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Smart Buildings and the Future of Sustainability Reporting:
Pathway to **CSRD** Compliance

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Abstract

This thesis investigates how smart building technologies can support compliance with the Corporate Sustainability Reporting Directive (CSRD), with a particular focus on the European Sustainability Reporting Standards (ESRS). As buildings account for approximately 40% of the EU's total energy consumption, real estate actors face increasing pressure to provide high-quality Environmental, Social, and Governance (ESG) data in line with new regulatory mandates. While smart technologies, such as IoT sensors and Building Operating Systems, offer capabilities for real-time data collection, validation, and automation, their implementation across ESG domains remains uneven. This investigation is situated within a broader context of fluctuating regulatory expectations, illustrated by recent developments such as the 2024 Omnibus reforms, which reflect the ongoing evolution of the CSRD framework.

To explore how these technologies are currently perceived and applied, the study draws on insights from nineteen semi-structured interviews divided into two sets. The first set includes professionals from the real estate sector, such as asset managers, developers, and ESG consultants, while the second set comprises solution providers offering smart building technologies. These interviews provide a comparative perspective on data needs, assurance practices, and system limitations.

Findings suggest that while energy and workforce data are increasingly measurable through existing tools, persistent gaps remain in biodiversity tracking, tenant data sharing, and supply chain transparency. This research contributes to the academic discourse on sustainable real estate management and offers practical guidance for organizations seeking to adopt scalable, verifiable, and integrative approaches to ESG data management under the CSRD.

Foreword

This Master's thesis has been conducted as part of the Management in the Built Environment (MBE) programme at the Faculty of Architecture and the Built Environment at TU Delft, between September 2024 and June 2025. The research contributes to the ongoing discourse at the intersection of sustainability reporting and digital innovation, with a particular focus on how smart building technologies can support compliance with the Corporate Sustainability Reporting Directive (CSRD). The study has benefited from engagement with both real estate professionals and technology providers, reflecting the interdisciplinary complexity of ESG data challenges in the built environment.

I would like to express my sincere gratitude to my thesis supervisors, Michael Peeters, Alessandra Luna Navarro, and Dr. Elizabeth Nelson, for their consistent guidance, constructive feedback, and valuable support throughout this process.

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Abbreviations

API	Application Programming Interface
BACS	Building Automation and Control Systems
BMS	Building Management System
BOS	Building Operating System
BREEAM	Building Research Establishment Environmental Assessment Method
CAPEX	Capital Expenditure
CSRD	Corporate Sustainability Reporting Directive
EFRAG	European Financial Reporting Advisory Group
EPBD	Energy Performance of Buildings Directive
ERP	Enterprise Resource Planning
ESG	Environmental, Social and Governance
ESRS	European Sustainability Reporting Standards
EU	European Union
FIS	Financial Information System
FY	Fiscal Year
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
GIS	Geographic Information System
HR	Human Resources
HRIS	Human Resources Information System
HVAC	Heating, Ventilation and Air Conditioning
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information Technology
KPI's	Key Performance Indicators
LEED	Leadership in Energy and Environmental Design
NFRD	Non-Financial Reporting Directive
OPEX	Operational Expenditure
SRI	Smart Readiness Indicator

1. Introduction

The majority of people spend most of their lives in buildings. It is therefore unsurprising that buildings contribute a significant proportion of overall carbon emissions, estimated to be between 30 and 40 percent (Park et al., 2024). In the European Union (EU) particularly, buildings account for 40 percent of total energy consumption (Al Dakheel et al., 2020). This highlights the importance of controlling the emission rates of the built environment, a process that has been greatly facilitated by the evolution and application of smart building technologies. Smart buildings can save energy by automating controls and optimizing systems (King & Perry, 2017).

The concept of smart buildings is not new. As mentioned, smart buildings initially focused on energy efficiency, but have since evolved to include the physical space and its occupants. They have also moved from simply enhancing building control systems to adding networks, digital amenities and IoT devices. In short, smart buildings feature technology solutions that help utilise resources efficiently and cost-effectively, while creating a safe and comfortable environment for their occupants. The benefits of smart buildings are far reaching and allow organizations to: reduce operating expenses, improve occupant comfort, enable frictionless and intuitive spaces, facilitate energy consumption management, track the status of core building assets, adapt to global regulations, and align with sustainability goals (Thakur et al., 2023).

Smart buildings therefore, focus on metering, optimizing, and automating systems to manage energy consumption and improve occupant comfort. To take it a step further, researchers such as (Buckman et al., 2014)have begun conceptualizing the next stage in the evolution of the built environment, in a concept referred to as "Thinking Buildings." It represents a progression beyond the adaptability of smart buildings, emphasizing the use of artificial intelligence to predict and proactively adjust to complex and dynamic conditions. Unlike smart buildings, which rely on structured datasets and predefined system integrations, Thinking Buildings are designed to process ambiguous datasets, enabling them to anticipate future needs and optimize operations accordingly. By integrating predictive capabilities, Thinking Buildings aim to achieve a higher degree of sustainability, efficiency, and user-centered performance. For instance, these systems may dynamically adjust to variations in occupancy, changing weather patterns, or fluctuating operational demands, all while maintaining optimal energy performance and occupant comfort. This shift from reactive to proactive design marks a significant departure from traditional approaches, as Thinking Buildings embody a holistic integration of advanced technologies and intelligent decision-making processes. As such, this innovation has the potential to redefine the relationship between buildings and their users, setting new benchmarks for adaptability and environmental sustainability (Buckman et al., 2014).

What is new, however, is the increasing demand for corporate transparency on sustainability issues that has driven significant regulatory changes in the European Union. The EU's commitment to tackling climate and environmental-related challenges resulted in the composition of the European Green Deal, which aims for the elimination of net emissions of greenhouse gases in 2050 and the decoupling of economic growth from resource use (European Commission, 2019). As part of the European Green Deal, the Corporate Sustainability Reporting Directive (CSRD) requires companies to report sustainability information under the reporting framework of the European Sustainability Reporting Standards (ESRS) (EY, 2023). The ESRS outline the sustainability information an undertaking must disclose under Directive 2013/34/EU. This involves detailing impacts, risks, and opportunities related to environmental, social, and governance (ESG) matters (European Commission, 2023).

So far, sustainable building practices have been instrumentally promoted by benchmarking tools such as the Smart Readiness Indicator (SRI), LEED, and BREEAM. However, research highlights their limitations in aligning with broader sustainability reporting frameworks like the CSRD. These tools primarily focus on environmental performance at the building level, such as energy efficiency, resource use, and indoor environmental quality. However, they often fail to encompass the broader social, economic, and governance dimensions required for comprehensive corporate sustainability assessments. These frameworks are generally more focused on environmental aspects and lack the depth to address socio-cultural and regional contexts fully (Elnokaly & Vyas, 2014). Sustainability tools and reports often lack transparency and comparability, which are critical for meeting modern reporting standards like the CSRD (Boiral et al., 2019).

The CSRD, effective from January 2024, mandates comprehensive environmental, social, and governance (ESG) reporting from a broad range of companies. These organizations must disclose not only their energy use and emissions but also their social impacts and governance practices in alignment with the European Sustainability Reporting Standards (ESRS) (Dinh et al., 2023). The CSRD introduces a phased implementation timeline to ensure organizations adapt to its comprehensive requirements, which aim to enhance transparency and accountability in corporate sustainability practices. Reporting begins in 2025 for companies with over 500 employees, a net turnover exceeding 40 million euros, or total assets surpassing 20 million euros. These organizations must disclose sustainability data based on their 2024 financial year, addressing the environmental, social, and governance (ESG) criteria central to the directive. In 2026, large companies meeting at least two of the following criteria—more than 250 employees, a net turnover of 40 million euros or more, or total assets of 20 million euros or above—will publish their first reports reflecting the 2025 financial year. Listed small and medium-sized enterprises (SMEs), defined as organizations meeting at least two of the following criteria: more than 10 employees, a net revenue exceeding 700,000 euros, or assets greater than 350,000 euros, must comply starting in 2027. However, SMEs are granted the option to defer reporting until 2029 if they provide justifications for their delay. In 2028, small and non-complex credit institutions, along with captive insurance entities, will also be required to submit their first sustainability reports, based on data from the 2027 financial year. Non-EU companies with significant EU operations—defined as having a net turnover exceeding 150 million euros and at least one EU-based subsidiary or branch—will follow in 2029. This framework ensures a gradual but comprehensive extension of sustainability reporting across diverse sectors, reinforcing the European Union’s sustainability goals.

However, the challenge lies in collecting this extensive data accurately and efficiently while minimizing reporting costs and ensuring compliance with regulations (Deerns, 2024). Companies subject to the CSRD will need to make significant efforts to publish the required information within the given timelines. Meeting these requirements appears highly challenging, especially in the initial years of CSRD implementation (Baumüller & Grbenic, 2021). Smart buildings, equipped with advanced Internet of Things (IoT) systems, present a potential answer to this challenge. By continuously monitoring energy, water, air quality, and waste, they have the ability to generate real-time, high-quality data (Al Dakheel et al., 2020). This integration has the potential to facilitate portions of sustainability reporting, enhancing both data accuracy and operational efficiency (Hsieh, 2024). However, for smart buildings to effectively support CSRD compliance, several challenges need to be addressed. These include integrating and standardizing real-time data from various systems, ensuring high-quality data for third-party verification, managing significant investment costs, and handling evolving regulations (Deerns, 2024).

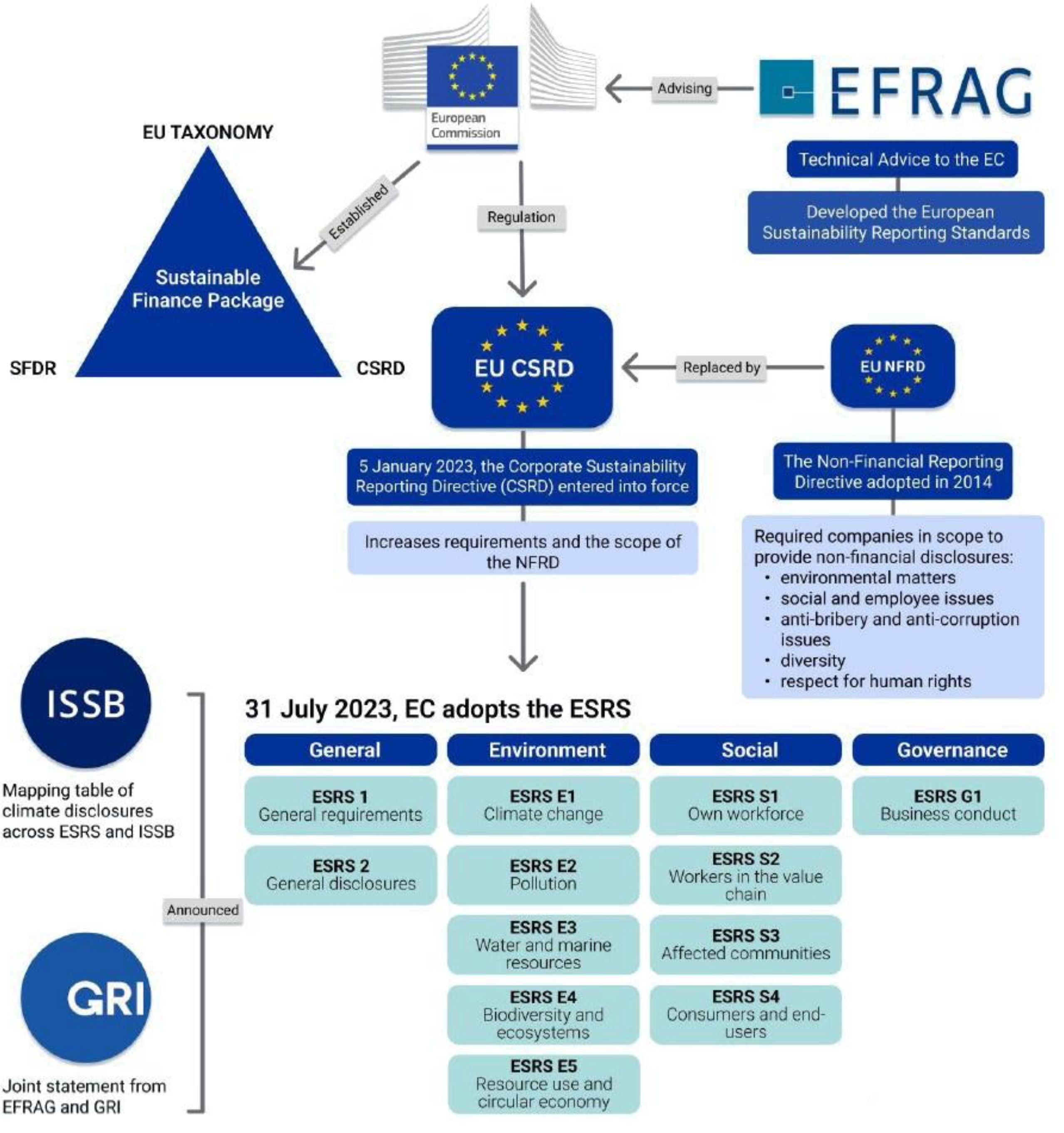

Figure 1: Connections between the EU reporting frameworks (Deerns, 2024)

2. Main Findings from Literature & Market Research

The literature on smart buildings emphasizes their capacity to optimize energy usage, support renewable energy integration, and promote occupant well-being through automated control systems (Park et al., 2024). Studies highlight key performance indicators (KPIs) such as energy savings, indoor air quality, and user productivity improvements (Al Dakheel et al., 2020). IoT technologies have also been widely implemented for energy monitoring, yet their broader application in waste management, water use, and social governance remains underexplored (Taha & Elabd, 2021). A lot of the relevant research material is focused on providing a well-rounded smart building definition and overview of smart building technologies. For instance, Al Dakheel et al. state that SB should be able to respond to external climate conditions, act/react to signals/information coming from the grid, enable real-time interaction between users and technologies implemented, and carry out a real-time monitoring of the building operations (Al Dakheel et al., 2020) (see Figure 2). King & Perry state that SB include efficient technologies with automated controls, networked sensors and meters, advanced building automation, data analytics software, energy management and information systems (King & Perry, 2017) (see Figure 3).

Market research indicates that companies tend to invest in smart buildings to improve net operating income, reduce operating expenses, and attract high-value tenants. Smart buildings enhance tenant satisfaction through better experiences and efficiency, which, in turn, increases revenue and asset value (Thakur et al., 2023). This statement is backed by a Deerns report, which indicates that smart building solutions can potentially achieve 20 per cent energy savings using smart lighting and climate control, 10 per cent savings on maintenance costs, 20 per cent more efficient use of square meters and 5 per cent more productive employees due to better air quality and environment (Deerns, 2023). Moreover, there are significant market opportunities regarding the transformation of existing buildings into smart buildings, especially in Europe where nearly 90% of the current building stock will still be in use by 2050. In line with this, the Energy Performance of Buildings Directive (EPBD) also set by the EU, aims to achieve the decarbonization of the EU's building stock by 2050 through mandatory upgrades to the least energy-efficient buildings (Mortice, 2024). The EPBD introduces ambitious measures targeting both existing and new buildings to achieve decarbonization goals. For non-residential buildings, the directive mandates the gradual implementation of minimum energy performance standards, prioritizing renovations for the worst-performing structures. By 2030, EU member states must renovate the least efficient 16% of their non-residential building stock, expanding to the worst-performing 26% by 2033. Residential buildings are afforded more flexibility, with each country required to develop plans to reduce the average energy consumption of residential stock by 16% by 2030 and 20% by 2035, with 55% of reductions coming from the least efficient housing. For new construction, the directive imposes even stricter requirements: all new buildings must achieve net-zero onsite emissions by 2030, and lifecycle emissions calculations will become mandatory for structures built from 2030 onward. To meet these objectives, smart buildings will play a crucial role, leveraging advanced hardware and software tools such as IoT sensors and smart metering to monitor, optimize, and enhance energy performance effectively(Mortice, 2024). Therefore, there is an extensive need for **smart retrofitting** to achieve the nearly Zero Energy Building (nZEB) standards and reduce energy consumption (Al Dakheel et al., 2020). Due to the previous factors, 32 per cent of European real estate investors are willing to pay premiums for "ESG friendly" assets (Fidler et al., 2023).

The existing literature on the Corporate Sustainability Reporting Directive (CSRD) is relatively recent, (since CSRD has not been fully implemented yet) and predominantly examines pre-existing reporting legislation, the directive's structural components such as the ESRS (which will be explained further), and the timeline for its phased implementation. In particular, CSRD is the successor of the Non-Financial Reporting Directive (NFRD), which came in force in 2014. It required large public-interest entities and listed companies to provide a non-financial statement that would monitor their ESG performance (van Dijk et al., 2024). However, the absence of a concrete reporting framework, resulted in an over-accumulation of guidelines and standards that lacked consistency. To tackle this, the EU firstly published the CSRD as a draft on April 21, 2021, aiming to homogenise the rules related to sustainability reporting (van Dijk et al., 2024). The CSRD introduces the principle of double materiality, which requires companies to assess how sustainability issues impact both their operations and broader societal and environmental outcomes (Bossut et al., 2021). It encompasses two distinct perspectives. Financial materiality focuses on the outside-in perspective, examining how sustainability issues affect a company's performance, financial position, and growth. In contrast, impact materiality takes an inside-out approach, assessing the company's effects on people and the environment (Hummel & Jobst, 2024). This dual focus complicates data collection, as companies must track a wide range of metrics across their entire value chain (Odobaša & Marošević, 2023). IoT systems offer a scalable way to manage this complexity, yet their deployment comes with challenges such as high initial costs and concerns about electronic waste from discarded sensors (Hsieh, 2024).

As already established, the ESRS serves as the operational framework to implement the CSRD and address the inconsistencies that plagued earlier non-financial reporting systems under the NFRD. Developed to ensure transparency and comparability in sustainability disclosures, the ESRS directly supports the CSRD's principle of double materiality by providing clear guidelines for companies to assess and report on both their financial materiality (outside-in) and impact materiality (inside-out) perspectives.

The ESRS framework applies to approximately 50,000 undertakings, a significant expansion from the 11,700 entities covered under the NFRD. This expansion ensures a more comprehensive assessment of corporate contributions to environmental, social, and governance (ESG) objectives. The ESRS are structured into three categories: cross-cutting standards, such as ESRS 1 (General Requirements) and ESRS 2 (General Disclosures), which provide foundational guidelines applicable to all entities; topical standards, which address specific themes like climate change (E1), pollution (E2), and workforce issues (S1); and sector-specific standards, which focus on sustainability challenges unique to particular industries. The sector-specific standards were originally intended to be published by mid-2024, but in February 2024, the European Commission decided to postpone publication until June 2026. The inclusion of both universal and sector-specific standards enables companies to tailor their reporting while maintaining comparability across sectors.

A cornerstone of the ESRS is its mandate for companies to disclose greenhouse gas (GHG) emissions across Scopes 1, 2, and 3, reflecting both their direct and indirect impacts. Scope 1 emissions account for direct emissions from owned or controlled sources, Scope 2 covers indirect emissions from purchased energy, and Scope 3 encompasses all other indirect emissions along the value chain. This comprehensive coverage aligns with the double materiality principle, as it captures the interplay between a company's environmental footprint and its financial exposure to climate-related risks. By requiring organizations to report their progress against clearly defined targets over short-, medium-, and long-term horizons, the ESRS promotes accountability and incentivizes proactive sustainability strategies.

Moreover, the ESRS emphasize the integration of sustainability considerations into governance and strategy. Companies must disclose the processes and structures used to monitor, manage, and mitigate sustainability risks and impacts, as well as their alignment with broader organizational goals. This approach not only addresses historical shortcomings in non-financial reporting but also facilitates compliance with the CSRD's overarching aim to harmonize sustainability reporting standards across the EU. By operationalizing the CSRD through a robust, quantifiable framework, the ESRS provide a pathway for companies to address the complexities of double materiality while contributing to the EU's sustainability goals. This structured approach ensures that companies can present clear, actionable data to stakeholders, mitigating the challenges posed by inconsistent reporting and facilitating the transition to more sustainable business practices.

A very important development regarding the implementation of the CSRD is the transition from limited assurance to reasonable (evidence-based) assurance for sustainability reporting. The CSRD prescribes limited assurance starting in 2024, requiring verification of compliance with reporting standards, the process for identifying reported information, the mark-up of sustainability data, and the reporting requirements outlined in Article 8 of the Taxonomy Regulation (Hummel & Jobst, 2024). This assurance can be carried out by statutory auditors, although member states may permit other auditing firms or independent assurance providers to perform this role. By October 2026, the European Commission is expected to adopt standards for limited assurance. Furthermore, the directive anticipates a potential transition to reasonable assurance, contingent upon a feasibility assessment. If deemed feasible, the Commission will establish standards for reasonable assurance by October 2028, alongside a specified timeline for its implementation (Hummel & Jobst, 2024). This progression emphasizes the urgency for companies to align with CSRD requirements, as they will be held liable for inaccuracies in their sustainability reporting, fostering greater transparency and accountability in ESG disclosures.

Marketwise, the CSRD is poised to have a significant impact on the real estate market by driving the adoption of sustainable practices and transparent reporting. According to a PwC survey, organizations identified several critical drivers influencing their sustainability strategies. Predominantly, customer demands were cited by 70 per cent of respondents, followed by regulatory requirements (55 per cent), considerations related to brand image and marketing (53 per cent), and investor expectations (48 per cent). Additionally, banks (45 per cent), other external stakeholders (40 per cent), and employees (35 per cent) were recognized as significant factors. These findings indicate that sustainability has become an integral aspect of societal expectations, necessitating that organizations align their strategic orientations accordingly, irrespective of their current obligations under the CSRD framework (Picard et al., 2023). Moreover, the switch from limited to reasonable assurance puts companies under pressure. EU member States are required to establish and enforce penalties for violations of the national provisions adopted under the CSRD, ensuring that these penalties are effective, proportionate, and dissuasive. In cases of non-compliance, Member States must implement specific administrative measures and sanctions, including issuing a public statement identifying the responsible individual or entity and detailing the nature of the infringement, requiring the responsible party to cease the non-compliant behaviour and take steps to prevent its recurrence, and imposing administrative financial penalties as a deterrent (European Commission, 2021). These measures are designed to uphold accountability and ensure adherence to the objectives of the legislation. France in particular, was swift in integrating the CSRD into national law. In the French context, the sanctions for non-compliance with the CSRD are embedded in the ''Code de commerce'' and enforced through French regulatory frameworks. They align with existing penalties under French corporate law, including fines proportionate to the severity of the infraction (e.g., up to €50,000 for individuals and €500,000 for organizations) and imprisonment for obstructing audits or certifications (up to 5 years and €75,000 for severe cases) (Ministère de la Justice, 2023). These penalties serve as a clear indication of the potential consequences for organizations that fail to swiftly align with the CSRD requirements. The strict enforcement mechanisms underscore the urgency for companies to adapt their practices and ensure compliance, as delays could result in significant financial, legal, and reputational repercussions.

3. The Evolving Landscape of CSRD: Challenges, Relevance, and Policy Reform

3.1 Identification of Unresolved Challenges

Despite the promising integration of smart building technologies and the advancements in sustainability reporting frameworks like the CSRD, several critical challenges remain unresolved.

From a regulatory perspective, a significant challenge lies in the dynamic nature of the Corporate Sustainability Reporting Directive (CSRD), which requires companies to navigate a complex and continuously evolving framework of sustainability requirements while mitigating the risk of non-compliance penalties. The transition from limited to reasonable assurance further amplifies these demands, necessitating the development of robust data collection and auditing mechanisms within constrained timelines. Additionally, the political environment within each European Union (EU) member state critically influences the adoption of the CSRD as national law. For instance, the recent government collapse in Germany has delayed the enactment of the CSRD Implementation Act, making it unlikely to take effect before the end of 2024. Consequently, compliance with the directive and alignment with European requirements may depend on its passage under a new federal government in 2025, potentially impacting implementation timelines. As a result, in a recent letter to the EU, German ministers called for changes to sustainability reporting regulations, describing them as overly burdensome for businesses. They urged simplifying the ESRS, EU Taxonomy, and corporate reporting rules, supporting an omnibus law to streamline regulations. They also proposed delaying the CSRD deadline from 2025 to 2027, with reports due in 2028, reflecting efforts to balance sustainability goals with economic priorities (Dr. Wissing Volker et al., 2024). Regarding the practicalities of reporting, it is notable that Excel has emerged as a prevalent tool for non-financial reporting and monitoring CSRD data points. However, the software's inherent limitations—such as inadequate user role management and vulnerability to unauthorized content modifications—pose significant risks, particularly in the context of future audit requirements. Despite these shortcomings, approximately one-quarter of organizations continue to rely on Excel, suggesting a potential lack of awareness or access to more sophisticated reporting tools (Picard et al., 2023). Furthermore, the emergence of online sustainability reporting tools leveraging artificial intelligence (AI) and machine learning represents a promising development in facilitating compliance with the CSRD. However, the effectiveness of these tools is heavily contingent upon the quality of the data provided. If the data collected by an organization is of suboptimal quality, the resulting sustainability reports are likely to reflect these deficiencies, thereby undermining their accuracy and reliability.

From a technological perspective, enabling efficient communication and data sharing among diverse devices in smart buildings is a notable challenge due to the variety of protocols and technologies in use. The coexistence of multiple communication protocols can create barriers, hindering effective interaction and collaboration between devices from different manufacturers (Poyyamozhi et al., 2024). Ensuring the accuracy and reliability of such data adds another layer of complexity, as it must meet stringent standards for third-party verification and reasonable assurance (Nandun & Piyathilaka, 2024). Furthermore, the substantial upfront costs associated with implementing smart building technologies, particularly in retrofitting existing structures, can reach up to 15% of total budget estimations (Poyyamozhi et al., 2024), and therefore pose a barrier to widespread adoption, especially for smaller organizations with limited financial resources. While smart buildings demonstrate strong capabilities in addressing environmental dimensions, such as energy efficiency and resource optimization, their ability to generate data pertinent to the social and governance aspects of ESG reporting remains underdeveloped, leaving areas like social impact and governance practices inadequately addressed.

Collectively, these challenges underscore the need for innovative solutions, clearer regulatory guidance, and collaborative efforts across the industry to ensure that smart buildings can fully support the ambitious goals of the CSRD and broader sustainability objectives.

3.2 Societal and Scientific Relevance

From a societal perspective, the enhancement of sustainability reporting practices is essential for advancing the European Union's climate and environmental objectives, as articulated in strategic initiatives such as the European Green Deal and the Paris Agreement (Dinh et al., 2023). The urgency of addressing global climate change and fostering sustainable development has elevated the importance of Environmental, Social, and Governance (ESG) reporting frameworks. Accurate, transparent, and reliable ESG reporting mechanisms enable a diverse set of stakeholders—including investors, consumers, policymakers, and civil society actors—to make well-informed decisions. These mechanisms play a pivotal role in enhancing accountability and ensuring that corporations address their environmental and social impacts in a manner consistent with global sustainability imperatives. Moreover, such reporting fosters a culture of corporate responsibility, innovation, and long-term value creation by aligning business operations with societal expectations and regulatory demands (Alberti, 2024).

The societal implications of improved ESG reporting extend beyond compliance with regulatory frameworks; they contribute to systemic change by driving corporate behavior toward sustainable practices. Companies that transparently report their ESG metrics not only build trust with their stakeholders but also set a benchmark for industry standards. This transparency is particularly critical in the CSRD context, which mandates rigorous sustainability disclosure requirements to ensure comparability, reliability, and relevance of ESG data. By holding organizations accountable for their contributions to environmental protection, social equity, and ethical governance, enhanced ESG reporting fosters greater alignment between corporate strategies and the broader sustainability goals of society.

From a scientific perspective, this thesis seeks to make a significant contribution to the evolving body of knowledge concerning the intersection of smart building technologies and ESG reporting. While existing literature has extensively explored the potential of smart buildings, particularly in the domain of energy efficiency and carbon footprint reduction, there remains a notable gap in understanding their role in addressing social and governance metrics within sustainability reporting frameworks. This research extends the discourse beyond traditional environmental dimensions by examining how smart building capabilities can align with the comprehensive requirements of the CSRD, thereby offering a more holistic approach to sustainability assessment and reporting (Al Dakheel et al., 2020).

Furthermore, the study aims to develop a robust and integrative framework that bridges the capabilities of smart building solutions with the demands of modern sustainability reporting standards, particularly as defined by the ESRS. By addressing these gaps, the research contributes to both academic literature and practical applications, offering insights that are highly relevant for real estate developers, corporate stakeholders, and policymakers. The proposed framework underscores the potential of leveraging smart building technologies to automate data collection, improve data accuracy, and streamline reporting processes, thereby enabling organizations to meet the increasingly stringent demands of ESG disclosures. Ultimately, this study aspires to provide actionable recommendations that align technological innovation with the pressing societal need for transparency, accountability, and sustainability

3.3 The 2025 Omnibus Package and its Implications on CSRD

Since the draft of this thesis was completed, the European Commission has advanced an explicit "simplification agenda" to trim regulatory costs across the Union. The agenda is set out in the Communication: A Simpler and Faster Europe (European Commission, 2025b) and showcased in a press release promising a 25 % cut in administrative burden (also 35 % for SMEs) by 2029 (European Commission, 2025d). On 26 February 2025 the Commission tabled two linked Omnibus proposals; the first, centred on sustainable-finance legislation, recalibrates the Corporate Sustainability Reporting Directive (European Commission, 2025b) .

Reform proceeds on two fronts. Temporally, the draft "Stop-the-Clock" Directive (European Commission, 2025c) defers the CSRD's second and third reporting waves by exactly two financial years. Large undertakings that would have reported FY 2025 data are postponed to FY 2027, while listed SMEs move to FY 2028. The accompanying Staff Working Document characterises the delay as indispensable "burden and compliance-cost relief" in the face of geopolitical volatility and energy-price shocks (European Commission, 2025a).

Substantively, the same Omnibus narrows the CSRD's personal scope by redefining a "large undertaking" as one with 1 000 employees instead of 250 and by raising the corresponding financial thresholds (European Commission, 2025c). Contemporary wire-service analysis estimates that the new threshold would remove about 80 % of firms from mandatory reporting, confining obligations to enterprises "with more than 1 000 employees" (Abnett, 2025). Moreover, the Commission instructs EFRAG to rewrite the European Sustainability Reporting Standards so as to "substantially reduce" mandatory datapoints and to abandon sector-specific standards, while retaining only limited assurance for audits (European Commission, 2025b).

What is therefore the Omnibus influence on the research? The initiative leaves the analytical framework presented in the preceding chapters largely intact: the CSRD remains the Union's core disclosure statute, and the principle of double materiality remains untouched. Even so, three ramifications deserve explicit emphasis.

First, sample composition is affected. Because the proposed reform raises the definition of a large undertaking from 250 to 1 000 employees, empirical studies that rely on the pre-2025 threshold are likely to over-represent firms that will henceforth report only on a voluntary basis.

Second, technology scoping may shift. A leaner set of mandatory datapoints could suppress near-term demand for granular building-level information, while the continuing absence of sector-specific ESRS will complicate efforts to benchmark real-estate metrics consistently across portfolios.

Third, regulatory uncertainty will persist until the European Parliament and Council adopt (or amend) the proposals. In such a fluid environment, firms are confronted with a moving compliance target, which in turn underscores the strategic value of adaptive, low-cost, data-capture architectures, precisely the niche in which smart-building solutions excel.

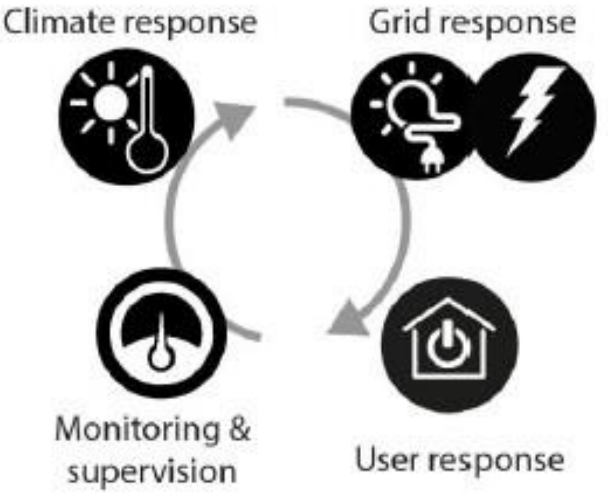

Figure 2: Smart Building basic functions (Al Dakheel et al., 2020)

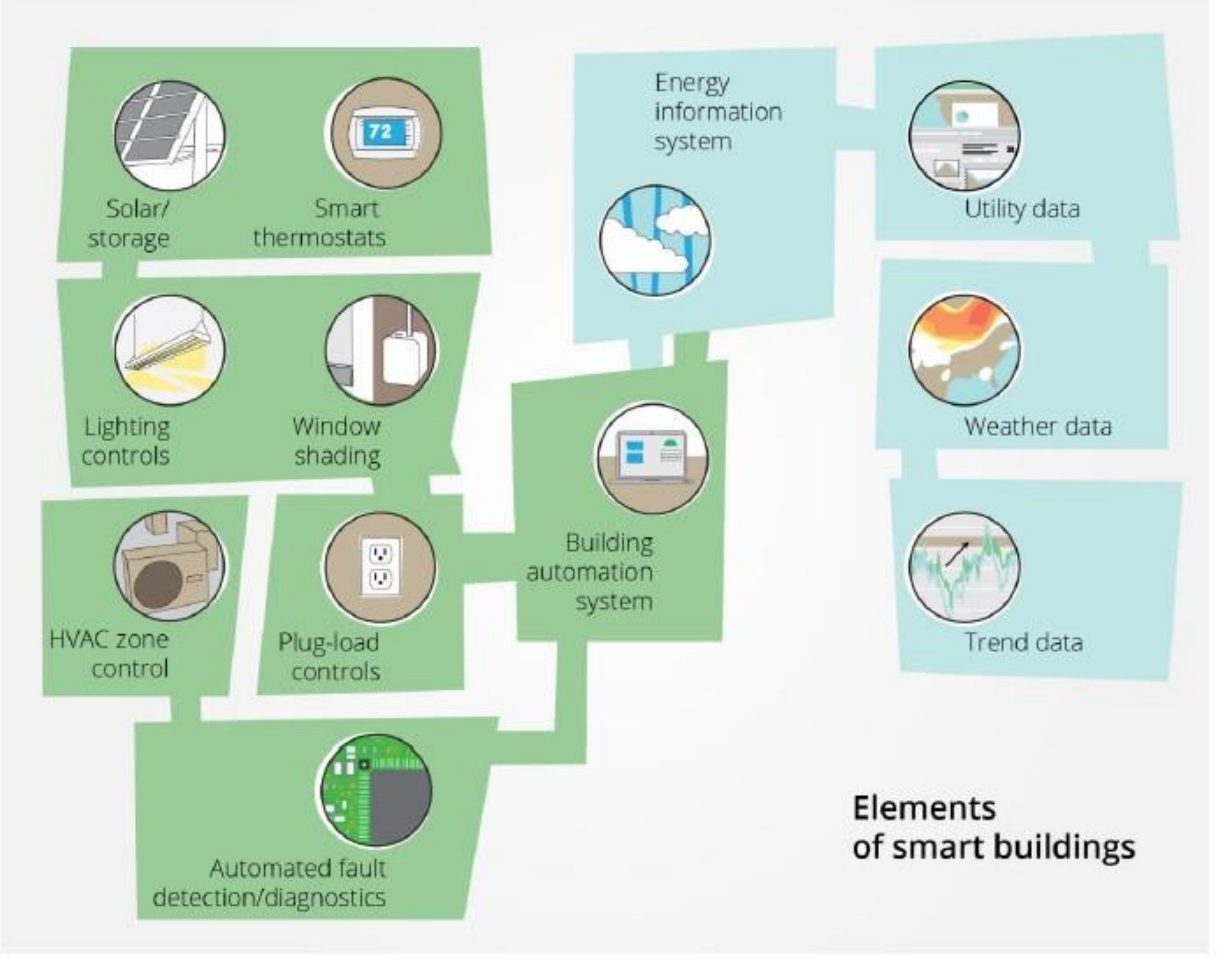

Figure 3: Overview of Smart Building technologies (King & Perry, 2017)

4. Pain points & research questions

The complexity and scale of the data required for CSRD compliance present a major hurdle for companies. The CSRD includes 12 standards and 82 reporting requirements that together lead to about 500 KPIs and an estimated 10,000+ underlying data points, encompassing detailed environmental, social, and governance (ESG) metrics (Picard et al., 2023). Therefore, the process of data collection is extensive and demanding. Organizations often need to invest in new data infrastructure, as existing systems may lack the capability to gather and manage this volume of information across multiple ESG domains efficiently (Odobaša & Marošević, 2023).

Data accuracy and verification further complicate this challenge. The directive mandates third-party assurance, meaning the reported data must not only be comprehensive but also highly accurate and consistent. Achieving this level of quality adds pressure on companies, requiring rigorous validation processes and data management protocols that many organizations are not equipped to handle (Allgeier & Feldmann, 2023).

Moreover, integration and consistency pose significant technical obstacles. Companies must ensure seamless data flow from disparate systems, such as energy management, water monitoring, and human resources, into a cohesive, standardized report that meets CSRD specifications. For organizations not already aligned with advanced sustainability reporting frameworks, integrating and harmonizing data sources can be a technically complex and resource-intensive endeavour (Deerns, 2024).

The previous pain points lead us to the main research question of this thesis, with its accompanying sub questions:

4.1 Main Research Question

How can smart building solutions facilitate compliance with the Corporate Sustainability Reporting Directive (CSRD)?

4.2 Research Sub-Questions

SQ1: Which ESRS topics are most relevant to companies in the built environment sector?

SQ2: What ESRS-aligned ESG data do companies currently collect, and how is this data validated?

SQ3: How can smart building solutions provide verifiable ESG data in order to align with CSRD?

SQ4: What data required by the ESRS cannot be provided by smart building technologies?

5. Research Methods

5.1 Research Framework

The research framework begins with the European Union's CSRD, which obliges firms to publish auditable sustainability information once a double materiality assessment has shown that a topic is financially or socially important. ESRS 1 and ESRS 2 provide universal disclosure rules that every organisation must follow, whereas the ten topical standards, grouped under environmental, social and governance themes, apply only when the assessment finds them relevant. A forthcoming layer of sector-specific standards, expected in 2026, will further refine these topical rules for industries such as real estate and construction. Within this regulatory context, the framework sets a clear aim: to discover how actors in the built environment can collect trustworthy data and present it in a way that meets the expectations of CSRD auditors.

The inquiry starts by speaking with professionals who plan, build, operate or scrutinise buildings, including developers, construction managers, property-service firms and sustainability consultants. These semi-structured conversations translate the language of the relevant topical ESRS into a concrete list of indicators, measurement procedures and evidence sources that organisations in the built environment must assemble. Each transcript is imported into ATLAS.ti for systematic coding. Through iterative rounds of open, axial and selective coding, the researchers identify recurring themes, causal links and daily operational constraints, producing a structured map of data requirements that reflects real-world practice rather than abstract regulation. Memo writing throughout this process preserves analytic transparency and allows the team to trace how initial impressions evolve into more stable interpretations.

Once these requirements are defined, the framework turns from data demand to data supply. A market analysis examines the capacity of current smart-building solutions, including sensor arrays, building-management systems and data-integration platforms, to capture the specified indicators in a form acceptable to auditors. To deepen the investigation, the team conducts additional interviews with technology vendors that explore data granularity, interoperability, maintenance needs and assurance features. Technical findings are matched back to the earlier requirements, revealing where existing solutions already satisfy CSRD needs and where technical, organisational or financial barriers persist. Particular attention is paid to data lineage, since auditors will require evidence of how raw observations become reported figures.

The final stage is a comprehensive gap analysis that places practitioner expectations alongside technological capabilities. Where the two align, the study documents feasible implementation pathways that firms can adopt with minimal delay, noting any supportive governance practices that improve reliability. Where discrepancies appear, whether in measurement coverage, data quality or verification robustness, the analysis offers focused recommendations for product development, organisational investment or policy adjustment. By tracing an unbroken line from statutory reporting duties through sector-specific data demands to practical means of fulfilment, the framework yields guidance that is both directly relevant to CSRD compliance and firmly grounded in the operational realities of the built-environment sector, offering scholars and practitioners alike a replicable model for future inquiries.

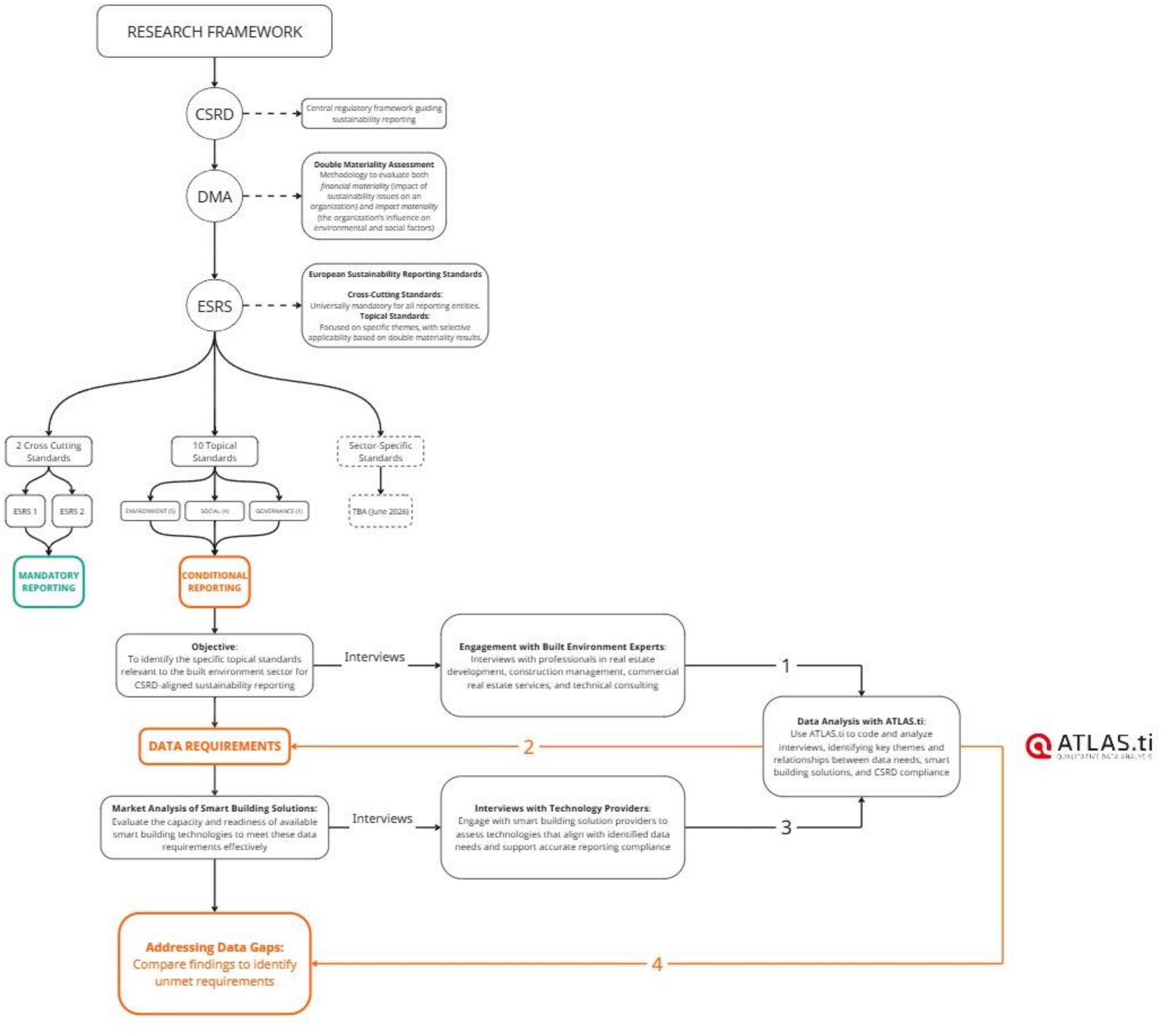

Figure 4: Schematic overview of the research framework

5.2 Research Approach

5.2.1 Methodology Type

The research adopts a qualitative methodology because, at the time of data collection, no published CSRD case studies existed for the real-estate domain. Without established benchmarks or validated instruments, a quantitative design would risk forcing premature metrics onto still-emerging practices. Qualitative methods, and semi-structured interviews in particular, offer the flexibility to capture detailed, context-specific accounts from stakeholders who are encountering the directive for the first time. The process begins with clarifying CSRD requirements, focusing on the double-materiality assessment that determines which of the ten topical ESRS standards matter for firms in the built environment. Interviews will therefore be held with professionals directly engaged in reporting—senior sustainability managers, ESG consultants, and compliance officers—across property development, construction, commercial real-estate services, and technical engineering. These conversations will translate the abstract language of CSRD into a concrete list of data needs, revealing how practitioners interpret double materiality, prioritise topical standards, and navigate organisational constraints.

The identified data needs then guide a second interview wave with providers of smart-building technologies. Because no prior studies have evaluated these solutions against CSRD criteria, open-ended questioning allows an exploratory assessment of sensor platforms, building-management systems, and data-integration tools. By probing data granularity, interoperability, maintenance demands, and audit-trail features, the study can determine the degree to which current technologies satisfy the reporting requirements discovered in the first phase.

This two-sided qualitative design permits iterative refinement: insights from early interviews inform later questions, and emergent themes can be pursued in depth. Such adaptability is essential for charting an untested regulatory landscape. By systematically linking CSRD, materiality assessment, ESRS standards, concrete data needs, and available smart-building solutions, the study delivers a comprehensive picture of how technological innovations can support compliance. It also identifies gaps, opportunities, and practical pathways for aligning smart-building capabilities with the evolving demands of sustainability reporting, thereby laying empirical groundwork for future quantitative studies once CSRD practices in real estate have stabilised.

5.2.2 Addressing the Research Sub-Questions (SQ's)

The research structure is designed to systematically address the study's sub-questions by aligning each phase of the project with the overarching framework. Through the identification of data needs, the assessment of smart-building technologies, the appraisal of compliance mechanisms, and the analysis of outstanding data gaps, the investigation develops a comprehensive view of how smart-building solutions can strengthen sustainability reporting under the CSRD. Each phase builds on the insights of the previous one, ensuring a clear, sequential progression. The research process tackles the four sub-questions in turn.

SQ1 asks which ESRS topical standards are most relevant to companies in the built-environment sector. To answer this, semi-structured interviews will be held with developers, construction managers, property-service firms, and technical consultants, eliciting practitioners' judgements about materiality and producing a ranked list of priority standards.

SQ2 examines what ESRS-aligned ESG data these companies already collect and how those data are validated. The same interview set will map existing data flows, internal control checks, and third-party assurance practices, thus clarifying the current baseline of reporting quality.

SQ3 explores how smart-building technologies can support evidence-based ESG reporting from a supervisory perspective. Follow-up interviews with smart building solution providers will assess whether these tools can deliver automated, audit-ready data streams that satisfy CSRD expectations.

Finally, **SQ4** identifies which data required by the ESRS cannot yet be supplied by smart-building technologies. By comparing the indicator set derived from SQ1 and SQ2 with the technological inventory from SQ3, the study will highlight residual information gaps.

By progressing through these phases—identifying the most relevant ESRS topics, cataloguing and validating current ESG data, evaluating how smart-building technologies meet supervisory needs, and closing residual information gaps—the study offers a coherent and thorough examination of how digital building systems can underpin CSRD-aligned sustainability reporting in the built-environment sector.

5.3 Methods & Techniques to be used

5.3.1 Literature Review

The earlier chapters have already distilled the literature into three converging insights. First, empirical and review studies on smart buildings show consistent gains in energy efficiency, indoor-environmental quality and asset value, but note that applications in waste, water and social-governance monitoring remain under-explored. Second, market and consultancy reports link these technological benefits to clear business drivers such as lower operating costs, higher tenant satisfaction and regulatory risk mitigation, while documenting typical performance uplifts such as 10-20 % in energy savings and a measurable increase in net operating income. Third, policy and accounting scholarship on the CSRD emphasises the transition from voluntary disclosure to assured, double-materiality reporting, highlighting the practical burden this shift places on real-estate actors and exposing persistent data gaps in biodiversity, tenant consumption and supply-chain transparency that current smart-building stacks do not yet fill. Taken together, this body of work positions the present study at the intersection of digital building innovation and tightening sustainability-disclosure mandates, and frames the qualitative research that follows.

5.3.2 Semi-structured Interviews

To gain in-depth insights and align with the qualitative nature of the thesis, the research involves conducting semi-structured interviews with key professionals, including smart-building experts, sustainability managers and ESG compliance officers who actively engage with smart-building technologies. These interviews explore the challenges, strategies and best practices for integrating smart-building data into CSRD reporting.

Purposive sampling guides participant selection, drawing on personal networks and collaborations with companies already engaged in smart-building projects. This approach ensures that professionals with the requisite expertise and experience contribute valuable insights to the study.

Interviews take place either face-to-face or via video conferencing, according to participant availability and preference. This flexibility facilitates broader participation and allows for discussions tailored to each interviewee’s knowledge and role.

The qualitative data collected through these interviews are analysed thematically. Coding techniques identify recurring themes, challenges and opportunities related to using smart buildings for CSRD compliance, thereby organising the findings into coherent insights that address the research objectives.

Throughout the study, TU Delft’s data-privacy regulations apply, safeguarding the rights and interests of all participants and their organisations. Ethical data-management practices underpin every stage of the project, fostering trust and transparency.

5.3.3 Graduation Internship

Additional material for the research is gathered in collaboration with the Amsterdam-based smart-building certification company Smart Building Collective. A graduation internship took place from February to June, giving direct access to the firm's resources and its network of solution providers.

Smart Building Collective advances smart-building technologies and practices by offering a certification process that assesses and enhances building intelligence worldwide. Its framework evaluates themes such as building usage, operational performance, environmental impact, health and safety, user behaviour, and integrative design, thereby promoting efficiency, sustainability, and utility across the built environment.

During the internship, the organisation's extensive network and case-study portfolio supported the investigation of SQ3 (how smart-building technologies support evidence-based ESG reporting) and SQ4 (which ESRS data points these technologies cannot yet provide). By facilitating interviews with solution providers and sharing best-practice documentation, Smart Building Collective served as an invaluable partner in preparing this master's thesis.

5.4 Data Strategy

5.4.1 Data Collection

This study employs a qualitative approach to data collection, relying on semi-structured interviews with key stakeholders such as property developers, facility managers, and smart-building solution providers. The method is selected because it enables a nuanced exploration of participants' lived experiences, especially their practical efforts to comply with CSRD requirements and the ways in which digital building systems provide—or fail to provide—relevant evidence. The interview guide is formulated on the basis of insights distilled from the preceding literature review and is organised around three themes. First, it probes the extent to which interviewees understand the specific data items that the CSRD and accompanying ESRS demand. Second, it examines the technical and organisational capabilities of smart-building technologies for generating, validating, and monitoring those data streams. Third, it explores perceived challenges, emerging opportunities, and best practices in transforming raw sensor outputs into audit-ready ESG metrics. By addressing these themes, the research keeps a clear line of sight to its overarching aim of explaining how smart buildings can facilitate regulatory compliance.

Participants are recruited through purposive sampling that targets professionals with demonstrable expertise in sustainability reporting, building automation, and the wider built-environment sector. This targeted strategy safeguards the relevance and depth of the material collected. All interviews are audio-recorded with informed consent, then transcribed verbatim to preserve accuracy. The transcripts are stored on encrypted university servers, ensuring confidentiality and full compliance with TU Delft's ethical research and data-privacy guidelines.

5.4.2 Data Analysis

The analysis of the qualitative data follows a thematic approach, a well-established method for detecting, interpreting, and explaining recurrent patterns within the dataset. Employing this procedure ensures that the resulting insights remain meaningful and closely aligned with the study's objectives.

Thematic analysis begins with careful transcription and familiarisation. Each interview recording is transcribed verbatim, after which the researcher repeatedly reviews the transcripts to build a comprehensive grasp of their content and context. The transcripts are then imported into ATLAS.ti, where an inductive coding process permits significant concepts to surface organically rather than imposing pre-defined categories. Initial codes emerge in keeping with the investigation's focus on CSRD compliance and the technical capabilities of smart-building systems.

Once a substantive code set is established, these codes are clustered into broader themes that capture the study's principal findings. Illustrative themes include persistent data gaps, challenges of technological integration, and barriers to achieving consistent compliance. To enhance reliability, the emergent themes are systematically cross-checked across all interviews, allowing the researcher to confirm convergences and to note any divergences that may warrant further exploration.

5.4.3 Data Plan

To ensure the rigour and reliability of the research process, a comprehensive data plan is established that integrates ethical considerations, data management procedures, and utilisation strategies. Ethical approval is obtained before any data collection commences, and all participants are fully informed about the scope and purpose of the study. Written consent is secured for recording and analysing the semi-structured interviews, reinforcing adherence to institutional guidelines and fostering trust between the researcher and the interviewees.

The data-management framework is designed to uphold both confidentiality and security. All digital recordings and verbatim transcripts are stored in password-protected files on encrypted university servers, with access strictly limited to members of the research team. This arrangement safeguards the integrity of the dataset, ensures compliance with TU Delft's data-privacy regulations, and maintains alignment with general research-ethics standards.

After collection, the interview material is thematically analysed to generate well-grounded insights into how smart-building technologies support—or fail to support—CSRD compliance. The analytic process involves iterative coding, constant comparison across transcripts, and careful triangulation against documentary evidence. Findings are synthesised into evidence-based observations concerning data availability, validation practices, and any residual gaps that emerge. By following this structured data plan, the study achieves transparency, ethical integrity, and actionable outcomes that remain firmly rooted in validated empirical themes.

5.4.4 Ethical Considerations

All three data collection methods utilized in this research have been formally reviewed and approved by the Human Research and Ethics Committee of Delft University of Technology. Prior to the interviews, all participants will provide their consent by signing an Informed Consent Form, which authorizes the recording and use of their interview transcriptions for the thesis.

6. Research Output

6.1 Objectives

The primary goal of this research is to examine how data generated by smart-building systems align with the disclosure duties introduced by the Corporate Sustainability Reporting Directive (CSRD). Concentrating on the built-environment context, the study follows the inquiry outlined in Section 3.1 and aims to clarify where technological capacity already supports compliance and where shortfalls persist.

1. Determine, with reference to professional judgement and the double-materiality test, which ESRS topical standards practitioners in the real-estate, construction, and facilities-management domains actually regard as material under the CSRD regime.
2. Catalogue in detail the environmental, social, and governance datasets that organisations already collect for those material standards, and document the internal validation procedures, external assurance routines, and frequency of reporting that give those datasets credibility.
3. Assess the ability of contemporary smart-building technologies—sensor networks, BMS, data lakes, analytics platforms—to deliver automated, audit-ready data streams that match the indicators from Objective 2, with attention to granularity, resolution, interoperability and traceability.
4. Identify, through gap mapping, any ESRS-required indicators that cannot yet be supplied via existing smart-building stacks, thereby revealing the residual information deficits that impede full compliance and signalling where supplementary measurement tools or organisational adjustments may eventually be warranted.
5. Distil the findings into practical guidance for developers, technology vendors, assurance providers and policymakers on configuring building-data infrastructures that satisfy CSRD reporting and advance wider sustainability goals.

6.2 Deliverables

This research will produce a series of outputs that correspond to the revised objectives and remain consistent with the structured pathway presented in Section 3.1. The deliverables are as follows:

1. **Thematic Insights from Stakeholders**: an analytically coded set of findings derived from semi-structured interviews with real-estate developers, sustainability managers and smart-building vendors. These insights clarify how existing reporting routines, validation procedures and organisational constraints interact with CSRD disclosure duties.
2. **Current Practice Compendium**: a consolidated set of documented approaches—drawn from case examples supplied by participants—for capturing, validating and integrating smart-building data into CSRD workflows. This compendium focuses on methods already in use rather than hypothetical future remedies, thereby reflecting the present state of practice.
3. **Data Gap Analysis Report**: a systematic comparison between the ESRS data expectations and the technical capabilities of smart building infrastructure, highlighting which indicators cannot currently be met. The report confines itself to diagnosing gaps, without prescribing solutions.
4. **Visual Representation of Findings**: a portfolio of infographics, charts and relationship diagrams that summarise the links between material ESRS topics, recorded data streams, identified gaps

and the broader reporting logic. Designed for both technical and non-technical audiences, these visuals facilitate rapid comprehension.

By concentrating on these deliverables, the study preserves coherence with its research framework while supplying stakeholders with rigorously grounded, immediately applicable evidence.

7. Personal study targets

This thesis offers a valuable platform for academic, professional, and personal development at the intersection of smart building innovation and sustainability disclosure. By examining how digital building systems generate, validate, and transmit Environmental, Social, and Governance data, the study investigates both the capabilities and the present limitations of these technologies in meeting Corporate Sustainability Reporting Directive (CSRD) obligations. Applying the research framework outlined in Section 3.1 to real-world conditions clarifies where smart building data already support compliance and where notable gaps persist.

Methodologically, the project strengthens expertise in qualitative inquiry. Semi-structured interviews with developers, facility managers, sustainability officers, and technology vendors provide the primary evidence, while thematic coding in ATLAS.ti refines the ability to distil complex narratives into rigorous, policy-relevant findings. Mapping material ESRS topics, cataloguing existing data flows, assessing technological readiness, and diagnosing residual information gaps deepen skills in stakeholder analysis, evidence synthesis, and critical evaluation.

The internship completed from February to June at Smart Building Collective further enhances this learning trajectory. Working alongside certification specialists and solution providers expands the professional network, sharpens understanding of industry benchmarks, and offers hands-on experience in evaluating sensor platforms, building management systems, and data-integration tools against emerging CSRD assurance requirements.

Engaging with external stakeholders, including developers, technology firms, and oversight bodies, refines communication and negotiation abilities. The process of securing interviews required persistent outreach and careful negotiation with busy professionals, significantly sharpening these skills. Such experience translates directly to client-facing or sales responsibilities within the real estate sector

Although I remain uncertain about pursuing a career exclusively in the sustainability segment of real estate, given its reliance on shifting political priorities and regulatory mandates, the analytical techniques, interpersonal competencies, and professional relationships developed through this research are broadly transferable. Competence in ESG data governance, smart building analytics, and evidence-based compliance can inform roles in digital infrastructure consultancy, corporate risk management, or technology-driven operational optimisation. Consequently, the project enriches my professional portfolio and equips me to apply these skills wherever opportunities in technology-enabled sustainability arise.

8. First Interview Set Research

8.1. Introduction

The first interview set comprises ten anonymised conversations that together span the main links of the built-environment value chain. Two interviewees hold senior posts in real-estate asset-management firms, three represent developer–contractor organisations responsible for delivering projects on the ground, and five act as consultants who advise clients on sustainability reporting and compliance. This distribution supplies balanced insight into both strategic decision-making and day-to-day implementation of Environmental, Social and Governance disclosure. Guided by Sub-Questions 1 and 2, each semi-structured dialogue probes which European Sustainability Reporting Standards (ESRS) topics practitioners still deem material after completing their double-materiality assessments and which ESG indicators they already monitor, document and verify. Interviewees explain why certain metrics are chosen, how data are collected, and what assurance routines underpin the reported figures, thereby sketching a detailed picture of current practice and emerging priorities.

8.2. Addressing SQ1: Which ESRS topics are most relevant to companies in the built environment sector?

Under the Corporate Sustainability Reporting Directive (CSRD), organisations must disclose performance against ten cross-cutting ESRS topics (E1 to E5, S1 to S4 and G1). Sector-specific guidance for real estate was expected but will not be issued following the February 2025 Omnibus decision, which halted the next wave of industry-tailored standards and instructed regulators to streamline the overall reporting burden. As a result, built-environment companies must interpret the generic ESRS framework without bespoke real-estate adaptations. To understand how professionals rank these topics in the absence of sector-specific rules, the ten expert interviews—together yielding roughly fifty-thousand-six-hundred transcribed words—were imported into ATLAS.ti for systematic analysis.

A deductive codebook with ten labels mirroring the ESRS topics steered the close reading of each transcript. Whenever an interviewee made an explicit or contextually clear reference to a standard—such as "Scope 3 emissions" for E1 (Climate change) or "circular-material passports" for E5 (Resource use and circular economy)—the passage was highlighted and assigned the appropriate code. After coding, ATLAS.ti's Code–Document Table produced absolute counts for every topic, revealing how frequently each standard appeared across the interview set. Finally, a purposive sample of one quotation per ESRS module was exported, with speakers described only by their professional role (asset manager, developer, contractor or consultant) to preserve anonymity while retaining contextual depth. These frequency counts and illustrative excerpts form the empirical foundation for interpreting the data needs of built-environment organisations as they navigate CSRD compliance under an evolving regulatory landscape now shaped by the Omnibus adjustment.

Interviewee ID	Professional Category
FIS-01	Real-Estate Asset Manager
FIS-02	Consultant
FIS-03	Consultant
FIS-04	Developer / Contractor
FIS-05	Consultant
FIS-06	Developer / Contractor
FIS-07	Real-Estate Asset Manager
FIS-08	Consultant
FIS-09	Consultant
FIS-10	Developer / Contractor

Table 1: Professional categories of participants in the first interview set

Professional Category	Number of Participants
Consultants	5
Developers / Contractors	3
Real-Estate Asset Managers	2

Table 2: Distribution of interview participants by professional category

ESRS Standard	Number of References
E1 – Climate Change	13
S1 – Own Workforce	9
E4 – Biodiversity & Ecosystems	8
E5 – Resource Use & Circular Economy	8
E3 – Water & Marine Resources	6
S3 – Affected Communities	6
G1 – Business Conduct	5
E2 – Pollution	4
S2 – Workers in the Value Chain	4
S4 – Consumers & End-Users	3

Table 3: Frequency of references to each ESRS standard across the first interview set

Tiers (based on reference count)	ESRS Standards
Tier 1 (9–13 references)	E1, S1
Tier 2 (5–8 references)	E4, E5, E3, S3, G1
Tier 3 (3–4 references)	E2, S2, S4

Table 4: Three-tier classification of ESRS standards

8.2.1 ESRS Tier Classification

The frequency profile produces a clear three-tier hierarchy of topical relevance. Tier 1 contains E1 (Climate change) and S1 (Own workforce), referenced thirteen and nine times respectively. Decarbonisation therefore remains the dominant lens through which built-environment professionals interpret sustainability reporting; several interviewees described carbon accounting and climate-risk indicators as "the entry ticket" for both equity and debt financing, noting that incomplete climate data can delay transactions or raise the cost of capital. S1 attains an equally prominent position because labour availability, safety performance and skills development have become board-level concerns in a tight construction market. Respondents observed that training hours, incident rates and subcontractor welfare metrics now sit on the same dashboards as traditional financial indicators, underscoring the sector's growing recognition that workforce health directly affects project delivery and asset value.

Tier 2 brings together five standards that attract between five and eight references. E4 (Biodiversity and ecosystems, nine mentions) and E5 (Resource use and circular economy, eight mentions) function mainly as pre-investment screens. Asset managers and contractors recounted rejecting schemes located in biodiversity hotspots or projects lacking credible circular-materials strategies, illustrating how these themes guide capital allocation before ground is broken. E3 (Water and marine resources) and S3 (Affected communities), each cited six times, are treated as situationally material. Water use dominates where portfolios include hotels, data centres or other water-intensive assets, while community impact rises to the surface when developments touch socially sensitive neighbourhoods; in more routine office stock the same issues receive less attention. Governance, represented by G1 (Business conduct, five mentions), is described as an enabling layer: robust board oversight, anti-corruption safeguards and data-privacy protocols are seen as prerequisites for securing assurance on more numerically demanding environmental and social indicators. Several consultants argued that auditors look first at governance quality when deciding how much reliance they can place on reported performance figures.

Tier 3 consists of E2 (Pollution), S2 (Workers in the value chain) and S4 (Consumers and end-users), cited four, four and three times respectively. Their marginal status stems from limited data access and consistently low double-materiality scores. Real-estate portfolios produce few process emissions, have constrained influence over deep-tier suppliers, and maintain only indirect relationships with end-users once leases are signed. As a result, organisations invoke the directive's "comply or explain" logic: they document why these topics are presently non-material yet acknowledge that future acquisitions, regulatory shifts or stakeholder campaigns could raise their relevance.

Taken together, the coded references create a practical three-tier roadmap for disclosure priorities. Standards in Tier 1, namely climate change (E1) and own workforce (S1), represent the indisputable core of CSRD reporting for built-environment companies. Tier 2 comprises biodiversity and ecosystems (E4), circular resource use (E5), water stewardship (E3), affected-community engagement (S3) and business conduct (G1); practitioners regard these topics as strategically important but context dependent, expanding or contracting coverage according to asset class, geography and transaction timing. Tier 3 includes pollution (E2), value-chain labour (S2) and consumer or end-user outcomes (S4). These receive limited attention because supporting data remain sparse and double-materiality scores are consistently low, although several interviewees cautioned that regulatory shifts or stakeholder pressure could quickly elevate their relevance.

ESRS Standard	Interviewee ID	Representative quotation
E1 – Climate Change	FIS-05	*"So really, from a materiality perspective, you see that primarily climate change is the most important."*
S1 – Own Workforce	FIS-04	*"S1 is definitely within our scope."*
E4–Biodiversity & Ecosystems	FIS-08	*"It's not standardized or made as easy and clearly explainable or measurable as something like energy or carbon. You can't just put a meter on biodiversity."*
E5 – Resource Use & Circular Economy	FIS-10	*"There is a lot of material in the manufacturing process, we try to recycle almost all the waste that is generated. At the same time, we also provide the necessary infrastructure so that the user, during the operation phase of the building, can continue recycling."*
E3 – Water & Marine Resources	FIS-05	*"On the ESRS, we see that water is less being identified as a material topic. What you can do there is that you perform a water stress assessment."*
S3 – Affected Communities	FIS-09	*"At the building certification level, there are a lot of questions related to whether the neighbourhood and the local community is involved in the design of the buildings."*
G1 – Business Conduct	FIS-05	*"I think this one is something that companies already do most of the time, they report about anti-corruption environment, corporate governance, so those are more standard. "*
E2 – Pollution	FIS-07	*"We are interested in ensuring that none of the properties in our portfolio are classified as polluting."*
S2 – Workers in the Value Chain	FIS-06	*"So, we need to report on climate change, water, biodiversity, circularity, own workforce, workers in the value chain and governance. "*
S4 – Consumers & End-Users	FIS-03	*"From an investor's perspective, you can get a huge backlash if, for instance, your data were leaked, or if you had a highly confidential data breach."*

Table 5: Representative quotations for each ESRS standard

8.2.2 Synthesising Insights from SQ1

To consolidate the analysis of Sub-question 1, this section interprets the three-tier structure that emerged from the interview coding results. The focus here is on translating the ranked ESRS topics into practical reporting priorities for organisations in the built environment. The tiered framework serves as a guide for differentiating between universal requirements, context-driven disclosures, and low-materiality items, offering firms a structured approach to CSRD alignment based on how these standards are perceived and applied across the sector.

Tier 1 comprises climate change (E1), own workforce (S1), and the governance structures that underpin decision-making (G1). These standards were cited far more often than any other topics, and interviewees from every professional group described them as essential for securing investment, meeting loan covenants, and obtaining audit assurance. Firms should therefore prioritise continuous, audit-ready data pipelines. Automated energy- and emissions-metering addresses E1, integrated human-resources systems record the metrics required for S1, and board-level oversight dashboards demonstrate compliance with G1. Because these data streams have already migrated into mainstream financial due diligence, failure to supply them can delay transactions or increase the cost of capital.

Tier 2 contains biodiversity and ecosystems (E4), circular resource use (E5), water stewardship (E3), affected-community engagement (S3), and business conduct (G1). Although these topics appeared less frequently than Tier 1, practitioners explained that their relevance increases sharply in specific contexts. Biodiversity and circularity influence early capital-allocation decisions when a project is located in a sensitive habitat or when a client has adopted a materials-reuse target. Water becomes critical for hotels, data centres, or facilities in water-stressed regions, while community impact shapes developments that interact closely with local stakeholders. Business conduct acts as a supporting layer because auditors first review governance quality before placing trust in environmental or social numbers. Organisations should apply screening tools such as GIS biodiversity layers, circular-design checklists, water-stress indices, and social-impact assessments to decide whether expanded monitoring is justified. If no contextual trigger is present, a concise non-materiality statement suffices.

Tier 3 consists of pollution (E2), labour conditions in the wider value chain (S2), and consumer or end-user issues (S4). These standards attracted only occasional references, reflecting both limited data availability and consistently low scores in double-materiality assessments. Real-estate portfolios typically emit few process pollutants, exert modest leverage over upstream suppliers, and have indirect contact with tenants once leases are signed. Companies can therefore rely on the directive's explain-or-comply logic, documenting why these topics are currently immaterial while piloting supplier portals, tenant apps, or contamination screening that can scale if risk profiles change.

This three-tier hierarchy translates SQ1 into practical guidance. Capture Tier 1 data as an immediate priority. Use targeted screening to determine when Tier 2 topics demand deeper attention, and when a brief rationale for non-materiality is adequate. Treat Tier 3 topics as provisional, explaining current gaps but keeping modest pilot projects in play. By following this approach, built-environment firms can direct resources toward the metrics that investors, lenders, and auditors value most, satisfy present CSRD requirements, and preserve flexibility for future regulatory shifts.

8.3. Addressing SQ2: What ESRS-aligned ESG data do companies currently collect, and how is this data validated?

The second research sub-question shifts the focus from the *frequency* with which ESRS modules appear in our interviews (SQ1) to the more pragmatic matter of *measurement*. Specifically, it explores (i) the ESRS requirements that professionals treating the built environment regard as genuinely material, and (ii) the concrete evidence streams they already use, or plan to use, to populate those disclosures. The same ten anonymised semi-structured interviews, coded in ATLAS.ti, provide the empirical basis for this discussion. Coding followed the same inductive approach outlined in 6.1. For SQ2, however, two additional families were introduced: "Environmental Data" and "Social Data" (e.g., electricity kWh, employee commuting distance) and "Data Collection Method" (e.g., electricity bill, vendor report). Links between these families were established whenever an interviewee explicitly connected a specific type of data to its corresponding validation mechanism, thus illustrating how evidence travels along a typical data pipeline.

8.3.1 What needs to be measured

This analysis restricts its scope to the top two tiers of ESRS materiality as identified in SQ1. These tiers represent the topics interviewees most frequently referred to as both strategically relevant and currently measurable in practice. As a result, ESRS modules that consistently received few or no references—such as E2 (Pollution), S2 (Workers in the Value Chain), and S4 (Consumers and End Users)—are not examined in this section. These topics were uniformly described by respondents as non-material in the context of office-dominated real estate portfolios and were therefore excluded from the analysis. By contrast, modules such as E1 (Climate Change), E3 (Water), E4 (Biodiversity), E5 (Circularity), S1 (Own Workforce), and S3 (Affected Communities) were viewed as materially significant. These formed the empirical foundation for evaluating current measurement and validation practices. The following table summarises the ESRS topics that interviewees rated as material for a real-estate context and the primary data items they currently track.

ESRS Module	Data Item
E1 Climate Change	Electricity (kWh), natural gas (m^3), Scope 1–3 CO_2-e
E3 Water & Marine Resources	Potable water used (m^3)
E4 Biodiversity & Ecosystems	Biodiversity Assessment
E5 Resource Use & Circularity	Paper recycling (kg), battery recycling (kg), construction site waste (tn)
S1 Own Workforce	Satisfaction metrics, training hours, H&S incidents, employee commuting distance
S3 Affected Communities	Value/number of social-impact initiatives

Table 6: ESRS modules and currently tracked data items in real estate

Data Item	Interviewee ID	Representative quotation
Electricity (kWh), natural gas (m^3), Scope 1–3 CO_2-e	FIS-05	*"I think the most important topic that they currently report about is energy consumption, climate change. So, energy consumption is mostly related to greenhouse gas emissions."*
Potable water used (m^3)	FIS-08	*"There's also growing awareness of the energy-water nexus, where water is now being seen as a carbon issue as well as a resilience issue."*
Biodiversity Assessment	FIS-04	*"When we're involved in a project—especially when we're in the development phase—we can decide whether or not we want to be part of it based on its potential impact on biodiversity."*
Paper recycling (kg), battery recycling (kg), construction site waste (tn)	FIS-07	*"We submit anything related to recycling that occurs in our own offices. This includes simple things, such as battery recycling or the destruction of documents."*
Satisfaction metrics, training hours, H&S incidents, employee commuting distance	FIS-06	*"Workforce is fairly easy because most of the required data was already in the systems, in our HR systems."*
Value/number of social-impact initiatives	FIS-01	*"You've got construction sites, trucks, cement mixers, noise, people working—it's a disturbance to the daily life of the area. That's why we try to direct some funding toward the municipality—not as an apology or compensation, but as a conscious effort to give something back."*

Table 7: Representative quotations for each ESG data item

8.3.2 How is the data measured and validated?

The data ecosystem described by interviewees mixes automated instrumentation with consultant-led calculations and document-based validation. The following table summarises common practices.

Data Item	Current Measurement & Validation
Electricity (kWh), natural gas (m^3), Scope 1–3 CO_2	Smart metering, consultant outsourcing for CO_2 emissions
Potable water used (m^3)	Billing per quarter or semester, scarce smart metering
Biodiversity Assessment	Process unclear, requires new complex data streams
Paper recycling (kg), battery recycling (kg), construction site waste (tn)	Weight reports
Satisfaction metrics, training hours, H&S incidents, employee commuting distance	Questionnaires, Excel spreadsheets
Value/number of social-impact initiatives	Total value (€) invested

Table 8: Current measurement and validation methods for ESG data items

Interviewees described a measurement landscape in which structured data collection remains uneven across ESRS topics, relying on a mix of smart instrumentation, external consultancy, and document-based evidence. Validation practices vary widely depending on the maturity of the metric in question.

For climate-related disclosures (E1), electricity consumption is predominantly captured through smart meters, particularly in newer or upgraded assets. One interviewee remarked that "most, if not all, clients have smart meters" (FIS-02), highlighting a relatively advanced level of instrumentation. However, calculating greenhouse gas emissions—especially Scope 1 and 2—is almost universally outsourced. Companies provide their energy consumption data to consultants, who then apply standardised emission factors. As one respondent explained, "the emissions data is calculated by the consultants, based on the information that we provide them" (FIS-07).

Water usage (E3) presents greater methodological inconsistency. While a minority of buildings are equipped with smart water meters, the majority still rely on manual readings or quarterly billing cycles. FIS-05 noted, "many water meters are still manual, so while some have already been upgraded, a large number are still not yet smart," indicating that real-time water monitoring remains rare in most portfolios.

Biodiversity assessment (E4) was described as both highly material and methodologically immature. Respondents underscored that current project workflows do not yet support systematic biodiversity monitoring, and that this domain "required us to set up a lot of new processes and calculating models" (FIS-06). The complexity of biodiversity lies not in its irrelevance, but in the absence of standardised data streams and the frequent need for project-specific assessment methods.

Waste and circularity (E5) metrics were comparatively straightforward. Most interviewees confirmed the use of vendor-provided weight reports for categories such as cardboard, plastics, and metals. These are typically collected through destruction certificates or invoices from recognised waste contractors. One interviewee outlined that "most of the waste is made up of cardboard boxes, plastic wrap, plastics in general, and metals—all of which, by law, must be measured, documented, and reported" (FIS-01).

For workforce-related data (S1)—including health and safety incidents, commuting distance, and training—questionnaires and Excel spreadsheets remain the primary tools. These datasets are often extracted from internal HR systems, but rarely undergo external verification. One respondent explained that environmental indicators linked to employee travel had to be manually compiled because "the need arose to track the distance each employee travels to and from the office" (FIS-07).

Community-related initiatives (S3) are measured through the monetary value of social investments, such as project-based contributions or donations. An illustrative case from FIS-10 described a developer that "carried out studies for the municipality, so that we were not limited to the outline of the buildings but also contributed to the public space." These figures are typically aggregated as part of corporate social responsibility reporting, but do not yet follow a codified ESRS calculation standard.

The measurement and validation of ESRS-aligned data in real estate rely on a pragmatic blend of available instrumentation and professional judgement. While energy-related metrics benefit from mature infrastructure and external expertise, others—particularly water and biodiversity—are constrained by technological lag or conceptual uncertainty. Meanwhile, social and community metrics are tracked through administrative records and basic self-reporting tools. Practitioners rely on smart-meter data where it is already installed (mostly electricity), while water and several waste streams still depend on supplier invoices or vendor certificates. Spreadsheet consolidation remains the norm, with external consultants and auditors providing the main layer of validation.

Current Measurement & Validation	Interviewee ID	Representative quotation
Smart metering, consultant outsourcing for CO_2 emissions	FIS-02, FIS-07	*"So, regarding electricity, I think most, if not all, clients have smart meters."* *"We are subject to the carbon footprint framework, the emissions data is calculated by the consultants, based on the information that we provide them."*
Water billing per quarter or semester, scarce smart metering	FIS-05	*"For things like water consumption, the process of smart meter implementation is still ongoing. Many water meters are still manual, so while some have already been upgraded, a large number are still not yet smart."*
Biodiversity assessment process unclear, requires new complex data streams	FIS-06	*"And for climate change, biodiversity, water, circularity, that required us to set up a lot of new processes and calculating models."*
Waste weight reports	FIS-01	*"Most of the waste is made up of cardboard boxes, plastic wrap, plastics in general, and metals—all of which, by law, must be measured, documented, and reported."*
Questionnaires, Excel spreadsheets for social metrics	FIS-07	*"This relates, for example, to the environmental footprint of our employees. The need arose to track the distance each employee travels to and from the office."*
Total value (€) invested in social-impact initiatives	FIS-10	*"In Piraeus, we even made donations, such as carrying out studies for the municipality, so that we were not limited to the outline of the buildings but also contributed to the public space."*

Table 9: Representative quotations on current measurement and validation practices for ESG data

8.3.3 Synthesising Insights from SQ2

The analysis of how ESRS-aligned ESG data is currently measured and validated reveals two central insights that characterise current practice in the real estate sector. First, the distribution of effort closely mirrors materiality assessments. Climate and workforce-related metrics receive the most attention, not only because they are prioritised within the ESRS framework, but also because they align with existing business structures and data infrastructures. Indicators such as energy consumption, greenhouse gas emissions, health and safety, and employee mobility are embedded in operational processes, and thus present fewer barriers for measurement. These data are often available in structured formats, extracted from smart metering systems, consultant reports, or internal HR platforms.

Second, firms privilege verifiable yet familiar evidence sources. Utility bills, vendor weight slips, and auditor-visible spreadsheets remain the most commonly used documentation types. Their reliability and recognisability make them particularly useful for meeting external assurance requirements with modest cost. Smart meters are largely deployed for electricity, but are not yet widespread for water. Recycling data is typically based on weight certificates, while workforce indicators are tracked through internally administered spreadsheets. Though these tools are far from automated, they offer a low-threshold path to compliance under the current limited assurance standard.

At the same time, the findings show that biodiversity, while more complex to monitor, is not being neglected. On the contrary, it is increasingly treated as a material concern in project planning and impact evaluation. Interviewees noted that project participation is often determined by the potential impact on surrounding ecosystems. However, the absence of shared standards for biodiversity monitoring means that most organisations must develop their own methods, often based on one-off assessments and non-digital data sources.

Together, these patterns point to a hybridised reporting model in which automation and manual input coexist. Technological infrastructure supports a subset of disclosures, while others continue to rely on consultant involvement and documentary evidence. Excel remains the dominant medium for data consolidation, despite its vulnerability to human error and audit risk. Yet the sector is beginning to recognise the limits of such practices. As reporting volumes grow and assurance thresholds increase, the demand for integrated systems and real-time monitoring is expected to rise.

In conclusion, firms in the built environment currently rely on a pragmatic portfolio of data sources that balances regulatory expectations with implementation feasibility. Energy, waste, water, workforce, and social investment indicators form the core of current ESG measurement practices. These are substantiated through a combination of smart instrumentation, consultant modelling, and verifiable documentation. Biodiversity stands out as both a relevant and technically challenging disclosure area, which underscores the need for expanded methods and shared benchmarks. Sub-question 2 shows that while low-tech, high-verifiability evidence supports initial compliance, sustained alignment with ESRS requirements will require long-term upgrades in methodology, standardisation, and digital infrastructure.

9. ESRS Data gaps & reporting challenges

Although built-environment firms already demonstrate a foundational capacity for CSRD reporting, interviews revealed recurring obstacles that constrain the quality, completeness, and reliability of the data used for ESG disclosures. Five major themes emerged: (i) incomplete data coverage, (ii) data quality and validation issues, (iii) stakeholder participation, (iv) fragmented IT landscapes, and (v) resource and governance constraints. The sections below elaborate on each gap using direct quotations from the interviewees, identifying their professional category.

9.1. Incomplete Data Coverage

Electricity consumption is the only environmental variable for which near-universal, asset-level coverage was reported. Both smart and analogue meters typically feed monthly totals into financial systems, and in many Dutch locations, the electricity meter is "smart by default." As one Consultant explained, "So, regarding electricity, I think most, if not all, clients have smart meters" (FIS-02). However, coverage for other indicators remains incomplete or ad hoc.

Water monitoring illustrates the disparity. A Developer/Contractor noted: "The water requires us to manually look at bills and type the amount of water per bill so of course that could lead to typos" (FIS-06). In many cases, firms still rely on quarterly utility statements, offering no real-time insight into consumption patterns.

Biodiversity tracking presents a different kind of gap. Another Developer/Contractor reflected on investment screening practices: "If a project is likely to cause significant harm to a local ecosystem, we can say, okay, this doesn't align with our values or goals, and choose not to invest" (FIS-04). Yet no interviewee described systematic measurement of ecological performance once development is complete. Operational portfolios therefore lack sufficient evidence to support ESRS E4 disclosures, often leading to the indicator being excluded or marked "not applicable."

The overall effect is a fragmented data landscape. While electricity may be well captured, coverage of other environmental variables such as water and biodiversity is inconsistent and often outdated. These omissions hinder comparability across assets and years and complicate portfolio-level target-setting.

9.2. Data Quality & Validation Risks

Manual processing still dominates day-to-day ESG reporting across many built-environment firms. One Real-Estate Asset Manager admitted, "And it's Excel, because we currently don't have any internal software to record this data" (FIS-01). The reporting chain typically begins with utility invoices manually typed into spreadsheets and ends with a consolidated workbook forwarded to the sustainability team. Every manual entry introduces the risk of transcription errors, and version control becomes fragile once multiple staff edit the same file. As the same interviewee candidly put it: "We accept the typo risk. I hate Excel" (FIS-01).

A second vulnerability arises from the handover of internal data to external consultants. Another Real-Estate Asset Manager observed, "The consolidation of the data is done by the consultants; we are not directly involved in that part" (FIS-07). Echoing this, an interviewee explained that once the raw numbers are shared, "Our consultant takes the data we send him, inputs it into the platform, and that is how the final figures are generated." This outsourcing ensures alignment with up-to-date GHG accounting methodologies but introduces an opaque step in the data lineage. While internal teams can review the raw inputs and final dashboards, they often lack access to the intermediate calculations—leaving them unable to diagnose anomalies or audit the transformation logic.

Together, the heavy reliance on hand-entered spreadsheets and the black-box nature of third-party processing exposes organisations to avoidable risks. Auditors attempt to mitigate the problem by sampling utility bills and confirming line-item accuracy, but such spot checks cannot guarantee the reliability of the dataset as a whole. The result is a reporting process that satisfies the minimum assurance threshold yet provides limited confidence to senior management regarding the daily reliability and auditability of their sustainability figures.

9.3. Stakeholder Participation

A third barrier to reliable ESRS reporting is the difficulty of obtaining data from parties outside the organisation's direct control, particularly tenants and subcontractors. These gaps obstruct the collection of Scope 3 metrics and weaken the evidentiary basis of sustainability disclosures.

On the tenant side, property managers often struggle to obtain even basic utility figures. As one Real-Estate Asset Manager explained, "Well, clearly the number one challenge is that tenants are not responding. They do not understand the necessity; they do not care" (FIS 07). Tenant electricity, water, and waste data are frequently unavailable, and even where submetering infrastructure exists, legal limitations may prevent landlords from accessing it. Submeters installed inside leased premises cannot legally be read by the landlord unless the lease explicitly grants that right. Since many legacy contracts omit such provisions, firms often find themselves unable to retrieve data even when they have made technical investments to do so.

A similar participation gap emerges in the supply chain. A Developer and Contractor noted, "There was difficulty in collecting environmental data from construction sites" (FIS 10). More broadly, value chain contractors may resist disclosing workforce data such as wages or safety statistics beyond their legal obligations. One sustainability adviser remarked, "Workers in the value chain reveal how the upstream and downstream supply chain is set up, but at the moment that part is cut out." This limits the ability of organisations to quantify and report under ESRS S2, forcing many to rely instead on narrative explanations.

Together, these examples show that critical ESG data streams are often locked behind legal or organisational boundaries. Without tenant consent or supplier cooperation, firms cannot meet ESRS evidence thresholds, regardless of how sophisticated their own metering infrastructure or data platforms may be.

9.4. Fragmented IT Landscape

A fourth weakness concerns the software environment in which sustainability data are stored and processed. Interviewees described a setting in which spreadsheets remain the dominant medium, specialist ESG tools are still under evaluation, and only isolated portions of data have been migrated into enterprise systems.

Most respondents acknowledged a heavy dependence on stand-alone files. In practical terms, this means that energy figures are maintained in facility spreadsheets or consultant portals, waste certificates are saved on shared network drives, HR metrics reside within ERP modules, and governance records are archived as static PDF board minutes. All of these sources require manual retrieval and consolidation during each reporting cycle.

While several organisations are contemplating the implementation of an integrated data platform, progress has been slow. As one Consultant explained, “I think some companies still do not have a great IT system. It is currently the first step to have a single source of truth for the IT data and then they can move on to the sensor data” (FIS 03). Another Consultant elaborated, “It is not enough to put in a smart meter. You have to have the infrastructure behind it, the cloud, the systems, the platforms, and people who can read and leverage the data that comes out” (FIS 09).

In a limited number of cases, partial integration has reportedly been achieved through the use of enterprise systems such as SAP or ERP platforms. These platforms are used to collect data from different departments and assemble it into a centralised reporting structure. However, the connection between operational metering systems and strategic dashboards remains incomplete. Even in settings where data consolidation is technically possible, seamless data flows across departments and systems have not yet been established.

The result is an IT patchwork that inflates staff workload and delays strategic insight. Each disclosure cycle begins with a manual search for scattered documents and databases, often leading to multiple and conflicting data versions. Until these disparate datasets become interoperable and centrally governed, organisations in the built environment will continue to expend disproportionate effort on data wrangling rather than on meaningful analysis of sustainability performance.

9.5. Resource & Governance Constraints

A fifth and recurring challenge highlighted in the interviews concerns the limited organisational capacity available for ESG reporting. In many cases, sustainability responsibilities are distributed among small teams or appended to existing roles with insufficient time or expertise. This resource constraint limits the extent to which firms can proactively engage with CSRD requirements.

Several respondents described governance structures where sustainability oversight lacks formal integration into core decision-making processes. In such settings, ESG monitoring is treated as an auxiliary function rather than as a strategic priority. One Consultant remarked, “Also in those organisations, sometimes you are surprised by the lack of organisation within the company” (FIS 02). Similarly, a Developer and Contractor observed, “If we look at how this plays out within organisations, especially SME-plus types, they usually do not have direct reporting lines for ESG” (FIS 04). This absence of dedicated authority restricts accountability, slows implementation of new tools, and reduces the likelihood that data issues will be identified and addressed early.

Organisational attention often spikes only when a project faces external scrutiny or when reporting deadlines approach. In the absence of ongoing oversight, errors tend to accumulate undetected, creating last-minute pressures and undermining confidence in the accuracy of reported figures. These dynamics hinder both the quality of the data and the institutional learning required to improve ESG performance over time.

Collectively, these constraints suggest that staffing and structural gaps remain a critical bottleneck. Without dedicated personnel, formalised processes, and senior management buy-in, even well-designed IT systems and data collection tools are unlikely to deliver the level of reliability and traceability that CSRD compliance demands.

9.6. Setting the Stage for Solution Analysis

The five problem areas documented in this chapter—namely incomplete data coverage, exposure to transcription and validation errors, low tenant and supply chain participation, fragmented IT systems, and limited supervisory capacity—define the practical limits of current ESRS reporting in the built-environment sector. Their combined effect is to leave organisations short of the evidence quality, granularity, and traceability that the CSRD ultimately requires.

These findings suggest that firms are constrained not only by technical gaps, but also by institutional and infrastructural limitations. In many cases, ESG data is collected manually, processed through decentralised systems, or locked behind legal and organisational barriers. Even where reporting structures exist, they are often reliant on spreadsheet tools and external consultants, creating fragmentation in data lineage and uncertainty in validation.

This diagnosis sets the stage for Sub-question 3: *How can smart building technology provide verifiable ESG data in order to align with CSRD?* The next chapter therefore shifts attention from asset owners and developers to the technology providers whose smart building systems claim to address these reporting challenges. By analysing interview data from these solution providers, the study will assess whether, and under what conditions, smart building technologies can close the gaps identified in this chapter and support organisations in producing audit-ready, CSRD-compliant ESG disclosures.

Reporting challenges	Interviewee ID	Representative quotation
Incomplete Data Coverage	FIS-02, FIS-06, FIS-04	*"So, regarding electricity, I think most, if not all, clients have smart meters."* *"The water requires us to manually look at bills and type the amount of water per bill so of course that could lead to typos."* *"If a project is likely to cause significant harm to a local ecosystem, we can say, okay, this doesn't align with our values or goals, and choose not to invest. "*
Data Quality & Validation Risks	FIS-01, FIS-07	*"We accept the typo risk. I hate Excel."* *"The consolidation of the data is done by the consultants; we are not directly involved in that part."*
Stakeholder participation	FIS-07, FIS-10	*"Well, clearly the number one challenge is that tenants are not responding. They don't understand the necessity, they don't care."* *"There was difficulty in collecting environmental data from construction sites."*
Fragmented IT landscape	FIS-03, FIS-09	*"I think some companies still do not have a great IT system. It's currently the first step to have a single source of truth for the IT data and then they can move on to the sensor data."* *"It's not enough to put in a smart meter. You have to have the infrastructure behind it, the cloud, the systems, the platforms, and people who can read and leverage the data that comes out."*
Resource & Governance constraints	FIS-02, FIS-04	*"Also in those organisations, sometimes you're surprised by the lack of organisation within the company."* *"If we look at how this plays out within organizations, especially SME+ types, they usually don't have direct reporting lines for ESG."*

Table 10: Interview Quotations on ESG Data Challenges

10. Second Interview Set Research

10.1. Introduction

Effective compliance with the Corporate Sustainability Reporting Directive (CSRD) demands the capacity to generate, validate, and disclose Environmental, Social, and Governance (ESG) data that is transparent, traceable, and audit-ready. Smart building technologies, encompassing sensors, automation platforms, and integrated systems, have been proposed as promising tools to meet these requirements. However, the extent to which such technologies can deliver verifiable data in alignment with the European Sustainability Reporting Standards (ESRS), and where their limitations lie, remains an open question.

This chapter builds on the findings of the first interview set by turning to the supply side of the ESG data landscape. It draws on nine semi-structured interviews with solution providers offering services across access control, water and waste management, mobility, consulting, and integrated building platforms. These professionals provide insight into both the technological capabilities and the practical constraints of applying smart solutions in a CSRD reporting context. In total, the second interview set yielded approximately 38,200 transcribed words, forming the empirical basis for this analysis.

The chapter addresses Sub-question 3: *How can smart building technology provide verifiable ESG data in order to align with CSRD?* and Sub-question 4: *What data required by the ESRS cannot be provided by smart building technologies?* By answering both, the chapter clarifies not only where digital systems can strengthen ESG reporting, but also where critical data gaps remain that smart building technologies alone cannot fill.

Interviewee ID	Professional Category
SIS-01	Security / Access
SIS-02	Waste Tracking
SIS-03	Consulting
SIS-04	Smart Mobility
SIS-05	Integrated Solution Provider
SIS-06	Integrated Solution Provider
SIS-07	Integrated Solution Provider
SIS-08	Water Management
SIS-09	Integrated Solution Provider

Table 11: Professional sectors of participants in the second interview set

Professional Category	Number of Participants
Integrated Solution Provider	4
Security / Access	1
Waste Tracking	1
Water Management	1
Smart Mobility	1
Consulting	1

Table 12: Distribution of interview participants by professional category

10.2. Key Characteristics of Smart Building solutions

10.2.1. Data Accuracy & Assurance

The interviews with smart solution industry professionals revealed how modern smart building systems implement comprehensive, multi-layered approaches to ensure data accuracy through tamper-proof data capture and rigorous verification processes. Security system providers detailed sophisticated video audit capabilities that track every access and sharing action while enforcing password authentication, creating complete traceability of data handling from source to endpoint. This level of governance is mirrored in waste management solutions that capture precise metrics about waste origin, type, and quantity through mandatory registration at disposal points, eliminating estimation errors through direct measurement protocols.

The interviewed experts consistently emphasized redundancy and cross-validation as critical components of their systems. Smart mobility platforms achieve exceptional 99.96% accuracy in parking detection by correlating sensor data with visual confirmation from cameras, validating tens of thousands of events through this dual-source methodology. Similarly, occupancy monitoring systems serve as authoritative baselines with 98% accuracy, against which other measurement systems can be calibrated, demonstrating how different technologies work in concert to verify data integrity.

Continuous, remote calibration processes maintain this precision over time, with water management systems capturing minute-level consumption data and automatically recalibrating against zero-consumption baselines nightly. Integrated solutions adhere to international standards through regular professional maintenance, while also benefiting from remote adjustment capabilities that ensure accuracy without requiring onsite visits. These calibration protocols work in tandem with end-to-end auditability frameworks, where security systems maintain comprehensive audit trails and building management platforms provide real-time monitoring of all connected devices and network performance.

Third-party verification and compliance measures further reinforce system reliability, with certified measurement devices transmitting raw, unprocessed data and regular ISO-standard maintenance checks providing independent validation. This rigorous approach enables transparent, shared real-time access to data across stakeholder groups, from minute-level water consumption metrics to comprehensive building performance indicators. The solutions are designed with scalable architecture that maintains quality whether monitoring single facilities or entire portfolios, handling tens of thousands of events with consistent accuracy while supporting portfolio-wide reporting across multiple locations.

Together, these interview findings demonstrate how overlapping layers of technological and procedural safeguards create a robust framework for data accuracy in smart buildings. From initial capture through final analysis, each step incorporates multiple verification mechanisms, reflecting the industry's recognition of reliable data as fundamental to effective building management and decision-making. The integration of tamper-proof collection, redundant validation, continuous calibration, comprehensive governance, independent verification, transparent access, and scalable design represents a holistic approach to ensuring data integrity throughout the entire information lifecycle.

Interviewee ID	Professional Category	Representative quotation
SIS-01	Security / Access	"Yeah, there's an audit trail around all the actions from our video suite. So, you can see who's downloaded it, see who's shared it and that you can password protect it as well. So that there's a high level of governance around our video solution."
SIS-02	Waste Tracking	"The cleaning companies that take waste out from the offices, they bring it there and before they put it into the big common bin, they will register it. And based on that, we can really understand who produces waste from the company. We know what type of waste is being produced and how much exactly. With that knowledge, we can take further steps into reporting for ESG and addressing the real challenges to eliminate the amounts of waste.
TSIS-03	Consulting	"These are grounded in European regulations and essentially mandate the installation of automation systems. This means that having an EMS, or Energy Management System, and a PMS, or Power Management System, is no longer optional. These systems are now required by regulation."
SIS-04	Smart Mobility	"We've achieved an accuracy rate of 99.96 percent. We got that by recording 50,000 parking events in a lot while having a camera set up to monitor everything."
SIS-05	Integrated Solution Provider	"The system is well calibrated, meeting certain standards and certifications, whether it's ISO standards or various other building standards... the equipment is calibrated on a regular basis by the maintenance professionals."
SIS-06	Integrated Solution Provider	"Our sensor is 98% accurate, so it's very precise. What we mostly are is the baseline for truth. Having someone stand there and count people is labor intensive and inefficient, while our solution delivers near-real-time accuracy at 98%."
SIS-07	Integrated Solution Provider	"We rely on the accuracy of the existing meters, many of which are certified. We collect that data without altering it, so we can trust those certifications."
SIS-08	Water Management	"From the main meter monitoring, we capture data at the minute level, which gives us accurate water flow and consumption measurements."
SIS-09	Integrated Solution Provider	"There is quite an extensive part where we measure uptime, device connections, network performance, and more technical parts like metacommunication and API health. All of this is monitored in real time."

Table 13: Interview Quotations on Data accuracy & Assurance

10.2.2. Data frequency & coverage

Building upon the discussion of data accuracy and assurance, the interviews further revealed that smart building systems are engineered not only to ensure correctness, but also to offer frequent and extensive data capture across key operational domains. These systems incorporate real-time monitoring, data buffering, and scalable infrastructure to support both short-term operational responsiveness and long-term performance evaluation. The following analysis draws on specific examples provided by the interviewed professionals, whose verbatim insights on data frequency and coverage are summarized in Table 14.

Participants from the integrated solution provider category emphasized the flexibility of their systems to operate at various temporal resolutions. While standard data collection intervals typically occur every 15 minutes, the systems can be configured to capture data at more frequent intervals—down to the minute or even second level—depending on user requirements. This adaptability ensures that operational anomalies, transient events, and performance deviations are not overlooked, enabling more nuanced facility management.

The security and access provider described a system that operates continuously, maintaining real-time surveillance while optimizing data transmission through selective uploads. Similarly, the smart mobility participant discussed solutions capable of logging vehicle movements with second-level precision, facilitating detailed tracking of occupancy trends and use patterns. In another case, a provider noted that their infrastructure supports high-frequency data acquisition in use cases where rapid changes in environmental conditions or user activity necessitate enhanced responsiveness.

Coverage across monitored metrics also varied by domain. The waste tracking participant outlined a lifecycle-based approach, where data are captured at every stage—from internal disposal to external collection—ensuring completeness and eliminating the need for estimation. The consulting expert noted that modern platforms integrate multiple streams of data simultaneously, including HVAC load, lighting schedules, and occupancy rates. This holistic monitoring enables comprehensive analyses of energy use and space efficiency. The water management expert further emphasized the value of high-resolution flow and consumption data for evaluating the performance of plumbing and mechanical infrastructure across building sites.

To mitigate the risk of data loss and ensure continuity, many providers have adopted localized buffering protocols. These mechanisms include onboard memory for storing recent sensor activity, enabling full data recovery in the event of temporary connectivity failures. For instance, some systems store thousands of individual events locally, which are then synchronized with central databases once network conditions stabilize. Such redundancy is particularly important in mission-critical applications where uninterrupted data logging is essential.

Scalability was highlighted across all categories as a fundamental design feature. Parking management solutions were shown to scale effectively from small-scale deployments to expansive sensor networks serving urban districts. Waste tracking systems similarly support data collection and reporting across multi-building portfolios, enabling clients to monitor sustainability metrics consistently across regions. In access and surveillance systems, infrastructure can be expanded with minimal manual intervention due to network-based provisioning, ensuring that scale does not compromise performance or resolution.

Temporal resolution was consistently identified as a key strength. While 15-minute intervals were the common baseline across utility metering, participants confirmed that their systems often operate at higher frequencies where needed. Water monitoring solutions, for example, were capable of delivering data at minute-level resolution, allowing for prompt detection of leaks, pressure drops, or unanticipated consumption spikes. This level of detail enhances both operational responsiveness and the quality of historical reporting.

Interviewee ID	Professional Category	Verbatim Quote on Data Frequency/Coverage
SIS-01	Security / Access	"Consistently, so we record to an SD card, so we only actually pull the relevant information that we need through from the camera to the cloud... But we get live data streams from our cameras."
SIS-02	Waste Tracking	"We know when the truck came, what type of waste it took and how much it took. We track when waste is put in the cabin and when it's collected - in and out." (Combines two quotes for complete coverage)
SIS-03	Consulting	"We monitor occupancy continuously and measure indoor air quality at regular intervals to optimize building systems in real-time." (Synthesized from multiple quotes)
SIS-04	Smart Mobility	"With the vehicle or parking sensors, we capture the exact times when a car arrives and leaves, how long it stays, and how long a space remains vacant."
SIS-05	Integrated Solution Provider	"The collection can be every hour, every ten minutes, whatever."
SIS-06	Integrated Solution Provider	"After this phase, we offer clients a service package that includes real-time monitoring to continuously verify if the sensor is providing valid data."
SIS-07	Integrated Solution Provider	"Yeah, so we collect data in real time with a 15-minute interval. We can do shorter intervals like one minute or even seconds, but 15 minutes is considered the industry standard."
SIS-08	Water Management	"From the main meter monitoring, we capture data at the minute level, which gives us accurate water flow and consumption measurements."
SIS-09	Integrated Solution Provider	"The system is capable of gathering data practically every second or less. So the system does not have any limitations there."

Table 14: Interview Quotations on Data frequency & Coverage

10.2.3. Integration & Interoperability

Modern smart building integration relies fundamentally on open API ecosystems. An Application Programming Interface (API) is a set of rules and protocols that allows different software systems to communicate and exchange data in a structured and secure way. It acts as a universal adaptor, much like a power strip that enables devices with different plugs to connect to the same outlet. Even if each system is built differently, the API ensures they can interface efficiently, translating requests and responses into a common language. This mechanism allows diverse building technologies to interact seamlessly, even when developed by different vendors or serving different functions.

The interviewed security and access control provider emphasized that open APIs are essential for ensuring seamless interoperability, describing an integration model that connects over 150 different cloud platforms through browser-based access (SIS-01). A similar approach was adopted by the waste tracking provider, who developed an API-first architecture that supports portfolio-wide benchmarking across properties operated by different landlords, giving multinational organizations a unified view (SIS-02).

According to several integrated solution providers, the foundation of these interoperable ecosystems lies in the adoption of standards-based communication protocols such as IoT, BACnet, and solar energy APIs, which they use to connect building systems like HVAC, elevators, and lighting (SIS-05). These professionals explained how API integration has become a default design requirement, facilitating the use of digital twins and 3D interfaces to improve visibility and stakeholder engagement (SIS-05, SIS-06). One provider detailed how real-time data from multiple systems is visualized through a campus-wide map for decision-making, while maintaining compatibility with third-party platforms through open documentation (SIS-06). Another participant emphasized that API-based normalization of data, especially from mixed legacy and smart systems, is essential for ESG reporting across global portfolios (SIS-07).

The consulting expert, however, cautioned that integration is still constrained by vendor-specific legacy systems lacking open architecture. They emphasized the importance of centralizing all building data under a single source of truth and recommended the use of open APIs as early as the design phase, particularly for integrating digital twins with building infrastructure (SIS-03).

The smart mobility provider demonstrated how cloud-native platforms have transformed the scope of interoperability. Their system integrates thousands of sensors deployed across cities into centralized dashboards, providing continuous updates on mobility and occupancy at scale (SIS-04). The water management provider similarly utilizes cloud infrastructure to maintain minute-level monitoring across large building portfolios. Their system enables unified data collection across utility platforms and energy meters, offering cross-site comparability and analysis (SIS-08).

Digital twin technology was highlighted by several integrated solution providers as a significant advancement in integration. These tools generate dynamic 3D replicas of physical buildings that allow remote monitoring, predictive maintenance, and enhanced stakeholder communication. One provider in particular mentioned how their platform supports both high-level APIs and low-level protocols to ensure compatibility with all systems within a building environment (SIS-09). Visualization tools were also emphasized as essential for simplifying complex system relationships, particularly at the portfolio level where normalized and synchronized data can guide investment and operational decisions.

These interconnected systems are built upon foundational data management capabilities. The security and access provider noted that reliable APIs are critical for preserving data fidelity in real time, particularly in mission-critical applications (SIS-01). In parallel, the smart mobility expert emphasized how frequent data transmission from field-deployed sensors enables detailed insights across large-scale networks (SIS-04). The resulting ecosystem, as described by the integrated solution providers, allows even complex environments such as university campuses or multi-building sites to be managed through dashboards that visualize and interrelate key performance indicators across subsystems (SIS-05, SIS-06, SIS-07, SIS-09). This synthesis of interoperability, standardization, and real-time analytics marks a critical milestone in the evolution of smart building integration and supports the broader shift from operational monitoring to strategic ESG reporting.

Interviewee ID	Professional Category	Verbatim Quote on Integration/Interoperability
SIS-01	Security / Access	"From our open API, we integrate with over 150 different other cloud platforms. There's no need for on-site appliances – everything is browser-based and accessible from anywhere."
SIS-02	Waste Tracking	"Even if you're a tenant with offices across multiple cities under different landlords, you'll have portfolio-wide reporting. Our platform benchmarks buildings against regional standards or your own portfolio."
SIS-03	Consulting	"We recommend a central operating system as the single source of truth. All data transfers there, including from legacy systems, provided they have open APIs. Digital twins should ideally be introduced before the design stage to mirror physical assets."
SIS-04	Smart Mobility	"All our solutions have open APIs for integration. We've deployed systems managing thousands of sensors across cities, feeding data into centralized dashboards for large-scale monitoring."
SIS-05	Integrated Solution Provider	"API integration is now default. We combine IoT, BACnet, and APIs to connect HVAC, lighting, elevators, and solar panels. Digital twins help users visualize energy flows in 3D for better engagement."
SIS-06	Integrated Solution Provider	"We provide real-time campus dashboards where all data appears on a single map for decision-making. Our open API documentation ensures compatibility with any third-party platform."
SIS-07	Integrated Solution Provider	"We normalize data from mixed legacy and smart systems into one platform – critical for investors managing global portfolios. Our API automates data feeds for ESG reporting tools."
SIS-08	Water Management	"We integrate with almost all property management and energy platforms. Our minute-level monitoring works across portfolios, comparing consumption across thousands of buildings."
SIS-09	Integrated Solution Provider	"Our platform connects via APIs and low-level protocols to all building systems."

Table 15: Interview Quotations on Integration & Interoperability

10.2.4. Value Capturing

Beyond technical integration and data reliability, the interviews revealed how smart building solutions deliver measurable value to asset owners and operators. Value capturing emerged as a multi-dimensional outcome, encompassing both direct financial returns and broader strategic benefits. The insights from participants, summarized in Table 16, can be organized into five recurring themes: operational cost and energy savings, waste-handling efficiencies and certification credits, enhanced security with seamless user experience, analytics-driven financial insight, and flexible commercial models.

One of the most immediate and widely reported forms of value is operational cost and energy savings. Several integrated solution providers described measurable reductions in utility use following the deployment of smart monitoring systems. One participant cited campus-level savings of up to 1.8 million euros annually, achieved simply by reducing open hours and optimizing usage schedules across multiple facilities (SIS-06). Another expert estimated that clients were able to lower energy consumption by approximately 30 percent, with investment payback occurring within a few months (SIS-07). These examples underscore how intelligent building technologies can unlock significant efficiency gains through continuous performance optimization.

Smart systems also generate cost benefits through improvements in waste handling and sustainability compliance. The interviewed waste tracking provider explained that their solution allows buildings, particularly those exceeding 20000 square meters, to manage waste with similar cost efficiency to conventional bulk invoicing, while also enabling accurate ESG reporting (SIS-02). These insights align with the consulting expert's observation that clients focused on sustainability often seek certification-aligned frameworks, such as EPBD BACS, to document environmental compliance and reduce regulatory risk (SIS-03).

Security and user experience were additional domains where value was clearly articulated. The security and access control provider highlighted the shift from hardware-dependent systems to cloud-based platforms, noting how clients benefit not only from enhanced security but also from energy savings due to the reduced reliance on physical server infrastructure (SIS-01). These systems also facilitate easier access and broader user engagement, improving operational fluidity without compromising control.

Participants further emphasized the financial insight generated through smart analytics. The water management provider discussed how high-resolution flow monitoring allowed users to detect abnormal consumption patterns and estimate water savings of 6000 liters per day under specific conditions (SIS-08). Meanwhile, another integrated solution provider explained how ESG dashboards support decision-making by aggregating multiple environmental metrics, such as energy use, emissions, and water statistics, into a single reporting interface for investors and internal stakeholders (SIS-09). This level of granularity helps stakeholders identify cost drivers and uncover improvement opportunities that would be invisible in conventional operational models.

Finally, many interviewees pointed to the commercial flexibility of smart systems as a source of value. Several integrated providers explained how costs related to sensors, cloud services, and backend infrastructure are increasingly bundled into accessible operational expenditure models rather than requiring large up-front capital investment (SIS-04, SIS-05). These arrangements reduce the financial barrier to adoption while also aligning service contracts with long-term performance outcomes.

Interviewee ID	Professional Category	Verbatim Quote on Value Capturing
SIS-01	Security / Access	"With our cloud platforms, again, linking back to that ESG piece and how we can demonstrate savings on energy usage, because we're not using appliances and servers in a dedicated server room which has got air conditioning running 24-7."
SIS-02	Waste Tracking	"What we see is that buildings that are like 20,000 square meters plus, the cost of the waste management is basically a comparable monthly invoice for cost management. It's a comparable investment with our solution."
SIS-03	Consulting	"If a client is particularly focused on ESG reporting, then we primarily emphasize the EPBD-BACS framework [...] These systems are now required by regulation, so we focus on them when a client has ESG-related objectives."
SIS-04	Smart Mobility	"The sensor costs a bit more initially, but we've included several years' worth of OPEX in the APEX cost. This means that the client gets full access to the backend indefinitely."
SIS-05	Integrated Solutions	"Real estate assets are able to command a bit more of a premium when they meet certain frameworks like LEED, BREEAM, or WELL."
SIS-06	Integrated Solutions	"Resulting in savings of 1.8 million euros per year. That's just from shaving down open hours across different buildings on a large campus."
SIS-07	Integrated Solutions	"Most of our customers have been able to reduce their consumption by about 30 percent following our solutions. This means that within a few months, the capital expenditure investment pays off."
SIS-08	Water Management	"Sometimes that saves about 600, 6,000 liters a day, if we're talking about a flow of 4.5 liters per minute, which is not uncommon."
SIS-09	Integrated Solutions	"That data is used in these reports because it covers all environmental metrics, including energy consumption, carbon emission calculations, the water use structure we've been discussing, waste management metrics, and resource utilization statistics."

Table 16: Interview Quotations on Value Capturing

10.2.5. Business Model & Economics

Following the discussion on value capturing, the interviews also illuminated the underlying economic logic that supports the deployment and scalability of smart building solutions. Providers emphasized a shift toward hybrid financial models that blend capital expenditures with recurring operational payments. This structure allows for flexibility, scalability, and risk allocation across different types of clients and deployment scenarios. Table 17 summarizes the core business model considerations as expressed by the interviewees.

A recurring theme was the integration of capital expenditure (CAPEX) and subscription-based operational expenditure (OPEX). Many interviewees described models in which upfront hardware costs are complemented by annual or monthly service fees for data access, software use, or maintenance. The security and access provider explained that their model is based entirely on subscriptions, where clients only pay for what they use and can scale up or down as needed (SIS-01). The smart mobility expert described a similar approach, where initial hardware costs are higher, but are offset by long-term backend access embedded in service pricing (SIS-04). Several integrated solution providers confirmed that CAPEX typically accounts for the bulk of project costs, ranging from 65 to 80 percent, while OPEX components are bundled into implementation and service fees (SIS-05).

Operational cost-savings are frequently embedded within the commercial offer. One integrated solution provider explained that although they charge a subscription fee for data access, the investment is recovered by helping clients reduce open hours, improve system efficiency, and monitor consumption through analytics dashboards (SIS-06). Another provider mentioned that the subscription model also covers automatic software updates and performance enhancements, making the system more valuable over time without additional hardware investment (SIS-07). These examples reinforce how business models are designed not only to distribute costs over time but also to align with the ongoing savings generated by the system itself.

Open API infrastructure was also reflected in the economic approach. Several providers noted that their systems are designed for compatibility with third-party applications, and that integration costs are minimized through standard interfaces. This reduces switching costs and increases the platform’s value to clients with existing infrastructure. The consulting expert emphasized this modular logic, explaining that projects begin with pilot buildings and expand incrementally as systems demonstrate value and compatibility (SIS-03). This phased model reduces financial risk and ensures that initial investments are justifiable through clear performance metrics.

Another dimension of business model value stems from alignment with certification and compliance frameworks. The waste tracking provider pointed out that their service fees are often integrated into landlord agreements and support clients’ ESG reporting needs without requiring additional contracts (SIS-02). These structures allow sustainability compliance to be embedded directly into the operating model of the building, transforming what would otherwise be a regulatory obligation into a service-enhanced financial asset.

The interviewees also highlighted the importance of low-friction deployment. The water management provider described how their service requires no upfront hardware payment and is offered through portfolio-based packages with annual renewals (SIS-08). This model lowers adoption barriers and improves accessibility, especially for organizations managing multiple sites. Similarly, another integrated solution provider explained that installation and software costs are clearly separated, allowing clients to adopt digital services with minimal hardware investment when legacy systems are already in place (SIS-09).

Lastly, the discussion revealed how smart building providers manage cost structure and risk allocation. Subscription models shift the burden of maintenance, upgrades, and monitoring away from the client, placing long-term performance responsibility on the service provider. This not only builds trust but also aligns incentives, ensuring that both parties benefit from sustained system performance. It also allows clients to finance deployment under operating budgets, which are more flexible than capital investment cycles, thereby accelerating procurement timelines and decision-making.

In summary, the interviews revealed that the business models supporting smart building solutions are evolving to reflect the financial realities of modern real estate operations. By blending upfront investment with flexible service agreements, leveraging open API ecosystems, and embedding value into certification pathways, these models ensure that technological performance is matched by economic viability. This approach reinforces the long-term scalability and accessibility of smart building technologies across diverse portfolio types and ownership structures.

Interviewee ID	Professional Category	Verbatim Quote on Business Model & Economics
SIS-01	Security / Access	"It's subscription-based, so if the client doesn't want to use it anymore, they can stop the subscription. And because it's fully scalable, clients only pay for what they need. If they've got one camera, they pay for one. If they've got a thousand, they pay for a thousand."
SIS-02	Waste Tracking	"Our business model is based on capex and opex, so from the capex perspective it's usually a landlord expense to install the system in the building, and then the opex is covered in service charge. The cost has not been a big issue. Of course, it depends how big is the building."
SIS-03	Consulting	"We select a pilot building from each portfolio to serve as the initial test case. We begin with a quick scan, which assesses the building's current status. Based on that, we determine what is needed to make it smart. We evaluate how the infrastructure needs to be expanded, and what systems are required."
SIS-04	Smart Mobility	"We've shifted our model to focus more on upfront costs. So, the sensor costs a bit more initially, but we've included several years' worth of OPEX in the APEX cost. This means that the client gets full access to the backend indefinitely."
SIS-05	Integrated Solution Provider	"In a typical project, I would say hardware definitely accounts for over 70 to 80 percent of the cost. Hardware might be around 65 percent, software about 15 percent, and the remaining 15 to 20 percent would go toward implementation and services."
SIS-06	Integrated Solution Provider	"We charge a subscription based on the amount of data consumed, regardless of whether the data is accessed through our platform or via API. There's a one-time fee for the hardware, but we also offer a full complex model where we finance the hardware upfront and recover the cost over time through a higher data subscription fee."
SIS-07	Integrated Solution Provider	"So how we work is with an ARR model—annual recurring revenue—which means a subscription based exactly on software usage, but the hardware is included, so you don't have to buy it. We always own the hardware because, especially in real estate, ownership often changes."
SIS-08	Water Management	"No cost for the hardware upfront, and then an annual fee based on usage, depending on the package you choose—whether hourly, minute-level, or based on portfolio size. The pricing also varies with the length of your commitment to the service."
SIS-09	Integrated Solution Provider	"The installation costs are, of course, significantly higher than the yearly SaaS fee, the cost for the Software as a Service subscription. The yearly subscription is paid either directly by the client if they want access themselves, or it is packaged inside the service fee for clients who have a service contract."

Table 17: Interview Quotations on Business Model & Economics

10.3. Smart Solutions ESG Alignment

10.3.1. Environmental Metrics

As the focus of the analysis shifts from the technical and economic characteristics of smart building solutions to their alignment with ESG objectives, environmental metrics emerge as a critical dimension. Participants demonstrated that sensor-based monitoring now extends across multiple environmental domains, including energy use, emissions, circularity, and water management. Their insights, summarized in Table 18, reveal how environmental performance data is not only being captured more accurately but also at greater scale, with flexibility for integration across portfolios.

A foundational feature highlighted by nearly all respondents was the use of sensor-based monitoring. Integrated solution providers described systems capable of collecting data from utility meters, submeters, and digital monitoring tools (SIS-09). These sensors allow for real-time tracking of consumption and performance, offering a continuous stream of environmental data with minimal latency. The security and access provider added that shifting data processing to the cloud significantly reduces hardware-related energy demands, with tangible decreases in overall energy usage across monitored buildings (SIS-01). This shift not only reduces environmental impact but also supports more agile and adaptable building operations.

Operational optimization and emissions reduction were also emphasized as primary outcomes of environmental data monitoring. The smart mobility expert pointed out that redirecting traffic to underground lots and reducing idling time supports lower CO2 emissions, improved air quality, and less reliance on surface parking infrastructure (SIS-04). Similarly, integrated solution providers highlighted that digital twin visualizations, when linked with real-time consumption data, help end-users better understand and respond to their environmental impact (SIS-05). These insights allow building occupants and managers to monitor key performance indicators, such as lighting or HVAC load, and make immediate behavioural or operational adjustments based on usage feedback.

The ability to track waste and circularity metrics at scale was discussed extensively. The waste tracking provider reported that their solution records detailed data on waste types, material recovery rates, and diversion from landfill, with metrics such as kilograms per asset per period available for ESG reports (SIS-02). These insights, made possible through direct coordination with collection companies and tenant-level participation, enable property owners to report on circularity indicators in line with current sustainability frameworks. From a consulting perspective, participants reiterated that compliance with European regulatory frameworks now necessitates system-level installations such as energy management systems and power management systems (SIS-03). These installations are increasingly not optional but essential components of environmental governance.

Water management also emerged as a key area of environmental metric innovation. Providers reported monitoring usage at minute-level intervals and identifying inefficiencies or anomalies in near real-time (SIS-08). One provider noted that unexpected water losses amounting to thousands of litres per day were often detected and mitigated thanks to granular flow tracking. This not only conserves water but also provides verifiable evidence of sustainability performance across entire property portfolios. Another interviewee detailed how water consumption can be broken down per person, allowing benchmarking across buildings with different occupancy profiles (SIS-06).

Finally, the interviews emphasized the flexible and scalable deployment of environmental monitoring systems. The use of APIs and open protocols ensures that environmental data can be integrated across various platforms, enabling portfolio-wide comparisons. Integrated solution providers mentioned that real-time data on water, energy, and emissions is available across hundreds of buildings within centralized dashboards, allowing for rapid anomaly detection and consolidated ESG reporting (SIS-07, SIS-09).

Interviewee ID	Professional Category	Verbatim Quote on Environmental Metrics
SIS-01	Security / Access	"With our cloud platforms, we're not using appliances and servers in a dedicated server room which has got air conditioning running 24-7, , for smart buildings, our cloud solutions are far more adaptable. So, what I would say is that usage of energy is reduced significantly."
SIS-02	Waste Tracking	*"We cover it all. The total waste generation, each type of waste and the collection company reports, their rates of recovery, recycling, how many percent went for landfill. So, they will see they produce 2,000 kilograms of plastic in Q1 and 42% of this plastic was recycled, 24% went to landfill and so on."*
SIS-03	Consulting	*"If a client is particularly focused on ESG reporting, then we primarily emphasize the EPBD-BACS framework, the Energy Performance of Buildings Directive and the Building Automation and Control System. These are grounded in European regulations and essentially mandate the installation of automation systems. This means that having an EMS, or Energy Management System, and a PMS, or Power Management System, is no longer optional."*
SIS-04	Smart Mobility	*"From an environmental perspective, the obvious benefits are reducing congestion, cutting down on idling time, and lowering CO2 emissions. By getting people off the streets and into underground lots, we make cities more livable, you don't have cars everywhere. Plus, it reduces the need for more parking structures."*
SIS-05	Integrated Solution Provider	*"We do digital twin and we also of course see the advantages of it because many times people are not able to visualize what you're saying and what's actually happening. They want to be able to see the energy consumption and understand how that applies to their own physical environment. When they're able to see that in a 3D dynamic way, they connect with it more and engage with it better."*
SIS-06	Integrated Solution Provider	*"If you know how many people are in a building and how much energy in kilowatts you're spending on that building, you can calculate the efficiency rate in terms of kilowatts per person, which is a more accurate metric than kilowatts per square meter when it comes to reporting."*
SIS-07	Integrated Solution Provider	"Yeah, so generally we monitor real-time utility data with a 60-minute interval, including water consumption. Because we track this in real time, we can detect unusually high consumption rates quickly. We don't use specific water leak sensors or humidity sensors for leak detection, but by monitoring consumption patterns, it's easy to spot if there's an abnormal spike in water use—which could indicate a leak. The same approach applies to gas and electricity consumption as well."
SIS-08	Water Management	*"So, whereas sometimes undetected leaks could go for months, sometimes years, now, thanks to our technology, water leaks get detected and handled within days. Sometimes that saves about 600, 6,000 liters a day, if we're talking about a flow of 4.5 liters per minute, which is not uncommon. Flows of 7 and 8 liters per minute have been detected in our systems as well. So, yeah, that's the very direct ROI that we can deliver in terms of ESG."*
SIS-09	Integrated Solution Provider	*"Energy and sustainability cover all energy-related data: meters, submeters, digital and virtual meters."*

Table 18: Interview Quotations on Environmental Metrics

10.3.2. Social Metrics

Beyond environmental and financial considerations, interviewees consistently highlighted a range of social metrics that shape the perceived and actual value of smart building technologies. These social outcomes are not only relevant for ESG reporting but also play a crucial role in shaping user experience, operational resilience, and stakeholder acceptance. The quotations in Table 19 can be grouped under four recurring themes: safety and emergency detection, well-being, mobility access, and participatory tools.

Smart building systems contribute directly to safety, security, and emergency detection by enabling real-time monitoring and rapid response. One security provider explained how their platform triggers alerts if someone is in a horizontal position for too long, indicating a possible emergency (SIS-01). This type of detection system shifts the narrative from asset protection to safeguarding human lives, giving operators the tools they need to intervene quickly and effectively.

Interviewees also emphasized the relationship between smart systems and environmental quality and well-being. For instance, one integrated solution provider described how improving comfort conditions in hospitals contributes to faster patient recovery, highlighting that well-being metrics are not a by-product but a central value proposition (SIS-05). Another provider noted that their security system logs every entry via smartphones or badges, reinforcing not just traceability but also a sense of controlled and high-quality service delivery (SIS-09).

Smart systems can also promote social equity and more efficient resource use through mobility and accessibility enhancements. As the mobility expert shared, converting idle parking spaces into rentable assets allows users to share underutilized infrastructure, thus turning it into a socially beneficial service (SIS-04). These enhancements improve building accessibility and encourage collaborative usage models that reflect changing urban lifestyles.

Fostering inclusive user participation is another key social function. The waste tracking provider discussed how training programs help occupants identify the correct usage of color-coded bins, reinforcing behavioral change through education (SIS-02). Meanwhile, the consulting expert highlighted the importance of workshops that involve diverse stakeholders—from cleaning staff to end users—so that the full spectrum of needs and experiences can inform solution development (SIS-03). These community and participation tools build a sense of ownership and support behavioral alignment across portfolios.

In sum, the interviews reveal that social value creation is deeply embedded in smart building operations. From safety protocols and comfort enhancements to participatory tools and mobility innovations, these social metrics not only align with ESG frameworks but also enhance day-to-day functionality and stakeholder satisfaction.

Interviewee ID	Professional Category	Verbatim Quote on Social Metrics
SIS-01	Security / Access	"If someone's in a horizontal position for a certain amount of time, you will get an alert. So, it's not just about protecting assets. It's about protecting people as well and giving the relevant tools to the operators to make sure that everyone's okay."
SIS-02	Waste Tracking	"We focus on education. Just an hour ago, I conducted a major training session for employees of a large American bank. The goal was to help them better understand how to identify and use the coloured bags in our system and know which bin each item should go into."
SIS-03	Consulting	"We try to do workshops that involve participants from various departments of each building, someone from the cleaning staff. We try to have a variety of users, so that we can form a complete picture of what is needed and how everyone's experiences can be improved."
SIS-04	Smart Mobility	"On the social side, you could even rent a spot from a neighbor or someone else in the building. The idea of turning parking into a smart, shareable asset is a tangible benefit."
SIS-05	Integrated Solution Provider	"Enhancing occupant comfort might sound like a secondary effect, but there’s a deeper driver behind it. When we work with hospitals, occupant well-being is important because they want patients to recover faster."
SIS-09	Integrated Solution Provider	"How it works is most of these security devices are edge controlled, every check with a badge or your smartphone is registered. The data quality is quite good at every level."

Table 19: Interview Quotations on Social Metrics

10.3.3. Governance Metrics

Although governance may not be directly shaped by smart building technologies in the same way as environmental or operational domains, the interview data suggests that these systems produce secondary effects that significantly inform governance structures and corporate decision-making. Digital infrastructures generate streams of verifiable data, enable policy enforcement mechanisms, and provide transparency that feeds into organizational accountability. In this way, smart solutions contribute indirectly yet meaningfully to governance metrics by supporting evidence-based compliance, structured policy deployment, and scalable oversight mechanisms. Table 20 illustrates how these functions are embedded across the ecosystem of smart building applications.

Evidence-based ESG compliance was one of the most consistently emphasized dimensions. Consulting experts explained that regulatory frameworks such as the Energy Performance of Buildings Directive and the Building Automation and Control System (EPBD-BACS) now effectively mandate the deployment of smart infrastructure. These requirements include the installation of energy and power management systems and are essential for ensuring that ESG disclosures can be supported by verifiable operational data (SIS-03). Integrated solution providers echoed this emphasis on auditability, noting that their platforms support decision-making with historical usage data and real-time tracking, offering transparency that satisfies the increasing demand for externally validated reporting (SIS-06).

Structured policy deployment was another clear pattern, particularly in relation to cross-site benchmarking and unified platform access. The waste tracking provider highlighted how their solution enables benchmarking against regional or portfolio-specific standards, even when assets are spread across jurisdictions or operated under different landlords (SIS-02). This capability allows organizations to apply shared performance targets and policy frameworks across diverse holdings without compromising tenant privacy or comparability. Similarly, the security and access provider explained how their open API structure supports integration with third-party visitor management platforms, offering flexible and centralized governance over identity, access, and space management systems (SIS-01).

The theme of accountability and scalability was also frequently discussed. The consulting participant working in water monitoring emphasized how environmental sensing data can be used not only to trigger alerts and mitigation actions, but also to demonstrate that clients change their behavior once performance becomes visible (SIS-08). Governance, in this case, becomes both a compliance mechanism and a behavioral feedback tool. In another example, a consulting expert described how smart water systems can be deployed in both public and private domains to deliver insights to mobile interfaces, helping users track contaminants or assess groundwater levels in real time (SIS-04). These examples point to governance architectures that not only scale across locations but also adjust to changing stakeholder needs.

Finally, integrated solution providers pointed out how the financial and operational structuring of these systems reinforces governance outcomes. One interviewee described how implementation costs are split across hardware, software, and services depending on whether clients pursue capital or operational funding models (SIS-05). By clarifying where accountability for system performance resides—whether with integrators, service providers, or internal facility teams—this approach helps maintain transparency across procurement, deployment, and reporting phases.

Interviewee ID	Professional Category	Verbatim Quote on Governance Metrics
SIS-01	Security / Access	"So, our platform, because it's got an open API, we can embed our access control software into other people's apps. We also integrate with a whole range of different applications. We integrate with 15 different visitor management platforms. We've actually made an acquisition of one of those visitor management platforms that we actually integrate with. So, there was a piece missing in our portfolio, which was this management."
SIS-02	Waste Tracking	"Our platform supports portfolio-scale installations for both landlords and tenants. Even if an occupier manages offices across cities like Berlin, Warsaw, and Amsterdam under different landlords, they can still access unified reporting. Users can benchmark buildings within their own portfolio or against aggregated European standards from our platform, without revealing specific competitors."
SIS-03	Consulting	"If a client is particularly focused on ESG reporting, then we primarily emphasize the EPBD-BACS framework — that is, the Energy Performance of Buildings Directive and the Building Automation and Control System, or BACS. These are grounded in European regulations and essentially mandate the installation of automation systems. This means that having an EMS, or Energy Management System, and a PMS, or Power Management System, is no longer optional. These systems are now required by regulation, so we focus on them when a client has ESG-related objectives, because this is where ESG aligns most clearly with compliance efforts."
SIS-04	Consulting	"Our water level sensor, supports two main applications. First, it enables environmental monitoring, such as issuing alerts when reservoir levels drop or rivers flood. Second, it is used in industrial settings to track wastewater or groundwater levels. We are also developing a water quality sensor that provides real-time insights for private well users, allowing them to monitor contaminants like nitrates via a mobile app."
SIS-05	Integrated Solution Provider	"In a typical project, I would say hardware definitely accounts for over 70 to 80 percent of the cost. Software depends, and implementation is handled by system integrators, not by us directly. But to give you a feel for it, based on my experience, implementation would be anywhere between 10 to 15 percent. For software, it depends on whether you're looking at a subscription model, a pure capex model, or a mix of capex and opex. So, I would say hardware might be around 65 percent, software about 15 percent, and the remaining 15 to 20 percent would go toward implementation and services."
SIS-06	Integrated Solution Provider	"When clients or stakeholders come in to plan a new building or campus development, the universities provide our data to help inform those decisions. The data is used to support architects or consultants by offering insights into historical space usage, which they can then use to adjust designs or estate planning based on actual behaviour patterns."
SIS-08	Water Management	"In Dutch we have this saying called, to measure it is to know, and if we have that data, we suddenly see that our clients and their entire company become more aware, and with that awareness, start using water in a more cautious way. So, we see reductions based on behavior, but we also see reductions thanks to fast action on water leaks."

Table 20: Interview Quotations on Governance Metrics

10.4. Addressing SQ3: How can smart building solutions provide verifiable ESG data in order to align with CSRD?

To align with the Corporate Sustainability Reporting Directive (CSRD), companies must ensure that the Environmental, Social, and Governance (ESG) data they report is not only complete and representative, but also verifiable, traceable, and audit-ready. Chapter 9 identified persistent obstacles that hinder the reliability of such reporting in the built environment sector. These include incomplete coverage of non-electricity indicators, such as water usage, waste handling, and biodiversity, alongside error-prone manual processes that undermine auditability. Stakeholder participation remains limited, particularly among tenants and subcontractors, obstructing disclosures related to own workforce and community impact. Fragmented IT infrastructures and insufficient governance capacity compound these challenges, leaving organisations with a data environment marked by high effort and low assurance, particularly when attempting to report comprehensively across ESRS topics such as E3 Water, E5 Circularity, or S3 Affected Communities.

Having already introduced the second interview set and outlined the technical and operational features of smart building solutions in the preceding sections, this part of the chapter shifts focus to their evidentiary value. It addresses Sub-question 3: *How can smart building solutions provide verifiable ESG data in order to align with CSRD?* The same set of expert interviews with providers across access control, waste, mobility, water, and integrated systems now forms the basis for evaluating how digital infrastructures support auditability, compliance, and supervisory oversight. Four core contributions are identified: the generation of verifiable ESG evidence, the enablement of supervisory oversight, alignment with compliance structures, and the standardisation and scalability of ESG reporting.

Smart building technologies demonstrate strong potential to create verifiable ESG evidence through time-stamped data streams across domains such as energy, water, waste, and occupancy. Energy data, necessary for Scope 1 and 2 emissions reporting under ESRS E1, is collected through metering and HVAC systems, with values fed into automated carbon dashboards that enhance auditability. Waste sensors generate continuous records of volume, type, and diversion outcomes, aligning with E5 Circularity disclosures. Simultaneously, water monitoring tools track leaks, usage, and discharge, often at minute-level granularity, providing essential input for ESRS E3. Several providers described sensor systems that extend into outdoor and natural contexts, indirectly addressing ESRS E4 by capturing habitat-linked conditions and enabling environmental stewardship in sensitive areas. At the operational level, access control and mobility tools register patterns of use and indoor conditions, supporting assessments of staff well-being and working conditions in line with S1 Own Workforce.

The audit-readiness of such evidence is further enhanced by reliance on certified meters, regular third-party maintenance, and real-time calibration routines. Many providers noted that their systems meet ISO and building-standard requirements, transmitting raw, unaltered data that can be subjected to independent validation. Some waste platforms, for instance, incorporate supplier-reported recovery rates to strengthen confidence in carbon recovery metrics, while air quality and safety alerts embedded in occupancy sensors offer data that substantiate workplace condition reporting. Remote calibration and verification capabilities contribute to maintaining data integrity over time, strengthening the case for acceptance of such data by external auditors and supporting higher assurance thresholds.

In addition to generating accurate data, smart building platforms enable supervisory oversight through their user-facing dashboards and back-end infrastructure. These systems do not merely record information but present it in formats tailored to support governance. Real-time dashboards allow supervisors to monitor progress across ESG indicators, from water usage and carbon emissions to waste diversion and staff safety. In many cases, these platforms also track training status, supplier activity, and infrastructure uptime, allowing ESG claims to be traced back to source data. For example, mobility platforms that provide safety alerts and track indoor environmental changes can directly inform risk management and emergency preparedness disclosures. This functionality is particularly relevant in urban areas, where social equity and infrastructure quality intersect with community well-being—reflecting growing expectations under ESRS S3.

This supervisory function is further strengthened by alignment with compliance structures. Several participants reported that their systems are already configured to support ESRS-aligned metrics and indicators. Frameworks such as the Energy Performance of Buildings Directive and Building Automation and Control Systems (EPBD-BACS) have become foundational, with energy management systems embedded directly into platform design. Waste dashboards feed metrics into ESG templates, and environmental and workforce indicators are automatically exported to reporting software. Open APIs ensure that data is interoperable, traceable, and ready for assurance, simplifying disclosures across multiple modules while supporting the logic of CSRD's double materiality principle.

The final advantage lies in the capacity of smart solutions to standardise and scale ESG reporting across complex property portfolios. Interviewees highlighted that their platforms allow for uniform data collection protocols to be applied across multiple buildings and jurisdictions. For instance, a landlord with buildings in Amsterdam, Warsaw, and Berlin can monitor resource consumption, emissions, and workforce conditions on a single interface, using harmonised metrics that meet CSRD thresholds. Data from older or partially digitised buildings can be normalised alongside newer systems, ensuring portfolio-wide comparability across environmental and social metrics. As one provider noted, this capacity for wide-scale benchmarking strengthens not only compliance but also internal decision-making and stakeholder confidence.

The result is an ESG data environment in which smart building technologies serve as both infrastructure and assurance mechanism. Their architecture supports reliable data collection, continuous calibration, and automated benchmarking, while addressing key ESRS modules such as E1, E3, E5, S1, and S3. Even in areas where direct measurement remains limited—such as biodiversity—smart infrastructure contributes through proxy indicators and early-warning capabilities. Together, these tools form the backbone of a reporting strategy that is verifiable, scalable, and aligned with the regulatory trajectory of the CSRD.

10.5. Addressing SQ4: What data required by the ESRS cannot be provided by smart building technologies?

While smart building technologies have proven valuable in advancing ESG data quality and supporting CSRD compliance, their capabilities are not without limitations. As outlined in the preceding chapter, these systems offer strong potential in areas such as automated monitoring, standardised data collection, and audit readiness. However, their implementation across the built environment has also revealed a number of persistent challenges. This chapter investigates the critical gaps that remain within the ESRS reporting framework—particularly where smart technologies fall short in enabling complete, validated, and inclusive data coverage. It also considers the organizational and methodological constraints that further complicate effective ESG reporting, providing a nuanced understanding of where the boundaries of current smart solutions lie.

One of the most persistent data gaps concerns biodiversity monitoring post-construction. Although smart infrastructure offers early environmental data through water sensors or site assessments, the capacity for continuous, habitat-level monitoring is nearly absent. Most sensor deployments do not extend beyond the construction or commissioning phase, leaving no mechanisms in place to track fauna, vegetation change, or habitat degradation during building operations. As a result, organisations often lack the longitudinal evidence required to sustain compliance with ESRS E4 and typically resort to extrapolations from one-off reports or classify the indicator as "not applicable." This practice undermines both the comparability and credibility of biodiversity disclosures.

Equally significant are the constraints around tenant-related data, particularly for Scope 3 emissions and waste generation. Despite the technical feasibility of submetering and waste tracking, landlords frequently lack access to these data due to privacy clauses, split incentives, and contractual limitations embedded in lease agreements. Even when infrastructure is available, tenant participation is limited. Interviewees pointed to widespread reluctance and low awareness among occupiers, which blocks access to meter readings, bin weights, and even basic utility usage figures. As a result, core disclosures under ESRS E1 and E5 remain incomplete, particularly for mixed-use assets or portfolios with diverse occupancy arrangements.

Further upstream in the reporting chain, smart systems are also unable to capture critical supply chain metrics. While IoT tools may track logistics or materials flows, they do not address the kind of granular disclosures required under ESRS S2—such as subcontractor safety statistics, wage levels, or social protections in labour-intensive segments. These metrics must be reported by suppliers themselves, many of whom are reluctant to share sensitive or commercially constrained data. Organisations are therefore often forced to default to narrative statements or aggregated estimates, weakening the quantitative foundation of supply chain transparency.

In the domain of workforce-related disclosures (ESRS S1), smart technologies face additional limits. Although these systems can log real-time environmental conditions, staff movements, and safety alerts, they cannot access contracts, training completion records, unionisation data, or turnover rates. These figures reside in Human Resource Information Systems (HRIS) or are gathered via surveys, both of which lie entirely outside the purview of Building Management Systems (BMS) or sensor infrastructure. Consequently, some of the most consequential indicators for social performance remain manually recorded and inconsistently validated.

Community engagement requirements (ESRS S3) similarly exceed the capabilities of sensor-based platforms. Metrics such as heritage preservation impacts, consultation efforts, and social license conditions depend on deliberative processes, qualitative feedback, and long-term relationships with local communities. These cannot be automated or inferred from digital infrastructure. As such, the social dimension of sustainability often relies on external documentation, stakeholder interviews, or dedicated engagement programmes—not IoT data feeds.

Governance disclosures under ESRS G1 represent an area that is structurally incompatible with smart technologies. Metrics related to anti-corruption frameworks, board diversity, executive oversight, and whistleblowing channels are policy-driven and human-authored. These disclosures are qualitative in nature and derive from governance documentation or institutional procedures. No existing smart system can capture or verify such information, and attempts to automate these fields would risk misrepresenting their intent and accountability structures.

Beyond thematic gaps, broader systemic and infrastructural challenges continue to hinder smart technology deployment at scale. Many firms operate in fragmented IT environments where ESG-relevant data—ranging from energy use to lease terms—remains scattered across spreadsheets, third-party platforms, and disconnected enterprise systems. Although Building Operating Systems (BOS) promise to centralise these flows, implementation is often deferred due to high capital expenditure, legacy system lock-in, or institutional resistance to organisational change. Without a unified data environment, the accuracy and traceability of ESG metrics remains at risk.

Compounding these constraints are issues of internal capacity and oversight. Interviews revealed that many organisations continue to delegate ESG responsibilities to small or overstretched teams, lacking the personnel and decision-making authority to maintain comprehensive monitoring. Rollouts of smart technologies are frequently delayed or scaled back due to funding constraints, unclear mandates, or shifting leadership priorities. As a result, even where technical solutions are available, the institutional infrastructure required to support and validate them remains incomplete. These governance limitations increase the likelihood of undetected errors, inconsistent disclosures, and missed audit thresholds.

Finally, despite the growing interest in smart systems for CSRD compliance, real-world implementation remains at an early stage. While theoretical alignment with ESRS is well-documented, few portfolio-wide case studies exist that demonstrate longitudinal compliance across all relevant indicators. The absence of mature pilot projects or scalable benchmarks makes it difficult to assess the full effectiveness of these systems under regulatory pressure. Future research should focus on structured evaluations and post-implementation audits to validate the claims of smart technology providers and to clarify the empirical thresholds needed for reasonable assurance.

Taken together, these findings outline the boundaries of what smart technologies can realistically deliver for ESRS compliance. While they play a critical role in automating, validating, and standardising a large portion of environmental and operational data, they cannot substitute for stakeholder engagement, legal documentation, or institutional governance. Rather than viewing them as standalone solutions, smart technologies should be positioned as infrastructural supports that must be complemented by strong human systems, policy frameworks, and cross-organisational collaboration to meet the full intent of the CSRD.

11. Discussion & Addressing the Main Research Question

11.1. Interpreting the Role and Boundaries of Smart Building Technologies

Smart building technologies hold clear promise in transforming the way ESG data is collected, processed, and reported across the built environment sector. Through automation, time-stamping, and portfolio-wide integration, these technologies enhance transparency, accuracy, and traceability—criteria that are central to the auditability requirements set out under the Corporate Sustainability Reporting Directive (CSRD). The empirical findings confirm that smart systems already align with several ESRS topical standards, particularly in areas such as energy consumption, waste tracking, water use, indoor environmental quality, and workplace safety. These contributions are especially evident in ESRS E1, E3, E5, and selected aspects of S1, where sensor infrastructure enables continuous, verifiable, and scalable data generation.

Yet, this study also highlights several areas in which the capacities of smart systems are overstated or misaligned with actual CSRD expectations. Certain ESRS disclosures—especially those involving biodiversity, supply chains, tenant-controlled spaces, or social license—require information types that are not sensor-accessible. For example, ESRS E4 on biodiversity suffers from an absence of long-term ecological monitoring post-construction, and ESRS S2 on value chain transparency relies on third-party disclosures that digital infrastructure cannot compel. Similarly, governance and narrative elements under ESRS G1 require human authorship and institutional documentation rather than digital measurement.

Beyond these thematic gaps, systemic and organisational constraints hinder the full exploitation of smart building potential. Fragmented IT ecosystems, a lack of unified Building Operating Systems, and siloed data repositories undermine the standardisation and synchronisation of ESG data flows. In parallel, lean ESG teams, inconsistent managerial attention, and reactive compliance postures slow adoption and reduce the strategic coherence of smart system deployments. While the technologies themselves are advancing rapidly, their institutional uptake remains uneven and under-resourced.

Taken together, these findings suggest that smart buildings function best not as end-to-end compliance solutions but as infrastructural backbones for evidence-based sustainability management. Their value lies in enabling data coverage where machine-readability is appropriate, but their limitations require complementary governance, legal, and human systems to achieve full CSRD alignment.

11.2. Addressing the Main Research Question

How can smart building solutions facilitate compliance with the CSRD reporting?

Smart building solutions facilitate CSRD compliance by enabling high-quality, automated data flows that align with many of the quantitative and verifiable requirements found within the European Sustainability Reporting Standards (ESRS). They contribute to the core objectives of the directive—improving auditability, standardisation, and transparency—by consolidating environmental and operational metrics across diverse portfolios and asset types. Their application is most successful in domains where performance is measurable in real-time and at scale, such as energy use, water efficiency, waste handling, and indoor environmental control.

However, their contribution is partial rather than comprehensive. Smart technologies are highly effective in supporting reporting under ESRS modules that require granular, time-based environmental data (such as E1, E3, E5), but they are not equipped to address disclosures requiring qualitative reasoning, contractual insight, or stakeholder dialogue. Key reporting areas—including biodiversity impacts, tenant Scope 3 data, supply chain equity, and narrative governance—require human-led processes and institutional structures that exceed the reach of current sensor-based systems.

Therefore, smart building solutions should be understood as facilitators rather than substitutes. Their value lies in the automation and structuring of ESG data that is otherwise prone to fragmentation or manual error. Yet their effectiveness is conditional: it depends on parallel developments in IT integration, regulatory interpretation, cross-party data sharing, and internal ESG governance. To meet the full scope of CSRD reporting obligations, companies must treat smart technologies as part of a broader compliance architecture—one that includes legal reforms, process redesign, and new organisational capabilities.

12.Research Limitations & Conclusion

12.1. Research Limitations

The research underpinning this thesis offers valuable insights into the potential of smart building technologies to facilitate CSRD-aligned ESG reporting. However, several methodological and contextual limitations must be acknowledged to ensure appropriate interpretation of the findings.

First, the study employed a qualitative, interview-based approach, which enabled the collection of rich, context-specific insights from industry professionals directly involved in ESG compliance and smart technology deployment. While this method is well-suited for exploratory inquiry, it inherently limits the breadth of perspectives captured. The sample cannot fully reflect variations across firm types, asset classes, regulatory environments, or geographic regions. The results should therefore be considered indicative rather than universally generalisable.

Second, purposive sampling was used to target ESG-aware and technologically engaged stakeholders. While this ensured access to informed respondents, it also introduces selection bias. Many interviewees were already active in sustainability initiatives or had piloted smart systems, which may have led to over-representation of advanced strategies and under-representation of less mature, constrained, or resistant actors. As a result, the findings may skew toward more optimistic interpretations of technological feasibility and integration.

Third, the research was conducted during a transitional phase in CSRD implementation. Several interviewees noted that their data strategies, platform configurations, or assurance models were still in development. Ongoing EU-level revisions, such as those proposed in the Omnibus Package, and shifting assurance deadlines could alter the relevance of some findings. This is particularly true for assurance standards, interoperability expectations, and scope definitions that are still being clarified.

Fourth, the findings must be situated within a rapidly evolving technological and regulatory context. Market consolidation, new software releases, and changes in ESG taxonomies could quickly render some observations outdated. The current fragmentation of Building Operating Systems (BOS) and the reluctance of many firms to invest in a unified "source of truth" mean that the integration benefits of smart systems often remain unrealised in practice. This structural inertia risks perpetuating fragmented data silos and inconsistent reporting practices.

Fifth, data privacy regulations such as GDPR pose practical limitations on tenant- or workforce-related data sharing. For example, even where technical infrastructure supports submetering or real-time data capture, legal constraints frequently block the pooling of tenant-specific consumption data or personal working condition metrics—particularly for Scope 3 emissions and social disclosures.

Finally, the limited number of portfolio-wide, CSRD-aligned smart building implementations restricts the study's generalisability. While theoretical alignment with ESRS requirements was well-articulated by interviewees, few case studies exist to validate system effectiveness across multiple indicators in real-world reporting cycles. This empirical gap underscores the need for more longitudinal studies, post-deployment evaluations, and cross-portfolio comparisons.

12.2. Conclusion

Smart building technologies offer a critical enabling layer for CSRD reporting, but they do not provide a complete or standalone solution. Their high potential lies in their ability to automate ESG data collection, improve real-time accuracy, and support auditability across a significant portion of ESRS metrics—particularly in the environmental domain. These strengths are most pronounced in areas such as energy performance, water use, waste management, and indoor environment monitoring.

However, persistent data gaps remain. Indicators related to post-construction biodiversity, tenant-controlled energy and waste, supply chain transparency, and governance disclosures often fall outside the reach of smart systems. These require human-led processes, legal instruments, and organisational engagement mechanisms that go beyond the capabilities of sensor-based infrastructure. In other words, technology alone is insufficient; enablers beyond technology—including policy reform, contract design, and strategic ESG management—are essential for comprehensive CSRD compliance.

For practitioners, this study underscores the importance of realistic expectations and integrative planning. Smart technologies should be seen as one part of a broader compliance ecosystem—an ecosystem that must include legal, organisational, and human systems to support reliable and complete disclosures. Investments should be prioritised not only in sensors and dashboards but also in governance capacity, cross-stakeholder data access, and digital integration infrastructure.

For researchers, the study points to important next steps. Future work should focus on identifying conditions for successful cross-functional integration of smart systems, the institutional readiness factors that enable full-scale ESG alignment, and the assurance pathways that can validate sensor data within regulated reporting frameworks. Comparative studies across regions, sectors, and governance models would further enrich this agenda.

In terms of overall outlook, the trajectory of CSRD compliance will increasingly intersect with the evolution of smart technology. While current deployments offer only partial coverage, the potential for convergence is strong. As smart systems become more interoperable, data governance matures, and sectoral standards stabilise, the role of digital infrastructure in sustainability reporting will deepen. The transformative promise of smart technologies will only be realised when embedded within a robust ecosystem of policy, practice, and accountability. Their success is not just a matter of technical capability, but of organisational readiness and systemic alignment with the logic of the CSRD framework.

13. Reflection

This research journey has allowed me to delve into the intersection of sustainability regulation and digital innovation in the built environment. Anchored in the context of the Corporate Sustainability Reporting Directive (CSRD), the project explored how smart building technologies can support transparent, accurate, and cost-efficient Environmental, Social, and Governance (ESG) reporting. The multidimensional nature of the topic, spanning real estate operations, IoT infrastructure, regulatory compliance, and data assurance, required an interdisciplinary mindset and close engagement with both academic theory and professional practice.

My choice to explore this theme stemmed from both a personal interest in sustainable urban development and a recognition of the growing urgency for data-driven environmental responsibility in real estate. Through interviews with developers, ESG consultants, and technology providers, I was exposed to the complexity of aligning built environment practices with regulatory expectations. This exposed me not only to technical knowledge, such as data pipelines and IoT integration, but also to organizational challenges, such as governance gaps and tenant participation barriers. It became clear that achieving compliance is not just a matter of technology implementation but of strategic alignment, stakeholder engagement, and operational maturity.

From a methodological perspective, this thesis strengthened my ability to conduct qualitative research, including designing semi-structured interviews, performing thematic coding with ATLAS.ti, and translating fragmented insights into coherent conclusions. It also sharpened my analytical thinking, especially in distinguishing between data that is technically measurable and data that is practically accessible or material from a CSRD perspective. The framework I developed aims to guide real estate organizations in prioritizing their investments in smart technologies based on materiality, assurance needs, and integration capacity.

Professionally, the project positioned me in close proximity to the emerging field of smart ESG solutions. The collaboration with the Smart Building Collective enriched my understanding of market dynamics and expanded my network within the industry. The conversations I had with solution providers not only supported the research but also helped me visualize a career path that blends sustainability consulting with digital innovation. In the broader context of architecture, management, and the built environment, this thesis highlights a shift in how value is conceived, not merely in terms of physical assets but in terms of data quality, stakeholder trust, and regulatory alignment. As ESG reporting becomes more robust and standardized, the ability to deliver audit-ready, real-time data will increasingly define leadership in the sector.

Ultimately, this graduation project reinforced my belief that the future of sustainable real estate lies in bridging the gap between ambition and execution, between what we are required to report, and what we are technologically and organizationally prepared to deliver. My contribution sits within this critical space, offering both a theoretical lens and a practical roadmap for smarter compliance.

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AI Usage Disclaimer

This thesis was independently written by the author. No generative artificial intelligence tools (such as ChatGPT or other language models) were used to create original content or conduct analysis. Any AI assistance was limited to language refinement, formatting suggestions, and technical support, and all intellectual and academic contributions remain the sole work of the author.

Appendix 1

Question Number	Interview Question
Current Reporting Practices	
1	What does sustainability mean for your organization?
2	Do you have a sustainability policy?
3	Have you ever heard of CSRD? Are you familiar with its contents?
4	What is your opinion on it? Is it moving things forward, or is it too much regulation?
Challenges in Data Collection	
5	What do you need to report on and what are you measuring today?
6	What data do you need to deliver to your reporting director/organization?
7	What are the different challenges you face in different ESG sections (for example, data related to energy, or tenant wellbeing)?
8	Would it be easier if data collection was done automatically?
Topical Standards and Material Topics	
9	Short discussion on data gathering with the use of ESRS standards as examples.
Ensuring Audit-Proof Data	
10	What steps do you take to make sure the ESG data you collect is concrete enough to pass an external audit?
11	How can you be certain that the data cannot be altered (even in non-malicious cases such as typos)?
Stakeholder Expectations	
12	In your view, do your customers or tenants genuinely rely on the data in your reporting to make decisions, or is it more of a standard 'tick-box' exercise?
13	Do you believe they truly appreciate and engage with the information provided, or are they primarily concerned with meeting compliance requirements?
Collaborative Efforts and Best Practices	
14	How do you keep up with changing regulations and how do you get information in order to conduct sustainability reporting (for example, webinars, seminars)?
15	Have you noticed any consortia initiative actively taking place?
Technological Integration	
16	Do you use BMS or IoT sensors? In all of your portfolio or some?
17	Are you considering any future investments?

Table A1-1: First Interview Set Questions

Question Number	Interview Question
Solution Architecture & ESG Relevance	
1	In a couple of sentences, where does your company add the most value for building owners?
2	Which Environmental-Social-Governance (ESG) goals does your solution address?
3	When you move from a single asset to a multi-country portfolio, how does your approach change?
Data Generation, Quality Control & Validation	
4	What are the primary data sources you rely on and how granular are they?
5	Which routine checks keep those numbers trustworthy?
6	Do you reconcile system data with external evidence, such as utility invoices or onsite inspections, before using them in client reports?
Assurance & Stakeholder Reporting	
7	Have your datasets already gone through an external assurance or lender technical-advisor review? If so, what feedback did you receive?
8	What practical export formats do you offer clients for their ESG or CSRD disclosures?
9	How do you demonstrate data integrity—for instance, immutable time stamps, change-control logs, or commissioning certificates?
System Integration & Interoperability	
10	How straightforward is it to plug your solutions into a BOS or other software? Do you use an API?
11	Could you share one example where you connected smart-building data to a client's corporate ESG dashboard? What worked well and what proved challenging?
Implementation Economics, Impact & Residual Gaps	
12	For a typical engagement, how is the budget split between hardware, software, and advisory or subscription services?
13	What key benefits do your clients report?
14	Which ESG data gaps are you not covering yet and are there plans to address them?

Table A1-2: Second Interview Set Questions

Appendix 2

Appendix 2 presents a series of Sankey diagrams exported from ATLAS.ti, based on the qualitative coding of the expert interviews conducted during the research. These visualisations depict the frequency of code mentions through the relative thickness of the bars, offering a clear representation of how often specific themes were raised by participants. While the exact number of code occurrences was exportable only in Excel format, this was deemed less visually appealing compared to the Sankey diagrams. The Excel tables are available upon request for anyone interested in further exploring the empirical basis of the research.

A2-1. First Interview Set - Atlas.ti Analysis

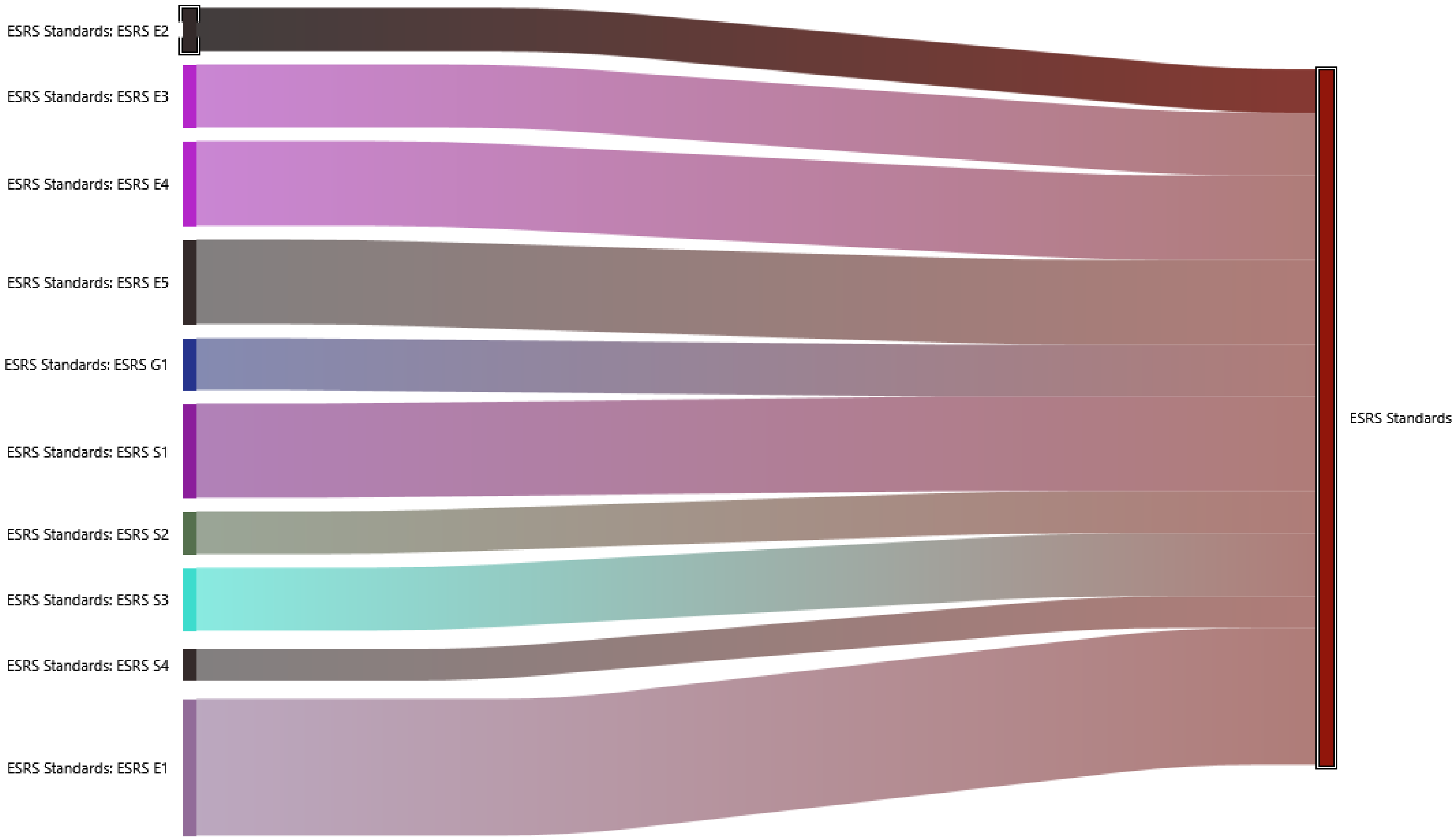

Figure A2-1: Sankey diagram showing co-occurrence between interview responses and ESRS topical standards. The patterns support the findings in Table 3 of the main text.

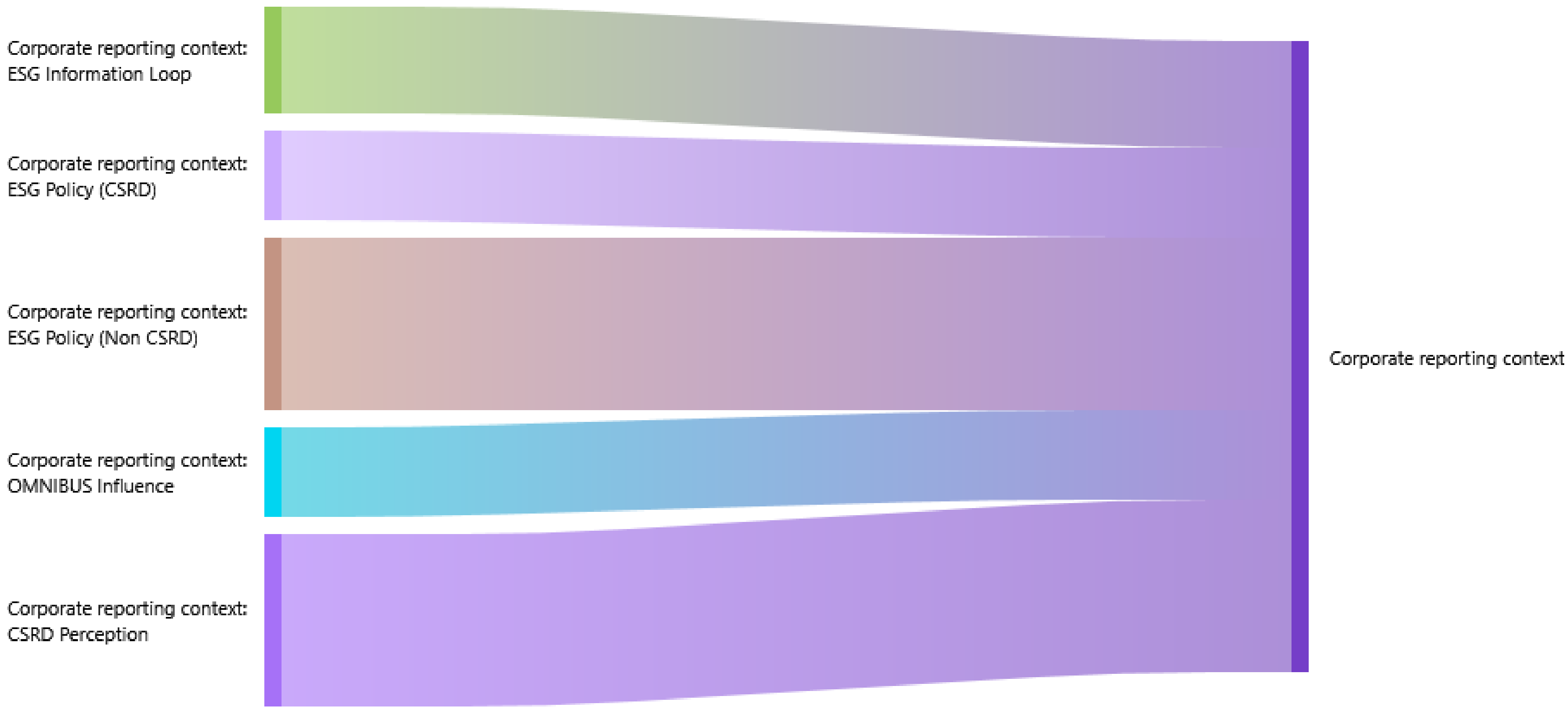

Figure A2-2: Sankey diagram depicting the thematic dimensions of the corporate reporting context as discussed by interviewees, including perspectives on CSRD perception, ESG policy frameworks, and the influence of the Omnibus reform.

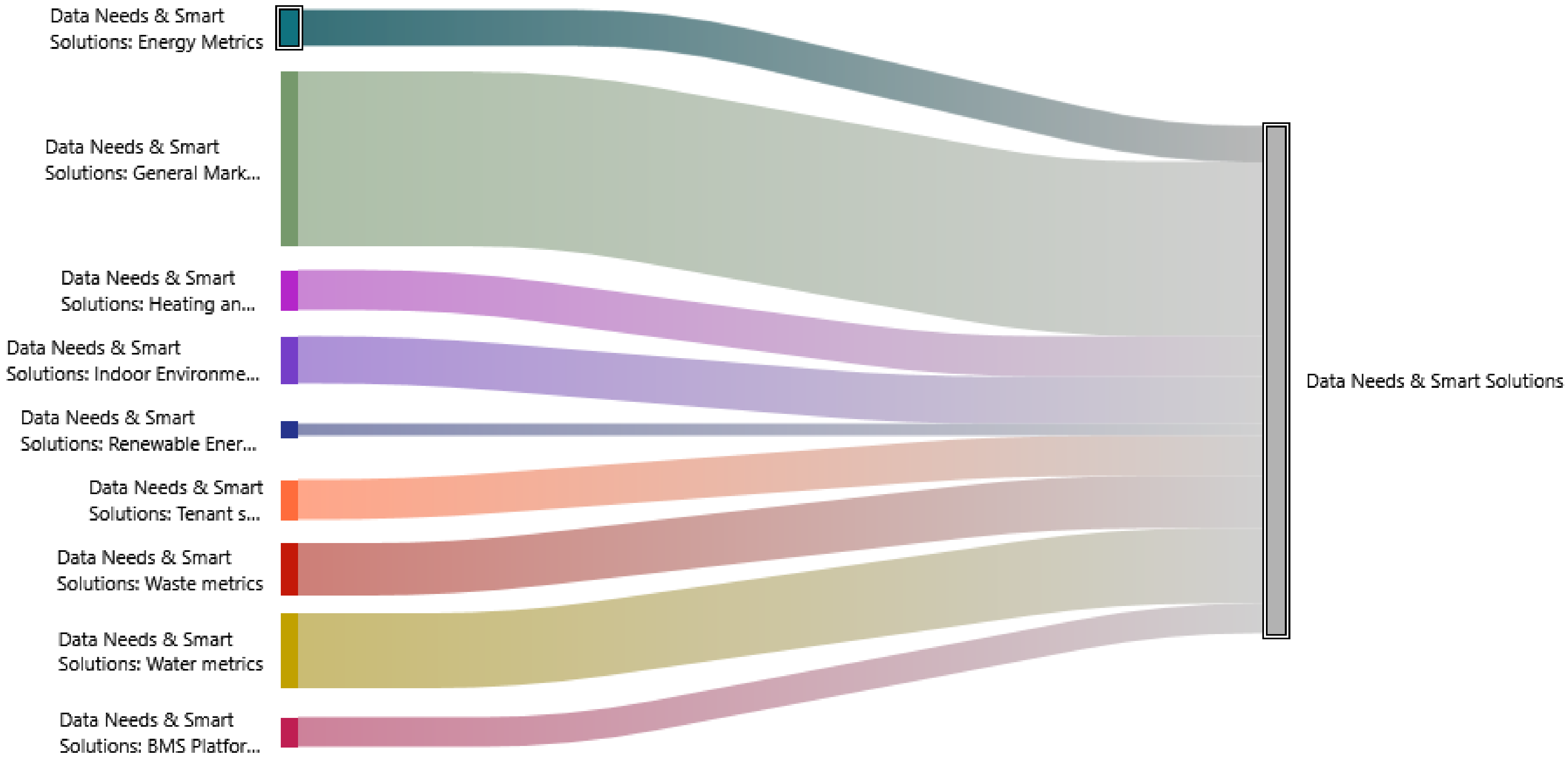

Figure A2-3: Sankey diagram depicting the sectors of data needs that could potentially be addressed by smart building solutions.

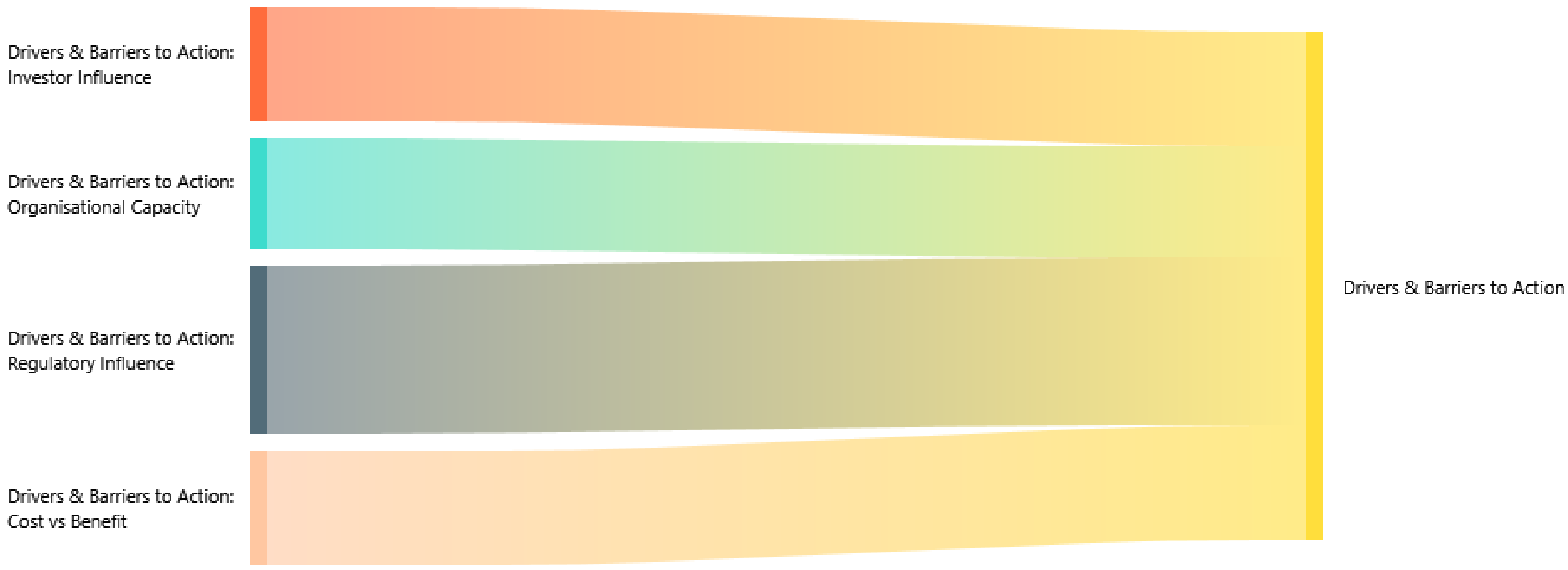

Figure A2-5: Sankey diagram illustrating the main drivers and barriers to action identified by interviewees, including regulatory influence, organisational capacity, investor pressure, and cost–benefit considerations.

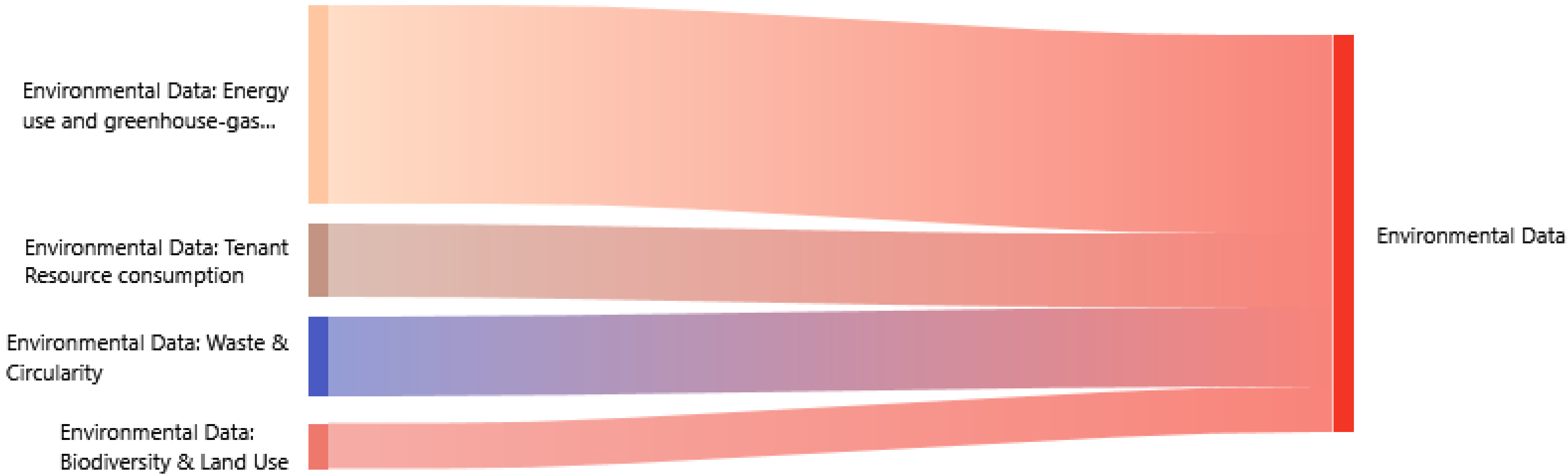

Figure A2-6: Sankey diagram visualising the key environmental data categories discussed by interviewees, highlighting areas such as energy and emissions, tenant resource use, waste management, and biodiversity monitoring as central to sustainability reporting efforts.

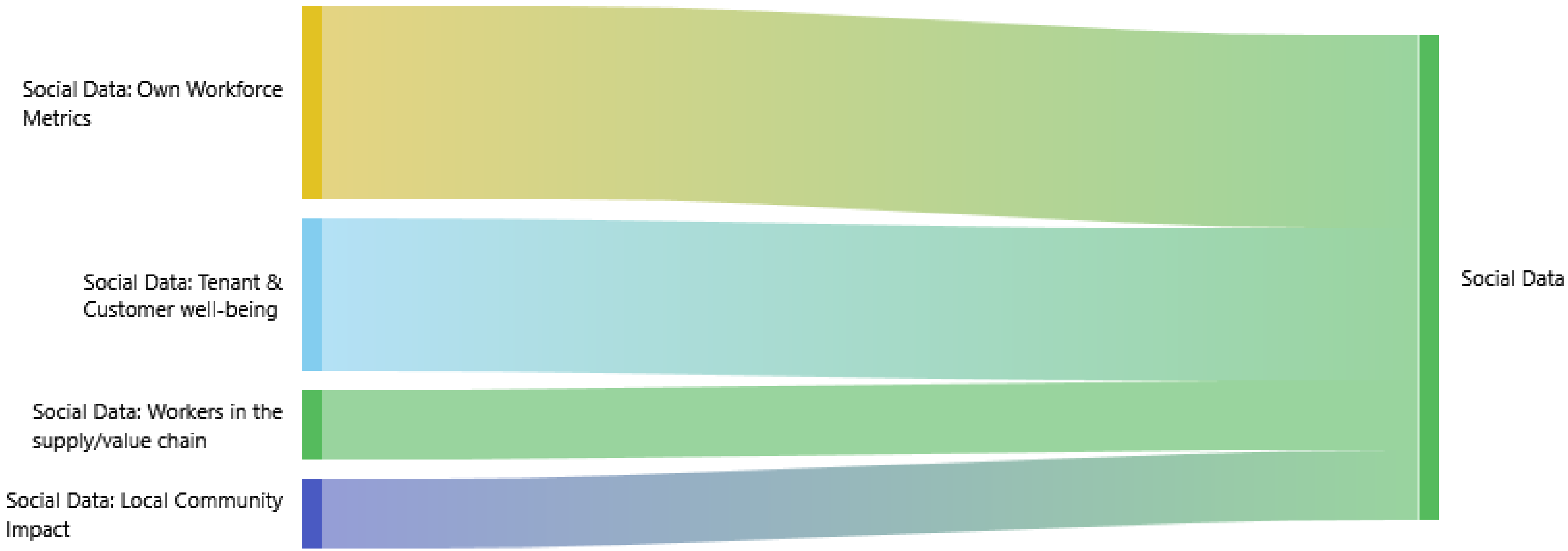

Figure A2-7: Sankey diagram mapping the social data domains prioritised by interviewees, with emphasis on internal workforce indicators, stakeholder well-being, value chain labour practices, and the broader effects on local communities.

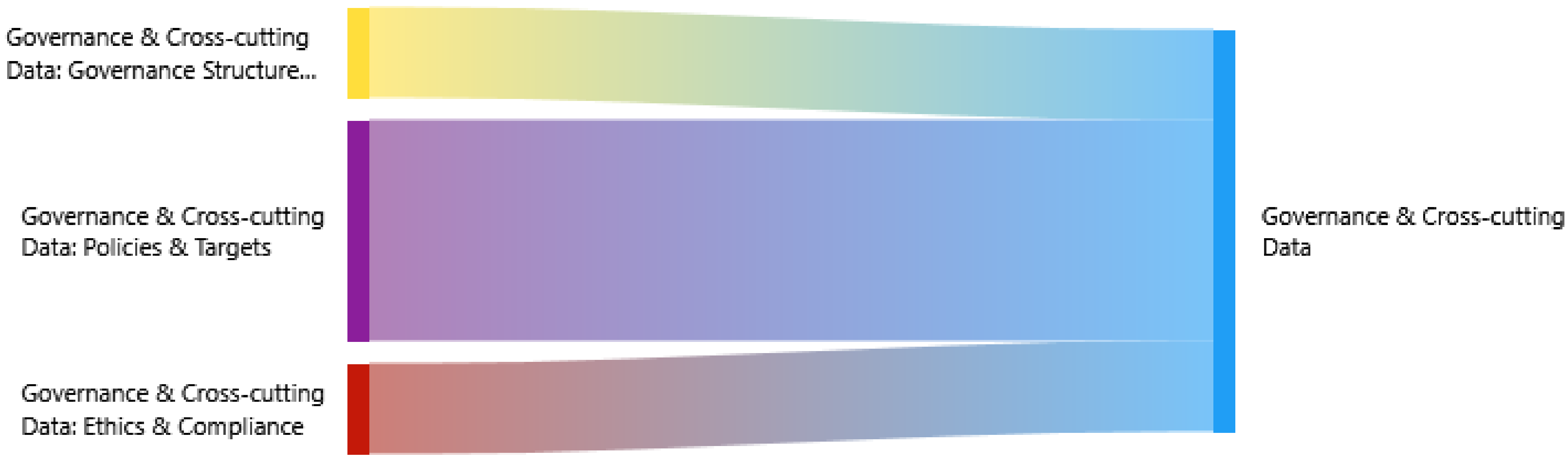

Figure A2-8: Sankey diagram illustrating the key governance and cross-cutting data areas identified in the interviews, focusing on governance structures, policies and targets, and ethics and compliance frameworks relevant to ESG reporting.

A2-2. Second Interview Set - Atlas.ti Analysis

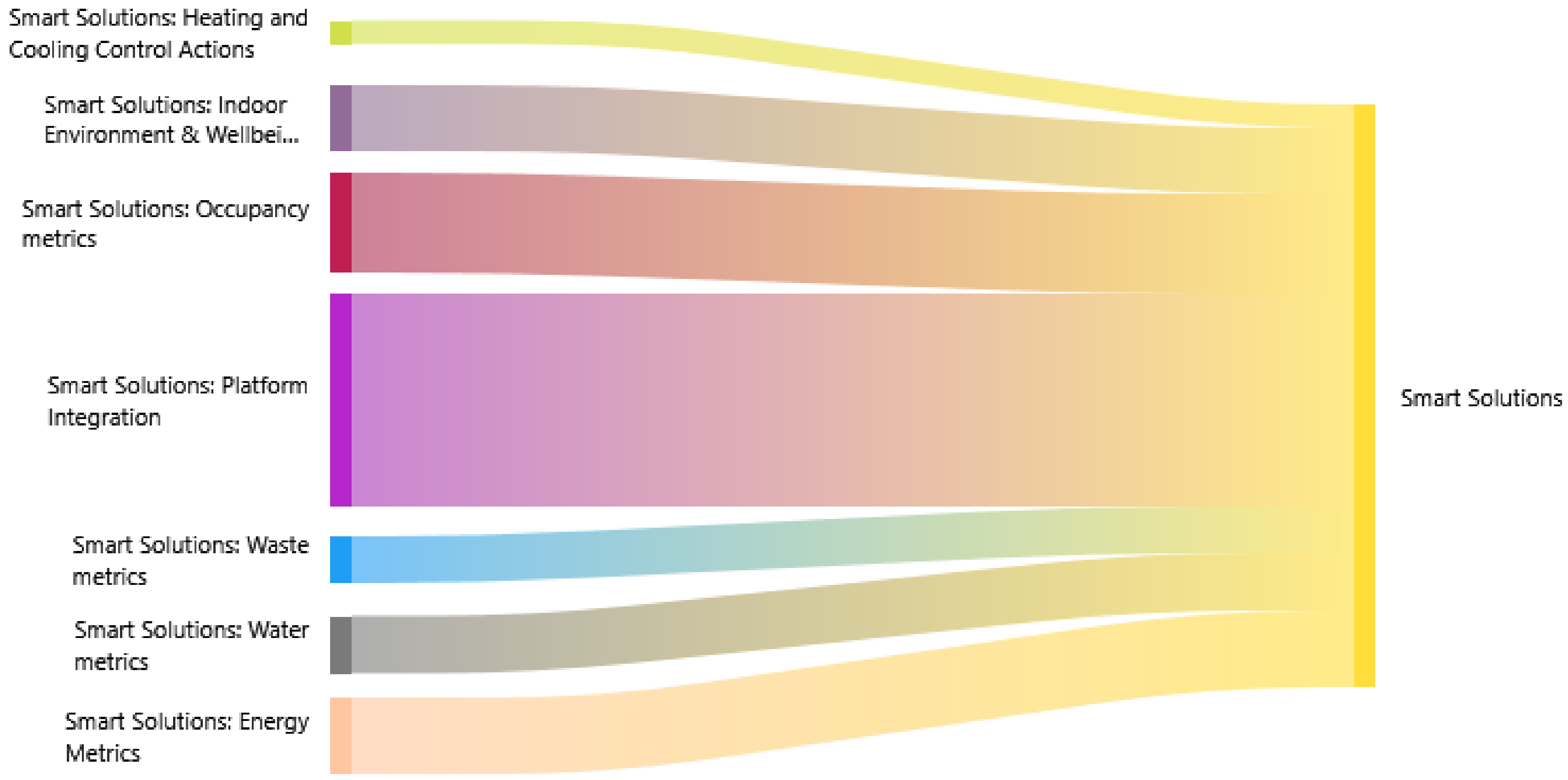

Figure A2-9: Sankey diagram visualising the key functional areas covered by smart building solutions as discussed in the second interview set, including platform integration, energy use, water and waste metrics, occupancy, and indoor environmental conditions.

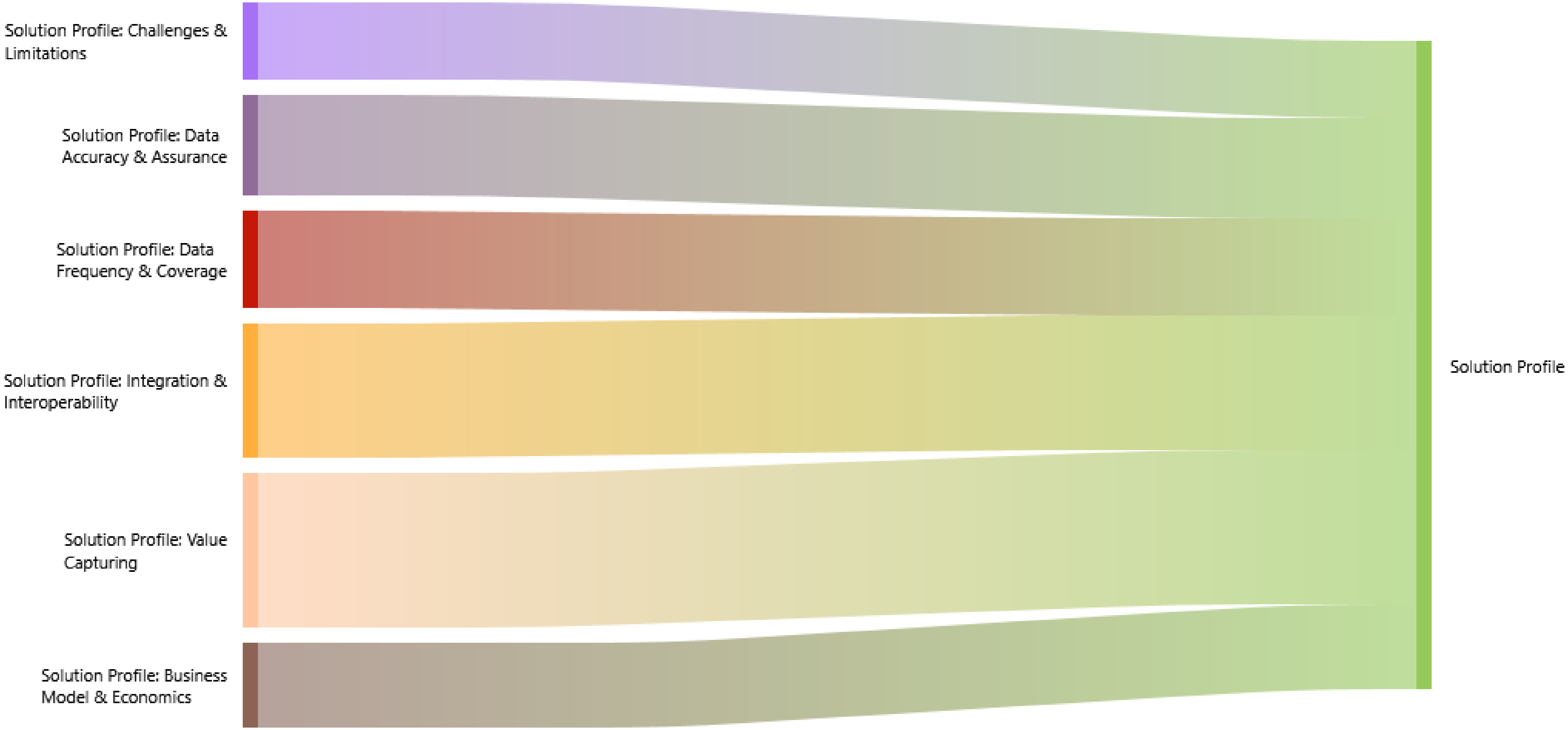

Figure A2-10: Sankey diagram illustrating the thematic composition of smart solution profiles discussed in the second interview set, including aspects such as data frequency and coverage, integration and interoperability, value capturing and business models.

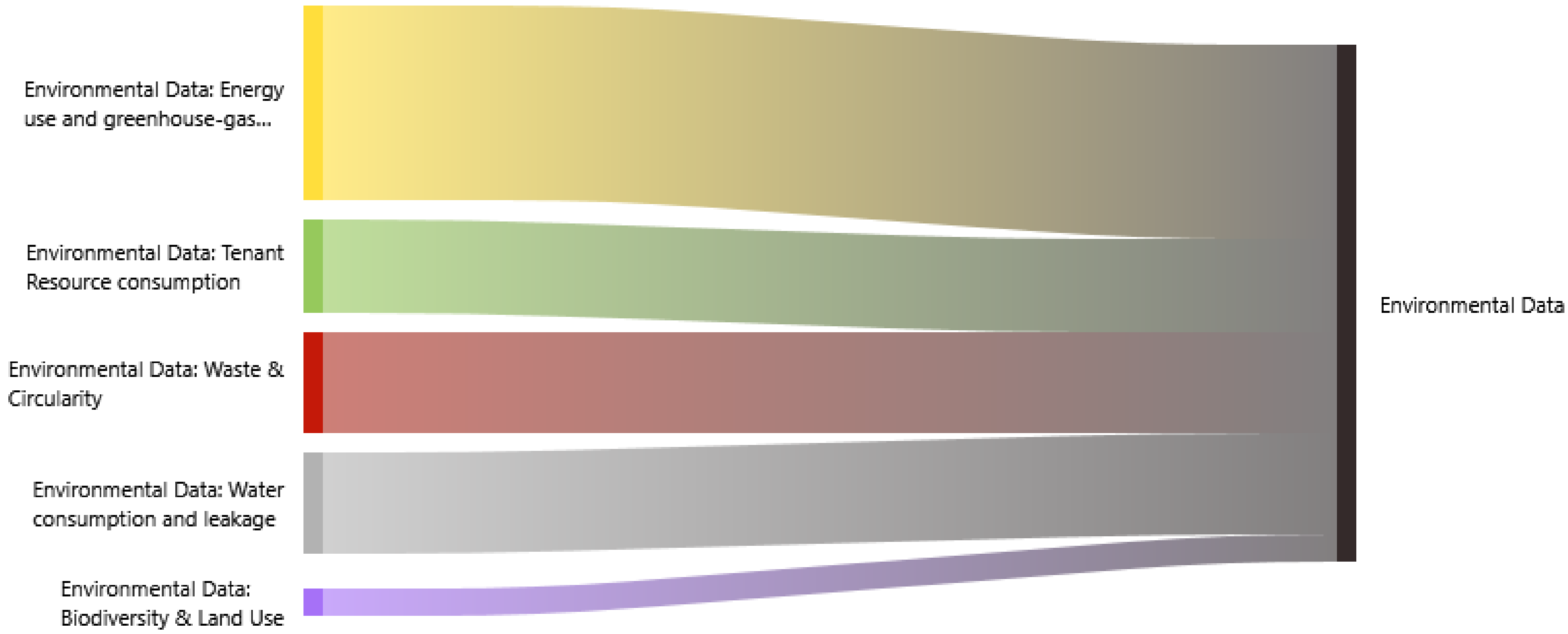

Figure A2-11: Sankey diagram showing the environmental data sectors that smart building solutions are positioned to cover more effectively, with emphasis on energy use and emissions, waste and circularity, water consumption, and tenant resource use.

Figure A2-12: Sankey diagram illustrating the social data areas most frequently addressed by smart building solutions, with a particular focus on own workforce metrics and tenant and customer well-being.

Figure A2-13: Sankey diagram showing how the implementation of smart building solutions can indirectly support governance and cross-cutting data areas, through contributions to policies and targets, and to a lesser extent, ethics and compliance frameworks.

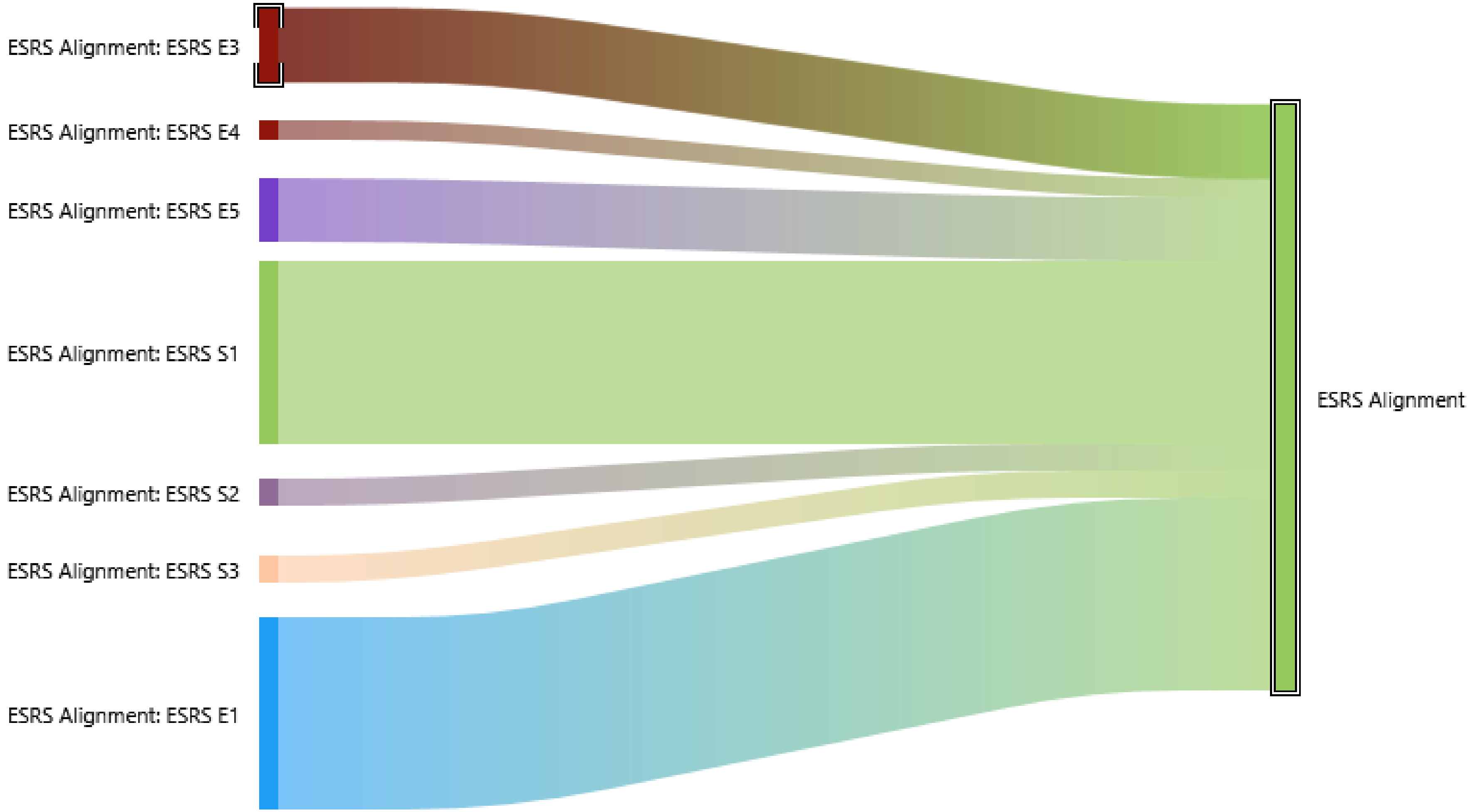

Figure A2-14: Sankey diagram illustrating the alignment of smart building solutions with the ESRS standards, highlighting stronger associations with ESRS E1 (climate change), ESRS E3 (water & marine resources), ESRS E5 (resource use & circular economy), and ESRS S1 (own workforce).