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An AI-Assisted Environmental Data Governance Architecture for MRV in Sustainable Infrastructure

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Abstract— Achieving global net-zero ambitions requires infrastructure sectors to move beyond aspirational sustainability narratives toward verifiable, data-driven environmental accountability. The construction industry, responsible for a significant share of global greenhouse gas emissions, struggles with fragmented environmental data, partial lifecycle assessments, and weak mechanisms for measurement, reporting, and verification (MRV). These challenges undermine policy credibility and the integrity of environmental claims.

This research proposes designing an AI-assisted environmental data governance framework to enable traceable, auditable, and ethically governed environmental performance assessment across the full lifecycle of infrastructure projects. The study positions Offsite Construction (OSC) as a demonstrative case, given its higher levels of process standardisation and digital maturity compared to traditional construction. While OSC offers structural advantages for data capture and traceability, existing datasets remain siloed, inconsistently governed, and weakly linked end-of-life performance.

The research maps current OSC environmental data practices in the United Kingdom, identifies governance gaps that limit lifecycle integration and MRV compliance, designs a standardised data governance architecture that links design, construction operations and an AI-assisted MRV prototype, using selected OSC case studies.

The research contributes theoretically by foregrounding data governance as foundational infrastructure for environmental accountability, methodologically by repositioning AI as a governance-support tool rather than a black-box predictor, and empirically by advancing understanding of OSC's role in sustainable infrastructure delivery. Beyond construction, the framework offers a transferable model for strengthening environmental accountability across other infrastructure sectors, supporting credible climate policy, green finance, and net-zero delivery.

Keywords— Artificial Intelligence, Data Governance; Offsite Construction; Net-Zero Accountability; Green Claims Directive; MRV Framework.

I. INTRODUCTION AND RESEARCH CONTEXT

Global efforts to achieve net-zero carbon emissions have intensified in recent years, placing unprecedented scrutiny on reported and acclaimed environmental performance of infrastructure systems. Among all sectors, the construction industry remains one of the largest contributors to greenhouse gas emissions, accounting for approximately 39% of global energy-related CO₂ emissions when both operational and embodied impacts are considered [1]. In response, governments, investors, and regulators are increasingly demanding credible, transparent, and verifiable environmental performance data to support climate commitments, green finance mechanisms, and sustainability claims [2].

Central to this shift is the growing emphasis on measurement, reporting, and verification (MRV) of environmental impacts across entire asset life cycles. Recent policy developments, such as the European Union's Green Claims Directive, highlight a broader regulatory move toward ensuring that environmental claims are evidence-based, auditable, and resistant to greenwashing. These developments signal a transition from aspirational sustainability narratives toward enforceable accountability frameworks grounded in reliable data infrastructures. However, the construction sector has struggled to meet these expectations due to persistent fragmentation of environmental data across project stages, actors, and systems. For example, studies [3], [4], [5], [6], [7], [8] that have reported environmental impacts of sustainable buildings cannot provide a traceable end-to-end system architecture of the acclaimed environmental impact.

Offsite Construction (OSC), also referred to as industrialised or modular construction, presents a distinctive opportunity within this context [6], [7], [9]. By shifting significant portions

of construction activity from site-based assembly to controlled manufacturing environments, OSC offers greater process standardisation, traceability, and data capture potential than traditional construction methods. These characteristics position OSC as a promising pathway for low-carbon industrialisation and productivity gains, while simultaneously offering a uniquely suitable test-bed for developing integrated environmental data governance systems. Despite this potential, existing OSC practices are yet to fully realise the benefits of systematic environmental data integration and verification for justifying improvements in construction sector.

While sectors like agriculture, airline and shipping lines have attempted an MRV system [10], [11], the construction industry is lagging behind [12]. More importantly, the pieces of reports available for the CI are fragmented and siloed. A phase report of a construction project does not suffice to conclude an EIA of the project. This research responds to this gap by proposing the design of an AI-assisted environmental data governance framework for Offsite Construction as a case for the construction industry. Rather than focusing solely on improving carbon metrics or lifecycle assessment techniques for siloed construction phases, the project foregrounds holistic data governance as the enabling infrastructure through which environmental accountability, policy credibility, and market confidence can be achieved. By treating OSC as a demonstrative case and the UK Construction Industry as a test bed (since the UK has been reported as one of the leading crusaders of OSC [13], [14]), the research aims to establish a replicable governance model capable of supporting whole-life environmental transparency across sustainable infrastructure systems for interested countries across the globe.

II. RESEARCH PROBLEM AND KNOWLEDGE GAP

A. Research Problem

First, Across the Architecture, Engineering, Construction, and Operation (AECO) sectors, environmental data are generated at multiple stages of project delivery, including project initiation, design development, material manufacturing, on-site assembly, and post-occupancy operation—the different stages of construction works. However, these datasets are rarely integrated into a coherent system. Instead, they remain siloed across disciplines, stages of works, contractual boundaries, and proprietary platforms, resulting in fragmented representations of environmental performance that are difficult to verify or compare across projects.

Current sustainability assessments in construction predominantly emphasise embodied carbon and operational energy use, often overlooking upstream emissions, in-use performance variability, and end-of-life impacts [8]. Also, most of these assessments are conducted for siloed phases of construction works rather than whole life cycle. This partial accounting produces an incomplete picture of whole-life environmental performance and limits the credibility of reported sustainability outcomes. Additionally, this reporting approach has generated a ‘for’ and ‘against’ proposition on the role of infrastructure development in Net-Zero Carbon pursuit, leaving construction industry stakeholders in rather a confused state as to the true contribution of the industry to environmental sustainability. As a result, policymakers, investors, and clients

are frequently required to make decisions based on inconsistent, untraceable or unverifiable evidence, undermining confidence in green procurement, climate disclosure regimes, and net-zero strategies.

The absence of a robust environmental data governance framework exacerbates these challenges. Without standards for data structure, lineage, validation, and ethical use, environmental information cannot reliably support MRV requirements or regulatory oversight. This gap is increasingly problematic in light of emerging climate policies that demand verifiable claims and transparent reporting [15]. The problem is therefore not simply a lack of data, but also a lack of governance mechanisms capable of transforming dispersed datasets into trustworthy environmental knowledge.

B. Knowledge Gap

In the United Kingdom, the test bed for this conceptual study and a case study for Europe, end-to-end project datasets for Offsite Construction are scarce to come by [12], [16] not even through industry and research organisations like the Offsite Alliance and Offsite Expo. Current search shows that there is no repository for these datasets and if any do exist, they are likely often uncoordinated and not project specific [12]. Reviews indicated a disconnect from post-occupancy evaluation or lifecycle carbon tracking [5]. It is hard to tell if they currently provide end-to-end traceability linking design intent, manufacturing decisions, construction execution, and environmental outcomes over time. Consequently, despite relatively higher OSC adoption rates compared to some other contexts, the UK construction sector continues to face similar challenges in evidencing the true environmental impacts of offsite delivery methods.

This research identifies a critical knowledge gap at the intersection of environmental governance, data systems, and industrialised construction. While existing studies have advanced understanding of OSC technologies, supply chains, and adoption drivers and constraints, far less attention has been paid to how environmental data should be collected, collated, governed, validated, and operationalised across a full project spectrum. Addressing this gap requires a shift from isolated analytical models toward system-level governance architectures that enable environmental accountability at scale.

III. RESEARCH AIM, RESEARCH QUESTIONS, AND CONCEPTUAL FRAMEWORK

A. Research Aim

The primary aim of this research is to design and evaluate an AI-assisted environmental data governance framework that enables robust measurement, reporting, and verification (MRV) of environmental performance across the full lifecycle of Offsite Construction (OSC) projects. The research seeks to move beyond fragmented sustainability metrics by establishing a traceable, auditable, and ethically governed data architecture capable of supporting credible environmental claims, regulatory oversight, and data-driven policy formulation. In this article, AI is positioned as a support mechanism for validation, anomaly detection, and lifecycle verification within a governed data architecture.

This aim directly responds to growing international recognition that true climate targets cannot be said to be met without trustworthy data infrastructures. Global frameworks such as the IPCC assessment process, the Task Force on Climate-related Financial Disclosures (TCFD), and the emerging International Sustainability Standards Board (ISSB) standards consistently highlight data quality, comparability, and verification as prerequisites for meaningful climate action [2], [11], [17]. Within the built environment, however, the governance mechanisms required to operationalise these principles remain underdeveloped.

By positioning Offsite Construction as a demonstrative case, the research leverages a production system that already exhibits higher levels of process standardisation and digital maturity than traditional construction [18], [19]. This allows the project to focus not on inventing new environmental indicators, but on governing existing and emerging data streams in ways that make environmental performance transparent, comparable, and resistant to greenwashing.

B. Research Questions

To operationalise this aim, the study is guided by the following research questions:

- **RQ1:** How are environmental data currently generated, structured, and governed across the lifecycle of Offsite Construction projects in the United Kingdom?
- **RQ2:** What governance gaps prevent existing OSC datasets from supporting reliable whole-life-cycle environmental assessment and MRV requirements?
- **RQ3:** How can an AI-assisted data governance framework integrate the different stages/phases of construction (design, manufacturing, construction, and post-occupancy) data to ensure traceability, verification, and ethical use?
- **RQ4:** In what ways can such a framework support policy credibility, market confidence, and net-zero delivery, while remaining transferable to other sustainable infrastructure sectors?

These questions focused on identifying critical OSC data management system using AI and machine learning. Here, AI is repurposed not as a predictive tool for wider adoption likelihood alone, but as an enabling mechanism for data integrity, anomaly detection, and verification within a governance architecture—marking a clear conceptual and methodological progression towards the 25% OSC usage targeted by the UK government or towards wider adoption of OSC as sustainable infrastructure approach or towards the target of any other nation aiming for the accountability of its construction industry environmental impact.

C. Conceptual Framework: MRV, Data Governance, and AI

The proposed conceptual framework underpinning this research will integrate three interrelated domains: environmental MRV, data governance, and AI-assisted analytics.

First, the project draws on MRV principles increasingly embedded in climate governance. MRV frameworks, originally

developed for emissions trading and international climate agreements, are now being extended to corporate disclosures, green finance, and product-level environmental claims [2], [20]. In construction, however, MRV remains weak due to inconsistent data sources and limited post-occupancy feedback, particularly beyond embodied and operational carbon metrics [8], [21].

Second, the research is grounded in data governance theory, which emphasises data lineage, ownership, accountability, standardisation, and ethical stewardship [22], [23]. Within AECO contexts, the absence of governance structures means that environmental data, even when collected, cannot be reliably validated, shared, or reused across project stages or institutions. This gap has been repeatedly identified as a barrier to digital transformation and sustainability assessment in construction [24], [25].

Third, AI is introduced not as a replacement for human judgment, but as a supporting governance technology. Machine learning techniques can assist in detecting inconsistencies, validating data completeness, identifying anomalous environmental claims, and forecasting lifecycle impacts under different design and manufacturing scenarios [26]. When embedded within a governed data architecture, AI enables scalability while maintaining transparency and auditability—an increasingly important requirement under emerging environmental regulation.

Together, these domains form a framework in which Offsite Construction functions as a controlled experimental environment for developing and testing environmental data governance mechanisms. The modularity, repeatability, and digital orientation of OSC make it particularly well-suited to addressing challenges that are otherwise intractable in conventional construction settings. Insights generated through this framework are therefore expected to inform broader sustainable infrastructure governance debates, monitoring and reporting, including those related to housing, transport, and energy systems.

IV. METHODOLOGY AND WORK PLAN

A. Research Design and Approach

To achieve the stated aim, this research proposes a mixed-methods, design-led, and applied research approach, combining qualitative inquiry, empirical data analysis, and prototype development. The methodological strategy is informed by prior research demonstrating that complex sustainability challenges in the built environment cannot be adequately addressed through single-method or purely technical approaches [27], [28], but first through a coordinated governance structure. To do this, data sources and governance structure would be defined. Data would be pulled from, for example, the eight phases of the RIBA-PoW. Sources of data would include architectural firm, manufacturing firms, planning authorities, offsite bodies among others. A proposed OSC project data aggregation system has been discussed by [12].

Further, this study thus proposes to integrate ethically governed socio-technical analysis with data system design to ensure both conceptual robustness and practical relevance.

The research is structured around three interlinked methodological strands:

- (i) empirical mapping and diagnosis of existing OSC data practices;
 - (ii) design and development of an environmental data governance framework and AI-assisted MRV prototype; and
 - (iii) validation and evaluation through real-world OSC cases.
- Together, these strands enable the research to move from problem identification to solution development and testing. Owing to the conceptual nature of this study, the role of AI in this approach is majorly assistive and not the technical, predictive role.

B. Phase 1: Mapping and Diagnostic Analysis of OSC Environmental Data

The first phase focuses on systematically mapping how environmental data are currently generated, structured, and governed across the lifecycle of Offsite Construction projects, using the United Kingdom Offsite Construction serves as a test-bed since the UK has been widely reported as one of the leading OSC adoption nation in the world. This will involve a critical review of reported OSC environmental impacts followed by a qualitative review of OSC projects that are completed, ongoing, proposed, or abandoned, drawing on publicly available project records, industry reports, and datasets maintained by organisations such as Offsite Alliance (OA) and Offsite Expo [12].

To complement this review, semi-structured interviews will be conducted with key stakeholders across the OSC value chain, including designers, manufacturers, contractors, and researchers. These interviews will explore data capture practices, governance responsibilities, interoperability challenges, and perceived barriers to environmental lifecycle assessment. This diagnostic stage aligns with prior studies identifying data fragmentation and governance gaps as critical constraints on digital transformation and sustainability assessment in construction [24], [25].

The outcome of Phase 1 will be a structured diagnosis of existing data flows, governance gaps, and opportunities for integration, forming the empirical foundation for framework design. These anticipated findings will provide a structured empirical framework and further direction of research for identifying governance gaps and informing the design of the proposed environmental data governance framework.

C. Phase 2: Framework Design and AI-Assisted MRV Prototype Development

Building on Phase 1 findings, the second phase involves the design of a standardised environmental data governance architecture tailored to Offsite Construction. The framework will define data schemas, lifecycle linkages, governance roles, and ethical protocols for environmental information management, drawing on established data governance principles such as data lineage, stewardship, accountability, and interoperability [22], [23].

- a) An AI-assisted MRV prototype will then be developed to operationalise the framework. Rather than functioning as a black-box predictive system, AI techniques will be employed in transparent and auditable ways to support data validation,

anomaly detection, completeness checks, and lifecycle performance analysis. Similar approaches have been shown to improve reliability and scalability of environmental accounting systems in construction and infrastructure contexts [26].

- b) The prototype will initially be developed as a minimum viable product (MVP) using a limited but representative set of environmental indicators (e.g., material emissions, energy performance, and post-occupancy metrics). This staged approach ensures feasibility while allowing future expansion to more granular datasets.

D. Phase 3: Case-Based Testing and Validation

The third phase focuses on testing and validating the proposed framework and prototype using selected OSC case studies within the UK context. In collaboration with OA and industry partners, a sample of OSC projects (anticipated 200–300 cases, or more, subject to data availability) will be used to evaluate the framework’s ability to support lifecycle traceability, MRV compliance, and decision-making.

Validation will be both technical and interpretive. Technical validation will assess data integrity, interoperability, and AI-assisted verification performance. Interpretive validation will involve feedback from practitioners and researchers on the usability, credibility, and policy relevance of the framework. This dual validation strategy aligns with best practice in applied sustainability and digital construction research [28], [29].

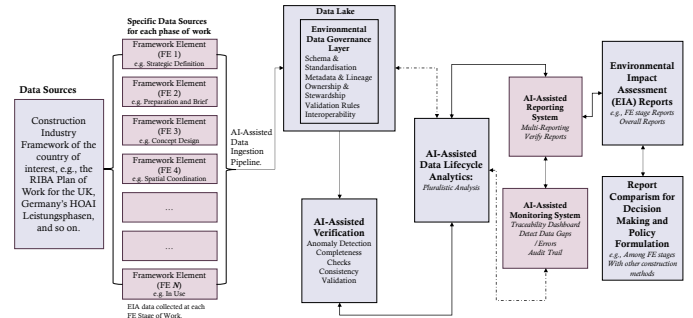


Fig. 1. An MRV Conceptual Framework for Reporting Construction Environmental Impact.

Summarily, the proposed architecture consists of four linked layers: lifecycle environmental data, data governance, AI-assisted verification, and MRV output. Environmental records from design, manufacturing, construction, operation, and end-of-life stages are integrated using standardised project and component identifiers. A governance layer defines metadata, lineage, ownership, and validation rules to ensure traceability and interoperability. AI-assisted functions, using rule-based and machine-learning techniques, support anomaly detection, completeness checks, and consistency validation. The output is an auditable MRV report that strengthens verification, comparability, and the credibility of environmental claims.

E. Phase 4: Illustrative Use Case

For example, in an OSC modular wall panel system, design-stage BIM data defining material specifications and embodied carbon estimates are linked to manufacturing records capturing

production energy and material sourcing. The governance layer standardises and aligns these datasets, while the AI-assisted layer detects anomalies and missing values across stages. This enables the generation of a traceable and verified lifecycle carbon profile, supporting MRV reporting and auditability of environmental claims.

V. EXPECTED CONTRIBUTIONS

A. Scholarly and Methodological Contributions

This research makes three interrelated scholarly contributions. First, it advances built environment scholarship by repositioning environmental data governance, rather than isolated sustainability metrics, as the foundational infrastructure required for credible climate accountability. While prior research has focused extensively on embodied carbon, operational energy, and lifecycle assessment techniques, far less attention has been paid to how environmental data are governed, verified, and ethically managed across project lifecycles. By integrating MRV principles with data governance theory and AI-assisted verification, this study addresses that gap directly.

Second, the research contributes methodologically by proposing a data governance architecture for MRV, with AI functioning as a supporting mechanism for data integrity and verification, rather than solely as a predictive or optimisation tool. By embedding AI within transparent and auditable data architectures, the study responds to growing concerns around black-box decision-making in sustainability analytics and aligns with emerging regulatory expectations for explainability and verification in environmental reporting.

Third, by using Offsite Construction as a demonstrative case, the research contributes empirically to the literature on industrialised construction and sustainable infrastructure. It shows how OSC's process standardisation, modularity, and digital maturity can be leveraged not only for productivity gains, but also for advancing environmental accountability at scale. These insights extend existing OSC research beyond adoption drivers and technical performance into the domain of governance-assisted sustainability transformation.

B. Policy, Industry, and Market Impact

Beyond academia, the proposed research has clear implications for policy design, industry practice, and market confidence. As governments and regulators increasingly scrutinise environmental claims, illustrated by instruments such as the EU Green Claims Directive and emerging sustainability disclosure standards, there is a growing need for verifiable, lifecycle-based evidence to underpin climate commitments. The proposed framework offers a practical mechanism for operationalising MRV requirements within the construction sector, supporting more credible policy enforcement and reducing the risk of greenwashing.

For industry stakeholders, particularly within the OSC ecosystem, the research provides a structured pathway for transforming fragmented datasets into actionable environmental intelligence. By enabling traceable links between design decisions, manufacturing processes, construction practices, and post-occupancy performance, the framework supports better decision-making, performance benchmarking, and investor

confidence. In this way, the research contributes to wider OSC market adoption by strengthening the empirical foundations upon which business models and policy incentives are built.

VI. CONCLUSION

While Offsite Construction serves as the primary empirical focus, and the UK as a test-bed, the proposed data governance framework is intentionally designed to be transferable to other countries with similar culture, including the global south who are considering giving OSC a try and the far West who want to widen their use of OSC. The principles, architectures, and MRV mechanisms proposed in this research can inform environmental accountability improvements across other infrastructure domains, including transport, energy, and public assets. As such, the project contributes not only to construction sustainability, but also to broader debates on how data governance can support climate action in complex socio-technical systems, thus making this style of accountability one of the best practices.

VII. FUTURE STUDIES

Future should explore possible and detailed AI architectures, including generalisable and interpretable models that can enhance data aggregation, analytics and reporting in OSC MRV environmental impact assessment reporting. This will in turn prepare the MRV governance structure for future predictability of OSC and the CI environmental impact assessment.

Additionally, comprehensive data governance methods that guarantee data lineage, validation, ethical use, and interoperability—all essential for trustworthy measurement, reporting, and verification (MRV) should be explored at a full scale beyond the suggested MVP level reporting this study presents.

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