues in construction are not limited to compliance with green standards but are increasingly understood as management challenges involving continuous monitoring, coordination, and improvement.

Research on the social dimension highlights that ESG in construction is strongly influenced by labor conditions, occupational health and safety, local employment, and relationships with communities and other stakeholders [2]. Existing findings indicate that social issues are particularly salient in large-scale and international projects, where construction activities may intensify tensions between contractors, workers, local communities, and host-country institutions. Several studies therefore argue that social performance depends on formal responsibility commitments, but also on whether firms can sustain meaningful engagement, protect workers, and respond effectively to local expectations during project execution [11,12].

Governance-related studies emphasize that ESG performance in construction projects is closely linked to transparency, traceable data management, accountability, and coordination across participating organizations [9]. This stream of research generally finds that governance challenges become more pronounced in cross-border settings, where projects are exposed to institutional differences, regulatory uncertainty, and fragmented responsibilities. Effective ESG governance therefore relies not only on corporate-level policies but also on the quality of decision-making, information sharing, and control mechanisms embedded in project processes [3,9].

Overall, the literature suggests that many of the most consequential ESG issues in construction ultimately emerge at the project level. Environmental impacts materialize on site, social tensions develop through day-to-day interactions, and governance quality is reflected in concrete management practices rather than in disclosure alone [1]. This need is reinforced by recent evidence from international engineering and digital infrastructure settings, where ESG risks are shaped by project-stage dynamics, governance-related events, and stakeholder complexity [3,13]. At the same time, an emerging body of research indicates that ESG implementation in construction increasingly depends on digital capabilities

and digital support mechanisms, particularly in monitoring, coordination, information reporting, and timely response [4]. This provides an important basis for examining the role of digital capabilities in project-level ESG governance.

2.2. The Role of Digital Capabilities

Digital capability refers to the higher-order dynamic ability of an organization to mobilize, integrate, and reconfigure digital resources in volatile environments [14]. High project-level ESG performance does not result from the simple accumulation of digital hardware or IT assets. Rather, it depends on how effectively an organization can configure digital resources and orchestrate them in response to uncertainty [6]. In this sense, digital capabilities allow firms to convert fragmented project data into strategic resources and embed digital tools into project governance processes [5]. In the construction industry, such capabilities have become increasingly important for contractors operating in uncertain and institutionally complex environments [4]. Recent construction research also shows that the effects of emerging digital technologies on project resilience are conditioned by relational governance, further indicating that digital technologies generate project value through interaction with governance arrangements rather than through technology adoption alone [15].

Through the lens of Dynamic Capability Theory, digital capabilities can be viewed as the ability to integrate, build, and reconfigure internal and external digital technologies and resources in response to rapidly changing environments [6,14]. For instance, digital sensing capability (DSC) helps enterprises identify external changes, institutional shifts, and emerging environmental risks in a timely manner [16]. Digital analysis capability (DAC) processes and interprets heterogeneous data from multiple sources. It provides support for evidence-based decision-making [17]. Digital integration capability (DIC) facilitates data coordination across departments, reducing communication barriers within and beyond the organization [17,18]. Digital connecting capability (DCC) strengthens interorganizational cooperation and improves information sharing and disclosure transparency [19]. In addition, digital agility (DA) enables project teams to respond rapidly to uncertainty, conflict, and changing sustainability requirements [20].

Therefore, this study identifies five dimensions of digital capability based on Dynamic Capability Theory and the relevant literature. Table 1 summarizes the analytical dimensions and their supporting literature.

Table 1. Analytical Dimensions for Digital Capability and Supporting Literature.

Dimension	References	Core Theoretical Support
1. Digital Sensing Capability (DSC)	Wohlleber et al. [16]; Warner and Wäger [6]; Baiyere et al. [21]; Zhang et al. [22].	Dynamic Capability Theory begins with sensing: organizations must detect external and operational change before seizing opportunities or reconfiguring resources. Wohlleber et al. [16] extend this logic to digital sensing, supporting DSC as the project-level capability to capture external, risk, and site-level signals.
2. Digital Analysis Capability (DAC)	Sang et al. [17]; Tumpa et al. [23]; Tumpa and Naeni [24]; Li et al. [5].	Dynamic Capability Theory requires sensed information to be interpreted before it can guide seizing and managerial action. Sang et al. [17] link big-data capability with the transformation of project data into decision-relevant information, supporting DAC as the analytical bridge between sensing and managerial response.

Table 1. *Cont.*

Dimension	References	Core Theoretical Support
3. Digital Connecting Capability (DCC)	Rajala and Hautala-Kankaanpää [19]; Gong et al. [9]; Baiyere et al. [21].	Within Dynamic Capability Theory, seizing and reconfiguration depend partly on access to external information and complementary resources. Rajala and Hautala-Kankaanpää [19] show how platform-based connectivity enables this cross-organizational linkage, supporting DCC as the capability for digital exchange and coordination across project actors.
4. Digital Integration Capability (DIC)	Abdirad [18]; Konopik et al. [25]; Liu et al. [26]; Li et al. [27].	The transforming/reconfiguring function of Dynamic Capability Theory requires resources, routines, and structures to be integrated and recombined as conditions change. Abdirad [18] identifies digital integration routines in engineering settings, supporting DIC as the project-level capability that aligns digital and organizational resources across functions and stages.
5. Digital Agility (DA)	Shi et al. [20]; Cherian et al. [28]; Teece [14]; Li et al. [3].	Dynamic Capability Theory links effective seizing and reconfiguration to rapid adjustment under uncertainty. Shi et al. [20] show the role of organizational agility in digitally enabled innovation, supporting DA as the capability to adapt or reconfigure digital practices when project conditions change.

Accordingly, the five dimensions are treated as project-level functional manifestations of the broader sensing–seizing–transforming logic of Dynamic Capability Theory rather than as five original higher-order categories of the theory. Table 1 summarizes this theoretical derivation.

Previous studies suggest that digital investment alone does not necessarily lead to improved ESG performance. The value of digitalization depends on how digital resources are mobilized, combined, and adapted to changing project conditions [3,6]. This indicates that the five digital capabilities should not be treated as isolated explanatory factors. Instead, they represent interdependent elements of project-level digital resource orchestration.

From the perspective of Dynamic Capability Theory, the contribution of one capability may depend on the presence or absence of other capabilities. Dynamic capabilities emphasize the sensing of change, the seizing of opportunities, and the reconfiguration of organizational resources in response to environmental uncertainty [6,14]. For instance, sensing capability may identify emerging environmental or stakeholder signals, but its contribution depends on whether these signals can be analyzed, shared across organizational boundaries, integrated into project processes, and translated into timely action. Similarly, strong analytical capability may have limited value when coordination or implementation capability is weak. Therefore, the effects of digital capabilities are likely to be conjunctural rather than additive.

The interdependence among different dimensions of digital capabilities is particularly important for international megaprojects. These projects operate across organizational, institutional, and national boundaries and face heterogeneous environmental, social, and governance challenges [2,29]. Different dimensions of ESG performance may therefore require different capability combinations. Environmental performance may depend more strongly on data analysis and operational control, and social performance may require timely sensing of stakeholder concerns and coordinated responses, while governance performance may rely more heavily on cross-organizational connection and integration [9,24].

Rather than examining the isolated effects of individual digital capabilities from a static perspective, this study considers how multiple dimensions of digital capabilities combine to shape the ESG performance of international megaprojects. This approach captures causal complexity, equifinality, and asymmetry and is consistent with a configurational perspective in which project-level ESG performance emerges from interactions among interdependent capabilities rather than from isolated factors [7,30].

2.3. Research Gaps

Existing research has provided important insights into ESG and digital transformation in the construction industry. However, several issues remain insufficiently addressed.

First, most prior studies examine ESG issues at the corporate level and rely heavily on firm-level disclosures, financial reports, or other macro-level data. As a result, they provide limited insight into how ESG is enacted, managed, and evaluated at international project sites [1]. Yet project sites are where environmental impacts occur, social tensions emerge, and governance practices are implemented most directly. A project-level perspective is therefore necessary.

Second, current research often adopts a linear analytical logic when examining the drivers of ESG performance, assuming that individual factors exert independent and additive effects. However, digital capabilities are multidimensional and heterogeneous, and their effects are often interdependent rather than isolated. In complex international projects, high project-level ESG performance is unlikely to be explained by any single capability alone. Instead, it may result from different capability configurations. This causal complexity has not been sufficiently addressed in existing studies [3].

Third, project-level ESG evaluation remains underdeveloped. Existing research offers limited guidance on how to identify and operationalize ESG indicators at the project level, especially in ways that reflect the specific characteristics of the construction industry [4]. In particular, there is still insufficient understanding of how digital technology applications can be meaningfully linked to concrete ESG criteria in project settings [1].

3. Methodology and Research Design

This study adopts a three-stage research design to investigate how digital capabilities jointly shape project-level ESG performance. The design combines case selection and corpus construction, project-level ESG framework development and evidence organization, and configurational analysis. It connects project-level evidence with theory in a transparent and systematic way. As shown in Figure 1, the theoretical and literature foundation precedes the three empirical stages and informs the definition of the five digital capability conditions and three ESG performance sets.

International megaprojects under the Belt and Road Initiative (BRI) provide the empirical setting of this study. BRI projects are typically cross-border, capital-intensive, and institutionally complex, making them a suitable context for examining project-level ESG challenges. They also involve diverse stakeholders, strong environmental sensitivity, and high governance uncertainty. These characteristics make BRI megaprojects an appropriate setting for investigating how digital capabilities are associated with project-level ESG performance.

This study examines project-level ESG performance from a configurational perspective, with particular attention to how different digital capabilities combine to support high project-level ESG performance. This design contributes to the development of project-level ESG evaluation and advances understanding of the configurational effects of digital capabilities in complex international construction contexts.

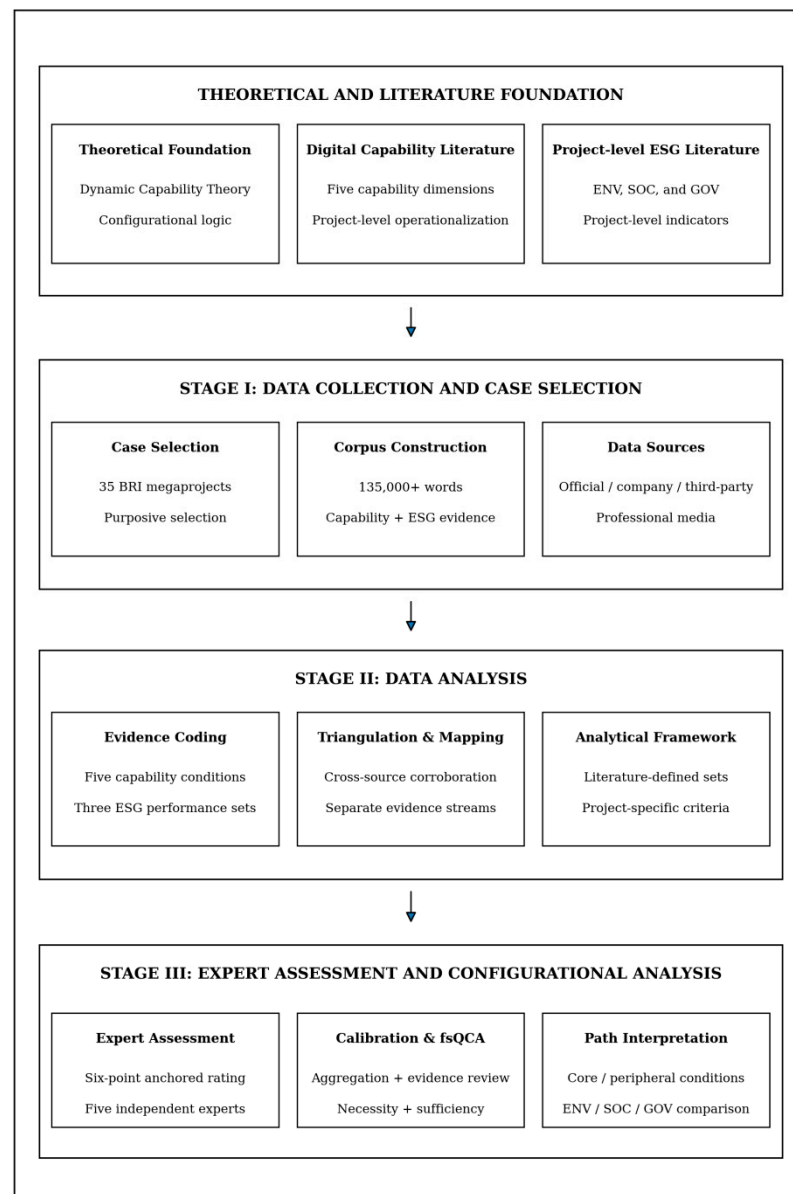


Figure 1. Research design process.

3.1. Stage I: Data Collection and Case Selection

Through criterion-based purposive case selection, 35 international megaprojects under the Belt and Road Initiative are included in the final sample. Candidate projects are screened according to whether they fit the BRI megaproject context and provide sufficient project-level evidence for evaluating digital capabilities and ESG performance. Transportation, energy, petroleum, and construction projects make up most of the sample because they are prominent sectors in Belt and Road cooperation and are closely associated with environmental, social, and governance challenges.

A multi-source textual corpus of more than 135,000 words is constructed to capture digital capability deployment and project-level ESG practices. The corpus includes four types of material. First, official sources such as government bulletins, regulatory announcements, and project portals are used to identify project background, policy context, and formally disclosed implementation information. Second, project-level ESG reports, sustainability reports, annual reports, and corporate social responsibility disclosures issued by contractors and project participants are used to identify reported ESG actions and digital practices. Third, third-party documents such as audit reports, environmental assessments, and pro-

professional evaluation reports are used to verify whether reported practices are supported by external evidence. Fourth, in-depth reports from professional financial and industry media provide supplementary information on project implementation, stakeholder issues, and public controversies that may not appear in official disclosures.

To improve source transparency and traceability, the project-level source records were organized into a case-by-case inventory. Supplementary Data S1 reports the sources used for each of the 35 projects, including the document or webpage, year/date, language, issuer, relationship to the project, URL, and project-level source counts. It further classifies source provenance as independent external, external government/public information, project-related, or contractor/project-participant disclosure, enabling direct inspection of source independence across the cases.

The study adopts a triangulation strategy during data collection and screening to strengthen the credibility of the corpus [31,32]. As summarized in Table 2, important project-level facts are not retained on the basis of a single source where corroborating material is available. Instead, the research team compares information across different source types to assess the consistency of evidence related to digital deployment and ESG practices. For example, when a contractor reports the use of a carbon-monitoring system, the team seeks corresponding support from project news, third-party assessments, government releases, or other project-level records. Because documentation availability varies across cases, identical source combinations are not required for every project; however, key coded facts must be supported by sufficiently credible and, where possible, heterogeneous evidence. When a fact can be corroborated by at least two different source types, it is treated as strong coding evidence. In addition, two research teams conducted coding independently and cross-checked key coded facts to reach consensus, reducing the risk of overreliance on symbolic disclosure.

Table 2. Data sources and their roles in triangulation.

Source Type	Examples	Primary Role	Use in Triangulation
Official sources	Government bulletins, regulatory announcements, and project portals	Confirm project background, policy context, and officially disclosed implementation facts	Cross-check reported project actions and implementation claims
Company disclosures	Project ESG, sustainability, annual reports, CSR disclosures	Identify reported ESG measures and digital practices	Verify against official, third-party, or media evidence
Third-party documents	Audit reports, environmental assessments, professional evaluation reports	Provide external evidence of actual practices	Assess whether reported practices receive independent support
Professional media	Financial media, industry reports, project news	Add implementation details, stakeholder issues, and controversies	Provide contextual information and supplementary verification

3.2. Stage II: Data Analysis

The purpose of Stage II is to develop and refine the project-level ESG evaluation framework reported in Table 3. The analysis begins with ESG dimensions and indicators identified from previous studies in engineering management and ESG evaluation [1,3]. These literature-based categories are then compared with the project-level evidence corpus to assess their relevance to international megaproject settings.

Table 3. Project-level ESG evaluation framework.

Dimension	First-Order Indicator	Second-Order Indicator
Environmental performance	Environmental management	Carbon emission reduction
		Effective environmental management system
	Resource utilization	Sustainable design and material use
		Waste management
		Water use efficiency
		Land use management
		Construction material efficiency
	Ecological protection	Energy use efficiency
		Biodiversity protection
		Fauna and flora protection Natural habitat protection
	Pollution prevention	Air pollution prevention
Water pollution prevention		
Land pollution prevention		
Noise pollution prevention		
Social performance	Staff and labor	Employee well-being
		Vocational training and education
	Local development	Health and safety
		Salary and benefits scheme
		Local infrastructure improvement
		Local employment creation
	Cultural integration	Local fiscal contribution
		Alignment with host-country development interests
The general public	Bilateral relationship enhancement	
	Mutual benefit creation	
	Product quality, health and safety	
Governance performance	Governance structure	Community philanthropy
		Public crisis response
		Organization structure optimization
	Governance mechanism	Stakeholder participation and role clarity
		Goal-setting and accountability system
Transparency and disclosure management		
	Conflict resolution mechanism	
	Incentive mechanism	
	Interorganizational coordination mechanism	

The project corpus is then reviewed to identify evidence relevant to the ESG indicators in Table 3 and to document project-level manifestations of the five digital capability dimensions established in Section 2.2. For the ESG framework, the evidence is used to refine and operationalize environmental, social, and governance indicators. For the digital capability conditions, the evidence is organized according to the predefined dimensions of DSC, DAC, DCC, DIC, and DA and is subsequently used as the basis for expert membership assessment in Stage III.

Through iterative content analysis, indicators that are too general, difficult to observe at the project level, or inconsistent with the empirical context are revised or removed. At the same time, recurring project-level practices that are not sufficiently represented in existing

corporate-level ESG frameworks are incorporated into the framework. In this way, the final ESG evaluation framework combines theoretical foundations from prior research with empirical refinement based on the 35 project cases.

For subsequent set-membership assessment, condition evidence and ESG performance evidence are organized as separate streams. The same source category may contribute to both streams, but the same evidence unit is not used as the primary basis for both condition and performance assessment. Key coded facts are checked against the original source materials, and highly promotional or vague claims require corroborating evidence before they are retained as substantive project-level practices.

3.3. Stage III: Expert Assessment and Configurational Analysis

Fuzzy-set membership for the five digital capability conditions and three project-level ESG performance sets is assessed through structured expert interviews supported by a standardized six-point Likert-type anchored rating form. Five experts complete the assessment independently using the same set definitions and project-specific evidence packages. Their professional backgrounds cover international engineering digitalization and data platforms, project control and BIM integration, environmental and HSE management, social impact and stakeholder management, and project governance and fsQCA. For each project-set combination, experts review the available supporting and limiting evidence before assigning a rating, and the subsequent fsQCA solutions are not available to them during the assessment.

The six ordered categories range from 1 = clearly absent to 6 = clearly present and are linked a priori to fuzzy-set membership anchors of 0.05, 0.20, 0.40, 0.60, 0.80, and 0.95. The use of substantively defined qualitative anchors and transparent case-based membership evaluation follows established fsQCA calibration practice [7,33,34]. The arithmetic mean of the five independently assigned memberships is used as the initial aggregate membership and is then checked against the corresponding project evidence. This calibration review follows established fsQCA calibration practice, in which set membership is determined using theoretical and case knowledge [35,36]. Tóth, Henneberg, and Naudé [33] provide a structured approach to translating qualitative evidence into fuzzy-set memberships through the Generic Membership Evaluation Template (GMET). Kammerlander, Kurta, and Heider [37] apply this approach by preparing assessments based on case evidence, assigning scores using predefined thresholds, averaging component scores, and discussing the GMET assessments until consensus is reached. This study adapts these procedures for a panel of five experts.

The initial mean for each project-set combination is checked against the corresponding evidence. Additional review is required when ratings fall on both sides of the 0.5 crossover, at least one expert flags limited evidence, or the sample standard deviation of the five anchored memberships is at least 0.12. These predefined criteria determine whether additional review is required. They do not require an adjustment or specify its direction or size. During both routine and additional review, the panel examines the supporting and limiting evidence in relation to the set definition and the qualitative meaning of the anchors. If the panel judges that the initial mean slightly overstates or understates set membership, the adjustment and final continuous membership are determined through documented case-by-case expert consensus. The numerical adjustment therefore rests on the panel's assessment of the case evidence rather than on a predefined adjustment formula. The fsQCA solutions were not available to the experts during calibration. Supplementary Data S2 records the initial mean, review status, signed adjustment, and final membership, while Supplementary S2-4 documents the supporting and limiting evidence for each project-set combination.

Repeated values of 0.950 and 0.050 in Table 4 represent predefined qualitative anchors for cases assessed as clearly present or clearly absent; they are not produced by post-hoc truncation, winsorization, or imposed numerical ceilings and floors. Intermediate three-decimal membership values arise from the aggregation of the five anchored ratings and the subsequent evidence-based calibration review. Detailed expert profiles, rating anchors, individual ratings, aggregation records, reliability statistics, and an illustrative calibration example are provided in Supplementary Data S2.

Table 4. Case Background and Fuzzy-set Membership Matrix.

ID	Project Name	Sector	DSC	DAC	DCC	DIC	DA	ENV	SOC	GOV
1	Mombasa–Nairobi Railway	Transportation	0.950	0.488	0.561	0.219	0.728	0.591	0.267	0.717
2	Piraeus Port	Transportation	0.066	0.950	0.349	0.651	0.050	0.623	0.950	0.524
3	China–Russia East Route Pipeline	Petroleum	0.200	0.491	0.507	0.505	0.376	0.938	0.950	0.950
4	Gwadar Port	Transportation	0.925	0.498	0.528	0.524	0.476	0.491	0.950	0.740
5	China–Laos Railway	Transportation	0.877	0.412	0.449	0.050	0.850	0.295	0.121	0.342
6	Padma Bridge	Transportation	0.649	0.501	0.663	0.322	0.634	0.562	0.353	0.950
7	Kyrgyzstan North–South Road	Transportation	0.925	0.638	0.357	0.638	0.374	0.158	0.950	0.748
8	China–Myanmar Oil & Gas Pipeline	Petroleum	0.288	0.950	0.566	0.603	0.050	0.345	0.145	0.843
9	Dubai CSP Plant	Energy	0.950	0.535	0.766	0.583	0.652	0.712	0.399	0.473
10	Peljesac Bridge	Transportation	0.255	0.950	0.535	0.469	0.050	0.938	0.950	0.500
11	Karot Hydropower Project	Energy	0.603	0.950	0.647	0.465	0.050	0.938	0.074	0.765
12	Hungary–Serbia Railway	Transportation	0.950	0.447	0.936	0.626	0.688	0.661	0.447	0.439
13	Tel Aviv Light Rail	Transportation	0.950	0.569	0.354	0.568	0.432	0.788	0.859	0.571
14	Puttalam Power Station	Energy	0.950	0.174	0.251	0.332	0.423	0.433	0.234	0.564
15	Egypt New-Capital CBD	Construction	0.800	0.950	0.669	0.877	0.950	0.735	0.122	0.525
16	Lekki Deep-Sea Port	Transportation	0.050	0.073	0.805	0.622	0.377	0.548	0.353	0.950
17	Jakarta–Bandung High-Speed Railway	Transportation	0.950	0.496	0.778	0.062	0.909	0.802	0.084	0.519
18	Karachi Nuclear-Power Plant	Energy	0.076	0.950	0.431	0.571	0.050	0.938	0.950	0.551
19	Gisé Hydropower Station	Energy	0.950	0.600	0.439	0.520	0.628	0.938	0.403	0.687
20	Nam Ou River Hydropower Project	Energy	0.950	0.885	0.722	0.870	0.921	0.315	0.127	0.106
21	Zhanatas Wind-Power Project	Energy	0.950	0.417	0.777	0.658	0.763	0.711	0.554	0.379
22	China–Belarus Industrial Park	Construction	0.950	0.492	0.848	0.339	0.909	0.808	0.342	0.891
23	Belo Monte Transmission Project	Energy	0.341	0.342	0.627	0.050	0.609	0.627	0.811	0.848
24	Montenegro North-South Highway	Transportation	0.950	0.371	0.577	0.483	0.913	0.536	0.106	0.679
25	Etihad Rail	Transportation	0.950	0.492	0.757	0.170	0.618	0.665	0.173	0.650
26	Addis Ababa–Djibouti Railway	Transportation	0.918	0.492	0.664	0.050	0.851	0.844	0.086	0.586
27	Walvis Bay Railway	Transportation	0.061	0.950	0.236	0.765	0.050	0.610	0.950	0.489
28	Karnaphuli River Tunnel	Transportation	0.950	0.477	0.574	0.067	0.796	0.353	0.073	0.721
29	Gwadar New International Airport	Transportation	0.881	0.473	0.644	0.050	0.578	0.315	0.124	0.718
30	Hambantota Port	Transportation	0.950	0.096	0.672	0.485	0.657	0.628	0.288	0.626
31	Djibouti Multi-Purpose Port	Transportation	0.950	0.500	0.673	0.050	0.684	0.795	0.080	0.343
32	Serbian Motorway	Transportation	0.950	0.469	0.492	0.472	0.526	0.787	0.792	0.697
33	Lahore Orange-Line Metro	Transportation	0.560	0.499	0.521	0.477	0.574	0.432	0.950	0.059
34	Siem Reap International Airport	Transportation	0.359	0.122	0.767	0.050	0.950	0.233	0.120	0.678
35	Iran Yadavaran Oilfield	Petroleum	0.415	0.538	0.228	0.433	0.491	0.938	0.228	0.950

Note: Membership values are displayed to three decimal places. The values shown as 0.500 for Peljesac Bridge–GOV and Djibouti Multi-Purpose Port–DAC correspond to full-precision values of 0.499998 and 0.499808, respectively, and therefore remain below the 0.5 crossover. Full-precision membership values reported in Supplementary Data S2 were used in all fsQCA analyses.

Inter-rater reliability is assessed across all 280 project-set combinations (1400 ratings) using a two-way random-effects model with absolute agreement. The calculations were implemented in Python 3.13 using NumPy 2.3.5 and SciPy 1.17.0, following the ICC(A,1)/ICC(A,k) inference framework of McGraw and Wong [38]. The resulting ICC statistics are reported in Section 4.1 and documented in Supplementary Data S2.

The final membership matrix is entered into fsQCA 3.0. Necessity analysis first assesses whether any individual condition consistently appears in cases with high project-level ESG performance. A truth table is then constructed, and parsimonious and intermediate solutions are compared to distinguish core and peripheral conditions within sufficient configurations [35]. This procedure identifies how combinations of digital capabilities are associated with high environmental, social, and governance performance while preserving the case-based interpretation of the underlying evidence.

4. Results and Analysis

4.1. Analytical Conditions and Membership Assessment

The five digital capability conditions used in the fsQCA were established in Section 2.2 through Dynamic Capability Theory and the supporting literature rather than derived from case coding. The project evidence collected in Stages I and II was then organized under these predefined dimensions and used as the basis for expert membership assessment. The five conditions are digital sensing capability (DSC), digital analysis capability (DAC), digital connecting capability (DCC), digital integration capability (DIC), and digital agility (DA).

DSC captures the digital sensing of environmental changes, external risks, and operational signals at the project site [16]. DAC captures the processing and interpretation of project data for evidence-based decision-making [17]. DCC reflects digitally enabled information exchange and coordination across teams and organizations [19]. DIC reflects the integration and reconfiguration of digital and organizational resources across project activities [18]. DA reflects the capacity to adjust digitally enabled practices rapidly in response to uncertainty and changing project requirements [20]. Figure 2 summarizes their analytical relationship with project-level ESG performance.

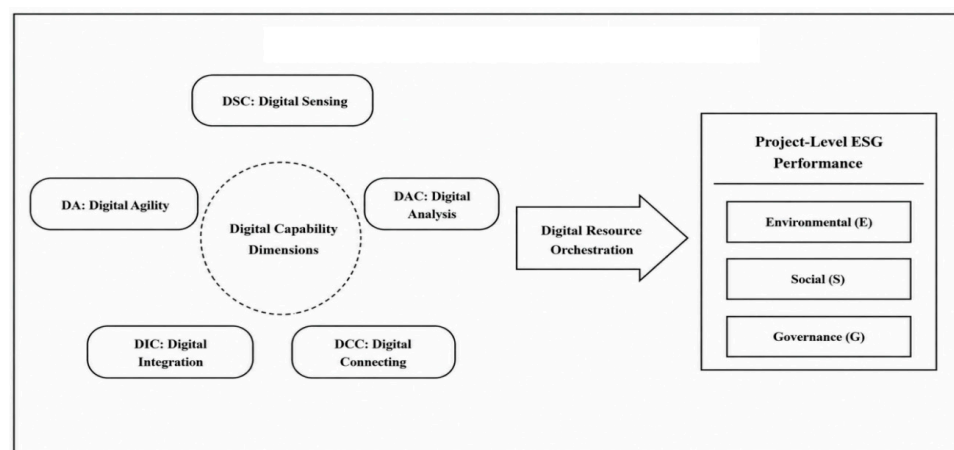


Figure 2. Configurational Analysis Model.

The five digital capability conditions and the three project-level ESG performance sets are calibrated from the project evidence using the structured expert-assessment procedure described in Section 3.3. Table 4 reports the final evidence-reviewed membership scores. Because the assessment combines predefined qualitative anchors, independent expert judgments, aggregation, and case-based evidence review, the matrix contains both repeated anchor values and intermediate three-decimal membership values.

Inter-rater agreement is high across the complete assessment matrix: $ICC(2,1) = 0.871$ (95% CI [0.845, 0.894]) and $ICC(2,5) = 0.971$ (95% CI [0.965, 0.977]). These results support the consistency of the expert assessments used to construct the final membership matrix.

The aggregated project-level fuzzy-set membership scores are reported in Table 4. This procedure connects the multi-source project evidence directly with the membership of each analytical set and provides the empirical basis for the subsequent necessity and sufficiency analyses.

4.2. Digital Capability Membership Matrix and Truth Table

The final sample comprises 35 BRI megaprojects across construction, petroleum, energy, and transportation. Table 4 reports fuzzy-set memberships for the five digital capability conditions (DSC, DAC, DCC, DIC, and DA) and the three dimensions of project-level ESG performance (environmental, social, and governance performance). Memberships are calibrated from the project evidence described in Sections 3.1–3.3, with condition evidence and performance evidence organized separately.

Before configurational analysis, fsQCA 3.0 generates a truth table with 32 logically possible combinations. Because the sample contains 35 cases, the case-frequency threshold is set to 1 so that empirically uncommon but potentially relevant configurations are not discarded prematurely [36]. The raw-consistency threshold is set to 0.80 and the PRI-consistency threshold to 0.75, providing the basis for the subsequent necessity and sufficiency analyses.

4.3. Necessary Condition Analysis

Before assessing configurational sufficiency, each digital capability is tested as a potential necessary condition. A consistency value of 0.90 is used as the conventional benchmark for necessity [36]. As Table 5 shows, none of the five capabilities reaches this threshold for high environmental, social, or governance performance. Therefore, no single digital capability is necessary for high performance in any of the three ESG dimensions.

Table 5. Necessary condition analysis.

	High Environmental Performance		High Social Performance		High Governance Performance	
	Consistency	Coverage	Consistency	Coverage	Consistency	Coverage
DSC	0.769	0.693	0.655	0.411	0.741	0.660
~DSC	0.395	0.824	0.528	0.768	0.399	0.824
DAC	0.735	0.842	0.777	0.621	0.699	0.792
~DAC	0.589	0.824	0.572	0.558	0.636	0.879
DCC	0.781	0.845	0.666	0.503	0.776	0.830
~DCC	0.596	0.898	0.659	0.692	0.604	0.899
DIC	0.586	0.879	0.690	0.722	0.558	0.827
~DIC	0.725	0.786	0.663	0.501	0.764	0.819
DA	0.707	0.793	0.570	0.446	0.685	0.760
~DA	0.600	0.861	0.764	0.764	0.595	0.843

This result is consistent with the configurational logic of fsQCA: high project-level ESG performance cannot be explained by any single digital capability alone. Instead, multiple capability configurations may be associated with high performance across different ESG dimensions, supporting the use of a configurational approach in this study.

4.4. Sufficiency Analysis

Sufficiency analysis is conducted in fsQCA 3.0. Parsimonious and intermediate solutions are compared to distinguish core from peripheral conditions: conditions appearing in both solutions are treated as core, whereas conditions appearing only in the intermediate solution are treated as peripheral [7]. In Table 6, large solid circles indicate the presence of core conditions, and large crossed circles indicate their absence; small solid and crossed circles indicate the presence and absence of peripheral conditions, respectively, while blank cells denote “do not care” conditions. The raw-consistency threshold remains 0.80 and the PRI-consistency threshold 0.75.

Table 6. Configurations for high ESG performance of international megaprojects.

Cause Factors	High Environment			High Social				High Governance			
	Env1	Env2	Env3	Soc1	Soc2	Soc3	Soc4	Gov1	Gov2	Gov3	Gov4
DSC		●	●	●	⊗	⊗	●	●		●	⊗
DAC	●	●		●	●	●	⊗	●	⊗	●	⊗
DCC	●		●		●	⊗	●	●	●		●
DIC		●	●	●	⊗	●	●		⊗	●	●
DA	●	⊗	●	⊗		⊗		●	●	⊗	
Consistent	0.901	0.944	0.919	0.907	0.900	0.875	0.908	0.872	0.923	0.946	0.905
Raw coverage	0.521	0.293	0.399	0.429	0.357	0.372	0.488	0.435	0.566	0.337	0.095
Unique coverage	0.145	0.035	0.061	0.066	0.062	0.081	0.059	0.018	0.026	0.073	0.026
Solution consistency	0.914			0.867				0.905			
Solution coverage	0.617			0.697				0.688			

The larger circles (●) and (⊗) represent the presence and absence of core conditions. The smaller circles (●) represent the presence and absence of peripheral conditions respectively. The blank spaces indicate that the condition is “do not care”.

Table 6 identifies multiple configurational pathways associated with high project-level ESG performance. For high environmental performance, Env1, Env2, and Env3 are the three identified configurations, with consistency values of 0.901, 0.944, and 0.919 and raw coverage values of 0.521, 0.293, and 0.399, respectively. The total solution coverage of 0.617 indicates that these three configurations jointly account for a substantial share of the high-environmental-performance cases. Env1 has the highest raw coverage and therefore exhibits the greatest empirical relevance among the environmental configurations. Digital analysis capability appears across several environmental configurations, while digital agility and digital connecting capability also appear in specific combinations. These patterns indicate that high environmental performance is associated with capability configurations that convert project-site information into operational control. In megaprojects, such information may concern construction-stage environmental risks, energy efficiency, ecological protection, pollution control, and resource use. The Dubai CSP Plant illustrates this logic: project-level data are used to support environmental management, resource scheduling, and energy-efficiency decisions, reflecting the role of digital analysis capability in translating site-level information into evidence-based environmental governance.

For high social performance, four configurations are identified (Soc1, Soc2, Soc3, and Soc4), with consistency values of 0.907, 0.900, 0.875, and 0.908, respectively. The overall solution consistency is 0.867 and the solution coverage is 0.697. Digital sensing capability is particularly prominent and appears as a core present condition in Soc4, indicating

the importance of identifying stakeholder concerns at an early stage. In international megaprojects, social risks often arise from employment, community relations, land use, labor conditions, public communication, and host-country expectations rather than from technical failures alone. The Mombasa–Nairobi Railway illustrates this configuration through its emphasis on local employment, workforce training, community engagement, and mechanisms for responding to public concerns.

For high governance performance, four configurations are identified (Gov1, Gov2, Gov3, and Gov4). The overall solution consistency is 0.905 and the solution coverage is 0.688. Digital connecting capability appears repeatedly as a core condition, indicating the importance of information sharing, platform-supported coordination, and interorganizational communication for governance-related performance. In some configurations, digital connecting capability is combined with digital agility; in others, digital analysis and integration capabilities play a more prominent role. The results therefore suggest that high governance performance can be associated with both adaptive cross-organizational coordination and structured internal integration. The Montenegro North–South Highway provides an example of this connection-oriented governance logic: platform-supported information exchange, coordination among project participants, and alignment of operational decisions across organizational boundaries are associated with its high governance performance.

Overall, the three ESG dimensions exhibit distinct capability logics. The analytical use of project data is more prominent in environmental performance, early identification of stakeholder concerns is more prominent in social performance, and cross-organizational digital connection and adaptive coordination are more prominent in governance performance. Digital capabilities therefore do not operate as a uniform driver of ESG performance; their contribution depends on the ESG task being addressed and on the capability configuration through which digital resources are mobilized.

4.5. Robustness Analysis

To assess the stability of the configurational results, two robustness tests are conducted following established QCA practice [39,40]. The raw-consistency threshold is increased from 0.80 to 0.85 and the analysis is rerun. In addition, a leave-one-case-out (LOO) sensitivity analysis removes one project at a time and recalculates solution consistency and coverage. This case-deletion procedure assesses whether the reported configurations depend disproportionately on any single project.

As Table 7 shows, the main configurational patterns remain stable under both robustness checks. The environmental, social, and governance configurations are retained when the raw-consistency threshold is increased, and the 35 leave-one-case-out runs produce only limited changes in solution consistency and coverage. The principal configurational findings are therefore not driven by the original threshold setting or by any single project.

Table 7. Robustness and sensitivity analysis.

Target Aspect	Baseline Settings	0.85 Threshold	LOO Consistency	LOO Coverage	Robustness Check
Environment	Env1, Env2, Env3	Env1, Env2, Env3	0.905–0.938	0.607–0.641	Highly robust
Social	Soc1, Soc2, Soc3, Soc4	Soc1, Soc2, Soc3, Soc4	0.857–0.893	0.697–0.724	Robust
Governance	Gov1, Gov2, Gov3, Gov4	Gov1, Gov2, Gov3, Gov4	0.894–0.933	0.665–0.689	Highly robust

Note: LOO = leave-one-case-out. The adjusted analysis increases the raw consistency threshold from 0.80 to 0.85. In the LOO analysis, each of the 35 projects is removed once and solution consistency and coverage are recalculated to assess whether the results depend on any single case.

5. Discussion

5.1. Discussion of Key Findings

Drawing on Dynamic Capability Theory, this study uses fsQCA to examine how configurations of digital capabilities are associated with project-level ESG performance in international megaprojects. The results provide three main insights into the relationship between digitalization and sustainable project governance.

First, project-level ESG performance is characterized by configurational rather than capability-specific effects. The necessity analysis shows that high environmental, social, or governance performance cannot be explained by any single digital capability dimension. This does not imply that individual capabilities are unimportant; rather, their contribution depends on how they are combined with other capabilities in specific project contexts. Consistent with the central argument of this study, digitally enabled ESG performance is associated with contextually aligned and dimension-specific capability configurations rather than with the isolated possession of any single capability. From a systems perspective, sensing, analysis, connecting, integration, and agility form an interdependent capability system and must be jointly organized within the broader project system.

Second, configurational pathways to high project-level ESG performance are not uniform. Multiple configurations are associated with high environmental, social, and governance performance, consistent with the equifinality emphasized in configurational research [7]. This extends research on international engineering project management by showing that dynamic capabilities contribute to sustainable project delivery through different combinations rather than through a single net-effect mechanism [3]. The results further show that these configurational effects differ across ESG dimensions. Digital capability therefore does not operate as a uniform driver of ESG performance; its contribution depends on the specific capability configuration and project context.

Third, each dimension of project-level ESG performance exhibits a distinct capability logic. Digital analysis capability is more prominent in the environmental configurations, consistent with prior research showing that digital technologies can support project sustainability through information processing and stakeholder collaboration [5]. Digital sensing capability is more prominent in the social configurations because social performance depends strongly on the early identification of worker, community, and stakeholder concerns. Digital connecting capability and digital agility are more prominent in the governance configurations, reflecting the importance of information sharing and timely cross-organizational response.

These findings also clarify the non-linear nature of the “digitalization paradox” discussed in prior research [3]. High project-level ESG performance is associated not simply with the scale of digital investment but with how digital capabilities are configured to mobilize, integrate, and adapt digital resources. The same capability may contribute differently under different governance objectives and institutional conditions because its role depends on the surrounding capability configuration. This provides a project-level explanation of how digitalization can support sustainable governance in international megaprojects.

The findings also provide a direct response to the two research questions. For RQ1, the necessity and sufficiency analyses show that the five digital capabilities operate as an interdependent capability system rather than as isolated performance drivers, and the eleven sufficient configurations demonstrate equifinality across alternative capability combinations. For RQ2, the configurations reveal different capability logics across environmental, social, and governance performance, with analysis more prominent in environmental configurations, sensing in social configurations, and connecting capability and agility in governance configurations.

5.2. Theoretical Contributions

First, this study shifts the ESG discussion in megaproject research from corporate-level disclosure to project-level implementation. Firm-level reports are useful for evaluating corporate responsibility, but they provide limited insight into how ESG practices are implemented during project delivery. By developing environmental, social, and governance indicators at the project level, this study shows that ESG performance is also shaped by on-site decisions, stakeholder interactions, and the governance arrangements of project participants.

Second, this study refines the application of Dynamic Capability Theory to digitalized international megaprojects by operationalizing digital capability through five interdependent project-level dimensions. Their value lies not in isolated technological accumulation but in project-level digital resource orchestration. The study therefore provides a more granular explanation of how digital capabilities operate under complex multinational institutional conditions [6].

Third, this study contributes to configurational and systems-oriented research on international engineering projects. Different ESG dimensions are associated with different capability logics, meaning that the same digital capability may play different roles depending on whether the project objective concerns environmental control, social responsiveness, or governance coordination. This helps explain why similar levels of digitalization can be associated with different sustainability outcomes across projects. Comparable levels of project-level ESG performance can emerge from different combinations of interdependent capability elements, reflecting equifinality within international megaproject systems [41].

5.3. Practical Implications

This study also offers practical implications for the management of international megaprojects.

First, digital investment should be aligned with specific ESG priorities rather than treated as a uniform accumulation of technologies. Under resource constraints, management teams should identify the most pressing ESG challenges and invest in the capabilities most relevant to those challenges. For environmental management, data-analysis systems supporting emissions monitoring, resource consumption, and pollution control should be prioritized. For social management, digital sensing and feedback mechanisms should be strengthened to identify local employment issues, community concerns, and stakeholder expectations. For governance objectives, stronger connecting capability can improve information exchange and coordination across organizational boundaries.

Second, the findings highlight the importance of capability alignment. High project-level ESG performance is not associated with maximizing every digital function independently but with developing complementary capability configurations that match project governance priorities. This is particularly important in international megaprojects, where stakeholder complexity, information asymmetry, and regulatory uncertainty are pronounced.

Third, the findings underscore the value of digital information-sharing mechanisms in multinational project governance. Stronger digital connectivity and faster adaptive response may reduce communication barriers, improve transparency, and mitigate compliance risks. Improved digital coordination may also help contractors maintain a longer-term social license to operate in host-country environments [3].

6. Conclusions and Future Research

6.1. Conclusions

Based on 35 Belt and Road Initiative megaprojects, this study examines how digital capabilities are associated with project-level ESG performance and identifies configurational mechanisms using Dynamic Capability Theory and fsQCA. The analysis links different capability configurations with high environmental, social, and governance performance.

The findings show that the relationship between digitalization and ESG performance is configurational rather than linear. No single digital capability is a necessary condition for high project-level ESG performance. Instead, high project-level ESG performance can be associated with multiple equifinal configurational pathways. Across the three ESG dimensions, digital capabilities play different roles: digital analysis capability is more prominent in environmental configurations, digital sensing capability is more prominent in social configurations, and digital connecting capability is more prominent in governance-related configurations. Practical suggestions are provided for practitioners, including aligning digital investment with specific ESG priorities, developing complementary capability configurations that match project governance priorities, and strengthening digital information sharing and adaptive response. The study therefore adds project-level empirical evidence on digital resource orchestration in sustainable project governance.

6.2. Limitations and Future Research

The study has several limitations. First, the case evidence is drawn mainly from public project documents, reports, and media materials and may not fully capture informal governance processes, unresolved implementation problems, or negative project-level ESG performance. Triangulation improves credibility but cannot completely eliminate selective disclosure, official framing, uneven documentation, or promotional presentation. A substantial share of the retained evidence originates from governmental/public-information, project-related, or contractor/project-participant sources rather than fully independent external sources. Although provenance coding and triangulation reduce this concern, source independence cannot be assumed for every case, and positive-framing bias may remain. Future research could combine document-based evidence with interviews, field observations, host-country stakeholder evidence, or internal project data. Second, expert calibration necessarily involves interpretive judgment. In this study, common rating anchors, independent expert assessments, evidence review, and inter-rater agreement checks improve the transparency of the calibration procedure, but future studies could compare alternative expert-panel compositions or calibration schemes. Finally, the cross-sectional design cannot fully capture how digital capability configurations evolve across project stages. Longitudinal research could examine whether sensing, analysis, connecting, integration, and agility play different roles during planning, construction, operation, and post-project evaluation.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/systems14101314/s1>. Supplementary Data S1 documents the case-level documentary evidence used in the study and its provenance across the 35 international megaprojects. Supplementary Data S2 documents the expert-based calibration procedure, including the rating protocol, set definitions, individual assessments, aggregation records, reliability checks, and the final fuzzy-set membership matrix.

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Data Availability Statement: The processed project-level membership data supporting the configurational analysis are reported in the article. The project-level source inventory and structured expert-rating, aggregation, and calibration records are provided in the Supplementary Materials. The underlying project documents remain subject to their original public-access conditions.

Conflicts of Interest: The authors declare no conflicts of interest.

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