ABC2: Journal of Architecture, Building, Construction, and Cities

Empowering research for Sustainable Development Goals, ABC2: Architecture, Building, Construction, and Cities is a fundamental manifesto to address these pressing issues, fostering dialogue and knowledge exchange among researchers, practitioners, and policymakers. Exploring sustainable design, resilient infrastructure, advanced construction methods, and equitable urban development, ABC2 aims to empower the global community to create adaptive, inclusive, and sustainable environments. The ABC2 focus on cutting-edge research, technological advancements, and transformative strategies is essential for navigating the future of our cities and communities.

Research Article

Integrating Embodied Carbon Accounting into the Role of the Quantity Surveying Profession in the Construction Industry

Frank Ato Ghansah[1*], Eseosa Jesuorobo[1], David John Edwards[2,3], Bert Ediale Young[1]

[1*] School of Construction, Property and Surveying, College of Technology and Environment, London South Bank University, United Kingdom
[2] Infrastructure Futures Research Group, College of the Built Environment, Birmingham City University, Birmingham, United Kingdom
[3] CIDB Centre of Excellence, University of Johannesburg, Johannesburg, South Africa

Correspondence: frank.ghansah@lsbu.ac.uk

Abstract

Despite unprecedented attention focusing upon embodied carbon accounting (ECA) and concomitant net-zero emissions in the construction industry, the quantity surveying (QS) profession's quintessential role in achieving this ambition has hitherto attracted scant academic attention. Thus, this study examines how ECA can become an integral part of the QS profession. An exploratory mixed-method approach is adopted, including descriptive analysis and inferential analysis such as factor analysis, correlation and thematic analysis. Primary quantitative data were gathered from 106 related experts, whilst qualitative data were gathered from twelve related experts. Emergent results show that QS skills in cost planning, procurement and early design involvement are directly relevant to ECA. Key enablers identified are: "industry collaboration and knowledge sharing", "tools, frameworks, and policy infrastructure" and "data integration and ECA cost planning". However, for QS to effectively contribute to ECA, a blend of technical expertise, digital proficiency, and communication skills is requisite. Nonetheless, the key strategies to integrate the ECA into the QS profession are: "formalised training and upskilling", "embedding carbon into existing QS workflows", "digital tool integration", "early-stage project involvement" and "policy and client-led requirements." This study recommends aligning ECA frameworks with established QS cost management systems to create unified cost–carbon standards. This development could encourage academic institutions to incorporate carbon literacy, environmental product declaration (EPD) interpretation and BIM-LCA integration into QS higher education curricula. Furthermore, the Royal Institute of Chartered Surveyors (RICS) and other bodies must enforce continuing professional development modules on carbon management and include carbon data reporting in standard QS deliverables.

Keywords: Carbon emission assessment; Construction industry, Embodied carbon accounting; Net zero target; Quantity Surveying profession

Received: 16/11/2025
Revised: 26/11/2025
Accepted: 30/12/2025
Published: 11/01/2026

Volume: 2026
Issue: 01
Pages: 85-106

Highlights

- Embodied carbon accounting (ECA) for the quantity surveying (QS) profession.
- Key enablers were identified for the ECA for the QS profession.
- Key strategies were recommended for integrating ECA into the QS profession.

1 Introduction

The UK construction industry is an economic powerhouse and contributes approximately 6.4-7% of GDP and employs circa 2 million people (Trading Economics, n.d.; RICS, 2024). However, it also produces large-scale anthropogenic emissions during the extraction, processing and transportation of construction materials (Global Alliance for Buildings and Construction & UNEP, 2024). According to Wang *et al.* (2024), the construction industry accounts for 30-40% of global carbon emissions, with forecasts predicting this figure could rise to 50% by 2050. This underscores the need for the industry to align with global sustainability targets and objectives, particularly those outlined in the Paris Agreement, which aims for global net-zero emissions by 2050. A significant portion of the industry's emissions originates from embodied carbon (EC), which accounts for 40-70% of a new building's whole-life carbon footprint (Keyhani *et al.*, 2024). EC is the carbon emissions associated with the production, transportation and assembly of building components, as well as their eventual demolition and disposal (Lützkendorf & Balouktsi, 2022). This accounts for a substantial share of a building's total lifecycle emissions, making it a critical area for intervention (Hamilton *et al.*, 2020).

Despite the urgent need to reduce EC, the construction industry lacks standardised methods for managing and specifying reused structures and materials (Hart *et al.*, 2019), which is a critical role of the quantity surveying (QS) profession (Butterick, 2021). Embodied carbon accounting (ECA) implementation is crucial and involves the process of measuring, assessing and calculating the EC in construction materials as a first step towards reducing them in projects (Tunley Environmental, 2025). The QS profession is essential in cost management and material quantification throughout the whole project lifecycle (RICS, 2024). Core QS responsibilities extend from project inception, providing financial advice and cost estimates throughout the lifecycle, to ensuring value for money (Reddy *et al.*, 2022). Additionally, Quantity surveyors work closely with clients, architects and contractors to optimise project costs and material efficiency, implementing effective cost management methods, including value engineering (VE) and cost-to-complete forecasting. These skills position the QS profession uniquely to influence reductions in EC. However, despite their pivotal role, QS's involvement in ECA remains enigmatically underexplored (Mohd Hafir, 2019). While architects, engineers and sustainability consultants often adopt ECA and reduction processes, QSs have yet to fully integrate into these efforts, despite cost management expertise and early project involvement being essential for implementing sustainable solutions (Bolade-Oladepo *et al.*, 2020). Some studies investigated construction industry carbon emissions, e.g. Omotayo *et al.* (2023) examined sustainable construction and the evolving role of QS in Singapore. The study emphasised that the QS professional must upskill in areas such as green costing, carbon cost planning and life cycle cost (LCC) analysis to achieve sustainable outcomes. However, the research (ibid) does not provide new or existing frameworks for how the QS professional can adopt ECA. Robati *et al.* (2021) explored carbon VE for the construction sector and highlighted its potential within current QS skills to reduce carbon emissions. However, the study stops short of recommending how QS can integrate ECA for carbon VE into its responsibilities. Similarly, Amarasinghe *et al.* (2024) examine the impact of EC in the construction industry and the necessity of EC reduction, but did not consider the QS's role. Lützkendorf & Balouktsi (2022) provided general explanations, interpretations and recommendations on EC emissions in buildings, but do not address the QS role in this context. While EC in the construction industry has been widely discussed, there remains limited research on the specific role of the QS in ECA and how their expertise can drive the industry to achieve its net-zero targets. The QS profession is uniquely suited for ECA because the QSs have a deep understanding of the construction process and materials and can track the carbon footprint of different building elements from the design to construction to completion (2050-materials, n.d.). From this contextual background, the overarching research question formulated is: "How can ECA be integrated into the role of the QS profession?"

To address this knowledge gap, this study examines the role of QS in terms of ECA. Specific objectives are to: 1) investigate the perceptions of industry stakeholders on the role of QS in addressing EC; 2) explore the enablers required by QS to contribute to ECA; and 3) propose strategies for successfully integrating ECA into QS practices. Emergent findings generated raise awareness on how QSs can engage with ECA in the construction industry and highlight the untapped potential of QS in sustainability efforts in supporting the construction industry's transition towards net-zero carbon emissions. Achieving these objectives delineated provides a roadmap for integrating carbon-conscious cost management into mainstream QS practice.

2 Construction Industry and Embodied Carbon (EC)

The construction sector remains a major contributor to anthropogenic emissions, responsible for 30–40% of global emissions and significant material waste (Wang *et al.*, 2024). For example, in the UK, demolition and construction waste alone accounts for around 30% of all waste streams (Hart *et al.*, 2019). It originates from fragmented procurement and insufficient reuse structures (Brandao *et al.*, 2023). EC refers to greenhouse gas emissions generated throughout the lifecycle of building materials, from extraction and manufacturing to transport, construction, maintenance and end-of-life disposal (Elghaish *et al.*, 2022). Unlike operational carbon, which relates to a building's energy use, EC is locked in before a building becomes operational. Research estimates that EC contributes approximately 11% of global carbon emissions and can reach 40–70% of a highly energy-efficient building's total footprint (RICS, 2023). Key international frameworks highlight the importance of addressing EC. For example, PAS 2080 guides infrastructure, while BS EN 15978 guides building-level assessment, offering a modular breakdown of lifecycle stages (A1–A5, B1–B5, C1–C4). The RICS Whole Life Carbon Assessment (WLCA) aligns carbon data with established cost structures such as NRM and ICMS, making it particularly relevant to QS practice and procedure.

Carbon emissions are often categorised as Scope 1 (direct emissions), Scope 2 (indirect energy use), and Scope 3 (supply chain) (Yamamoto, 2023). Since most EC falls within Scope 3, accurate assessment depends heavily on supply chain transparency and reliable Environmental Product Declaration(s) (EPD) (Vieira *et al.*, 2024). This reliance highlights the challenges QS face when integrating EC into cost planning, as supplier data remains inconsistent and fragmented (Lackner *et al.*, 2023). Recognising EC hotspots is crucial for effective intervention. Materials such as concrete, steel and masonry account for nearly 60% of construction-related emissions (Labaran *et al.*, 2021). Addressing these requires material substitution and design optimisation. By embedding lifecycle carbon assessment into early-stage project planning, QSs are positioned to guide clients toward strategies that simultaneously reduce costs and carbon emissions (Blumberg & Sibilla, 2023; Vieira *et al.*, 2024).

2.1 QS Profession and EC

The QS has evolved from its 18th-century origins as a cost measurer to a multi-faceted professional central to cost management and procurement (Seeley, 1988). With rising sustainability demands, QS responsibilities now extend beyond financial oversight to include VE, lifecycle costing and sustainability integration (Victar *et al.*, 2024). The profession's unique position (i.e. engaged early in projects, managing procurement and liaising with clients and contractors) makes the QS well-placed to influence ECA (Chamikara *et al.*, 2020). Traditional QS practice is centred on precise cost estimation through manual measurement and tender documentation (Owusu-Manu *et al.*, 2018; Al-Mazeedi, 2025). This approach, while financially transparent, restricted the QS to a narrow economic role and ignored environmental costs (Ogunseiju *et al.*, 2023). Manual processes also limited innovation and left little scope for engaging with sustainability (Al-Mazeedi, 2025). As priorities shifted towards carbon-conscious construction, the traditional model proved insufficient for addressing modern challenges (Khan *et al.*, 2024).

2.2 Opportunities for Expanding QS Roles in EC Management

There are significant opportunities for QS practice to expand its role in managing EC (Chamikara *et al.*, 2020), viz.: embracing digital innovation (Owusu-Manu *et al.*, 2020; Newman *et al.*, 2021); fostering collaboration (Celik *et al.*, 2023); and advising clients beyond cost alone (Chamikara *et al.*, 2020). By adopting these expanded roles, QS professionals can transition from traditional cost managers to strategic sustainability advisors, making them integral to achieving net-zero construction. In the contemporary era, the integration of building information modelling (BIM), digital twins and LCA tools provides QS professionals with new capabilities to align cost planning and carbon forecasting in real time (Hosamo *et al.*, 2024; Ghansah & Lu, 2024). Combining these tools with blockchain (Bayramova *et al.*, 2021) and IoT platforms (Ghosh *et al.*, 2020) can improve supply-chain transparency and ensure reliable carbon data (Mofatteh *et al.*, 2024). By collaborating closely with architects, engineers and sustainability consultants through shared platforms, QS professionals can influence early-stage material choices and reduce project emissions.

QS professionals can also educate clients about the long-term benefits of carbon reduction (Omotayo *et al.*, 2023). Previous studies have engaged the discourse of engaging the QS in ECA. For instance, according to Siriwardhana *et al.* (2024), by integrating carbon costing alongside financial costing, QS professionals can help decision-makers evaluate trade-offs and prioritise low-carbon options. Modiba & Harinarain (2024) added that training in carbon literacy and upskilling in LCA methods can further enhance the credibility of QS professionals. Seidu *et al.* (2019) asserted that the potential development of a Mechanical and Electrical Carbon QS specialisation demonstrates recognition of the expanded role. However, many argue mainstream QS practice should incorporate these skills instead (Nyamekye *et al.*, 2023). Mulisa (2022) mentioned that QS professionals can transition from traditional cost managers to strategic sustainability advisors, making them integral to achieving net-zero construction by embracing digital innovation, fostering collaboration and advising clients beyond cost alone. Other studies have also been conducted regarding EC in the construction industry (Robati *et al.*, 2021; Lützkendorf & Balouktsi, 2022; Omotayo *et al.*, 2023; Amarasinghe *et al.*, 2024). Amidst all the mentioned prior studies, there is little research that identifies the specific roles of the QS profession with the ECA, considering the profession's unique role of deeply understanding the construction process and materials, and tracking the carbon footprint of different building elements from the design to construction to completion (2050-materials, n.d.). As Table 1 details the potential opportunities for expanding QS Roles in ECA, Figure 1 demonstrates the conceptual framework of ECA into the QS profession throughout the building lifecycle phase.

Table 1. Potential Opportunities for Expanding QS Roles in ECA

Opportunity Area	Description	References
Sustainable Design Advisory	Advising on the feasibility and cost implications of environmentally sustainable design initiatives.	(Bolade-Oladepo *et al.*, 2020; de Bortoli *et al.*, 2023)
Life Cycle Costing and Asset Management	Integrating carbon and sustainability into life cycle costing and long-term asset planning.	(Hu, 2020; de Bortoli *et al.*, 2023)
Enhanced M&E Services Training	Developing expertise in mechanical and electrical services to advise on cost, capital allowances and tax benefits.	(Seidu *et al.* 2019; Bolade-Oladepo *et al.*, 2020)
Green Costing and Carbon Planning	Gaining competencies in green costing, carbon cost planning, and valuation of sustainable properties.	(Tukker *et al.*, 2020; Kaur *et al.*, 2022)
Diversification and New Procurement Methods	Expanding into alternative procurement methods and related professional fields.	(Tukker *et al.*, 2020; Kaur *et al.*, 2022)
Education, Research, and Training	Updating curriculum and training programs to include sustainable construction skills in QS education.	(Seidu *et al.* 2019; Omotayo *et al.* 2023)

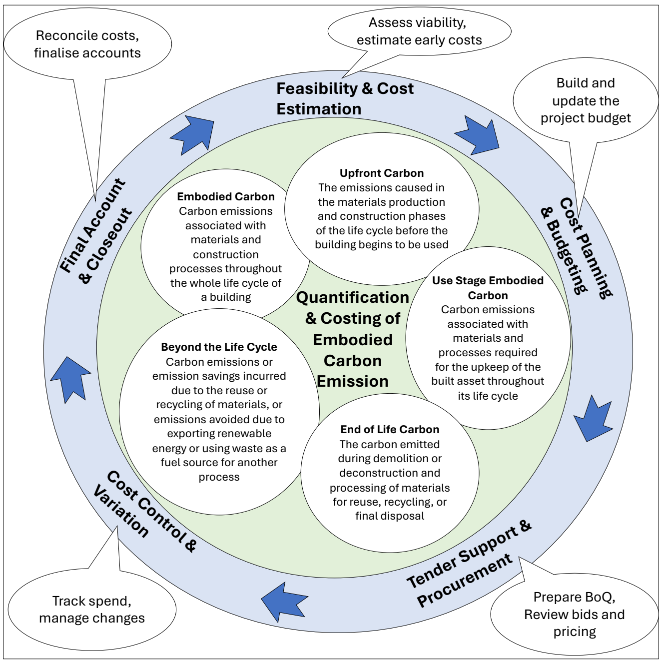

Figure 1: Conceptual framework of embodied carbon accounting (ECA) into the QS Profession (Salleh et al., 2020; Savage, 2022; Mastt, 2025).

3 Methodology

This study employed an exploratory mixed-methods approach to address the complexity of the research question elucidated at the outset of this research, which aims to examine the role of QS in ECA. Due to the lack of a well-defined outline for QSs' participation in ECA, the study is exploratory, using qualitative data as a crucial channel for collecting expert perspectives and identifying latent themes. Simultaneously, quantitative surveys were used to support insights from literature reviews and interviews, establishing conclusions about general trends on the phenomenon under investigation (Mulisa, 2022). Figure 2 illustrates the multiple steps involved in the study.

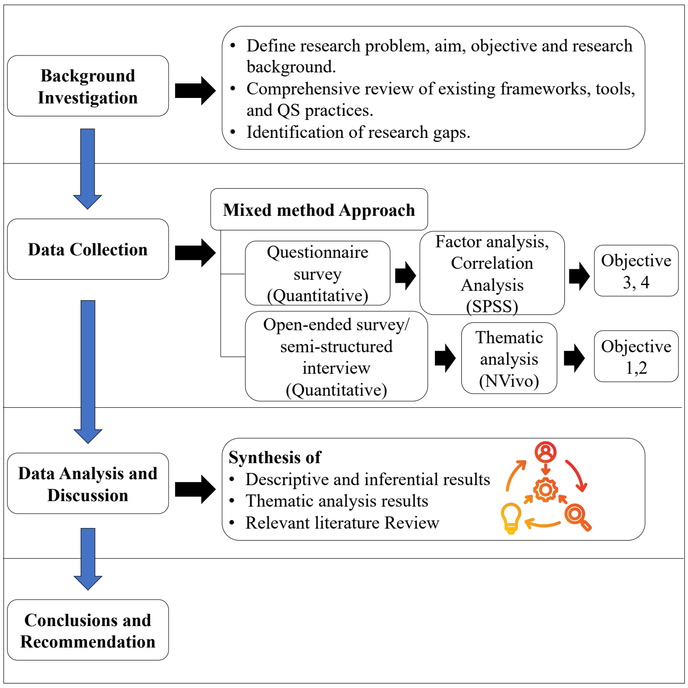

Figure 2: Study workflow.

3.1 Literature Review

A manual literature review was first conducted to provide a critical understanding of existing frameworks, tools and best practices in ECA, and the emerging role of QS (Fischer & Guzel, 2023). Important sources, such as BS EN 15978 and the WLCA framework, are discussed to identify current industry standards and methodologies (Ghanad, 2023). Rather than simply pointing out what has been previously researched, the literature review also highlights critical gaps, particularly in the underrepresentation of QS in EC practices (Phillips, 2023). These insights directly inform the development of the conceptual framework and the design of the primary research instruments, including questionnaires and interview protocols.

3.2 Questionnaire Survey

For the acquisition of the quantitative data, structured questionnaires (Supplementary Information S1) were electronically sent to a heterogeneous sample of QSs and other construction professionals using a purposive sampling technique (Etikan *et al.*, 2016). The survey was purported to investigate participants' knowledge and skills regarding EC, current practices, and their perceptions of QSs' role in ECA. This approach is validated by its ability to quickly collect vast amounts of primary data across a wide geographical expanse, enabling the identification of trends, patterns and correlations through statistical analysis (Marshall, 2005). In addition, it provides an opportunity to either support or refute existing literature and qualitative findings, thereby anchoring theoretical assumptions in actual industry perspectives (Taherdoost, 2022). The questionnaire comprised symmetrical Likert scale items of 1-5 as detailed in Supplementary Information S1 and multiple-choice questions that permitted comparison between occupational roles, experience levels and sectors. The questionnaire was administered using Microsoft Forms.

3.3 Subject Matter Expert Qualitative Survey/Semi-Structured Interviews

Open-ended survey/semi-structured interviews (Supplementary Information S2) were conducted with key stakeholders, including senior QS professionals and sustainability consultants, to collect qualitative data that provides depth and context beyond the scope of questionnaire surveys (Phillips, 2023). Open-ended interviews were purported to gather experts' subjective views on incorporating ECA into QS practices, identify the enablers, and the strategic paths to adopt. This provides flexibility, guaranteeing that spontaneous but relevant insights can be generated during the conversation (Flick, 2022). Depending on availability, these open-ended questionnaires/interviews were distributed electronically, and follow-up interviews were conducted via face-to-face and online platforms. All sessions were transcribed for thematic analysis using MS Word. Khan & MacEachen (2022) highlight that the use of both in-person and online methods enables a more expansive reach among participants. Additionally, purposive sampling helped ensure that participants are subject matter experts, thereby increasing the inherent reliability and richness of the collected data.

3.4 Data Collection and Analysis Tools

The study adhered to all ethical research practices and requirements. Informed consent was obtained from all participants, ensuring confidentiality and voluntary participation. Additionally, the research complied with GDPR and UK data protection regulations to ensure compliance with research integrity standards. Participants were briefed about their rights and the study's goals (Fisher *et al.*, 2018; Davies *et al.*, 2025). Subsequently, 106 responses were collected for the questionnaire and noted to be adequate for analysis as it met the threshold for the minimum sample of 30 (Ott & Longnecker, 2015). This has been adopted to justify relevant studies in the construction industry (Chan *et al.*, 2017; Adabre *et al.*, 2020). Also, 12 participants were engaged in the open-ended survey/semi-structured interviews, meeting the threshold for the minimum number of 5-50 for a qualitative study as recommended by Dworkin (2021).

The primary quantitative data collected from the structured questionnaires were analysed descriptively and inferentially using principal component factor analysis (PCFA) and correlation analysis via SPSS (version 26). Descriptive statistics (i.e. frequency and percentage distribution) provided a clear picture of respondents' demographic characteristics and responses. PCFA identified the underlying factors of the variables relating to the study objectives (Jolliffe, 1985; Mallawaarachchi *et al.*, 2025), whilst correlation analysis determined possible relationships between the roles of QSs and their participation in ECA activities (Janse *et al.*, 2021). The type of correlation analysis tool would be dependent on whether the dataset is parametric or non-parametric. The collected qualitative data were analysed using thematic analysis, a technique suitable for identifying patterns and extracting meaning from textual data (Braun & Clarke, 2019; Naeem *et al.*, 2023). This began by identifying and then coding recurrent themes, keywords and concepts from the questionnaire/interview transcripts (Naeem *et al.*, 2023). These codes were then arranged into broader categories that describe the main issues related to the roles and opportunities of QS in ECA. Finally, these categories were interpreted in relation to the study's research question and theoretical findings. Further, the study adopted Nvivo to ensure rigour and consistency in identifying meaningful insights of the qualitative data (Islam & Aldaihani, 2021). This provided an extraction of expert views and practical recommendations on incorporating ECA into the QS profession.

4 Data Analysis and Findings

Out of the 106 respondents, the majority came from the United Kingdom (frequency (*f*) = 75 or 70.7%). Other countries included Australia (*f* = 6 or 5.7%), Nigeria, and Ghana, each with *f* = 5 or 4.7%, making up *f* = 91 or 85.8% of the total sample (refer to Figure 3). Regarding educational qualifications, the most common degree was a Bachelor of Science (BSc), reported by *f* = 54 or 50.9% of respondents. This was followed by Master of Science (MSc) degrees at *f* = 33 or 31.1%, with doctoral degrees (PhD) being the third most common at *f* = 6 or 5.7%. Collectively, these accounted for *f* = 93 or 87.7% of the entire sample's qualifications. Most respondents identified their industry affiliation as: Main Contractor (*f* = 68 or 64.2%); consultants (*f* = 16 or 15%); Subcontractors (*f* = 12 or 11.3%); and academia (*f* = 10 or 9.5%). Regarding participants' roles, the most frequently reported job title was QS/Commercial Manager, accounting for *f* = 50 or 47% of participants. Other notable roles are shown in Figure 4. Participants' experience in the construction industry varied: *f* = 38 or 35.8% had 5–10 years, followed by *f* = 26 or 24.5% with 11–20 years, *f* = 23 or 21.7% with <5 years, and *f* = 10 or 9.4% with >30 years. Only *f* = 9 or 8.5% reported 21–30 years of experience.

Figure 3: Origins of the participants.

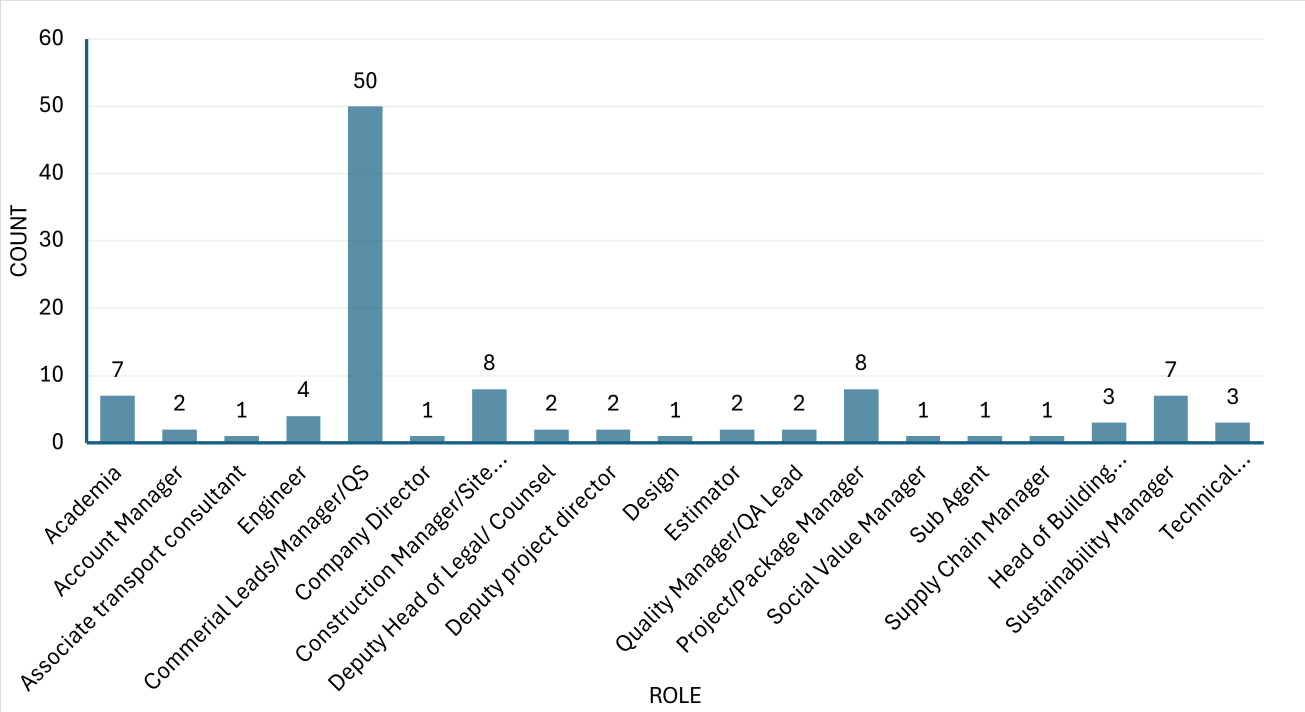

Figure 4: The distribution of participants' roles in the construction industry.

With the level of awareness and perception of ECA, participants were asked to rate their awareness of ECA in the construction industry. Over a third indicated they were "Aware" (*f* = 40 or 37.7%), while *f* = 32 or 30.1% reported being "Somewhat aware." *f* = 19 or 17.9% described themselves as "Very aware," suggesting moderate overall familiarity. A minority expressed neutrality (*f* = 10 or 9.4%) or no awareness (*f* = 5 or 4.7%). When asked to rate their level of agreement with the statement that standardised, reliable frameworks exist for ECA, responses leaned towards neutral to somewhat affirmative. The response was "Strongly disagree" (*f* = 3 or 3%), "Disagree" (*f* = 16 or 15%), "Moderate" (*f* = 50 or 47%), followed by "Agree" (*f* = 30 or 28%). Only *f* = 7 or 7% strongly agreed, indicating some scepticism or uncertainty about the robustness of existing frameworks. Regarding the statement that QS plays an active role in ECA, most respondents showed agreement. A combined *f* = 50 or 47.2% selected "Agree" and "Strongly agree," indicating agreement or strong agreement on the QS role in ECA. The moderate response was *f* = 36 or 34.0%, while disagreement regarding QS playing an active role in ECA was *f* = 20 or 18.9%, selected "Disagree" and "Strongly Disagree", suggesting a perception of moderate involvement. Thus, this study reveals a slight skewness in the agreement. However, it also highlights a diverse consensus and uncertainty about the level of involvement QS has in ECA.

Background information analysis forms a crucial basis for understanding the study's later findings. It demonstrated that respondents come from diverse, experienced backgrounds across various construction sectors, thereby enhancing the credibility of the results (Dhanasekar *et al.*,2023). Knowing the sample's background characteristics is key to contextualising QS professionals' role, enablers and strategies in ECA, and supports the validity of related conclusions.

4.1 Quantitative Data Analysis of Enablers and Strategies

Reliability statistics were computed for the three scales used in the survey (see Supplementary Information S3). It revealed that all three scales demonstrated strong internal consistency. Cronbach's alpha values ranged from 0.853 to 0.920, exceeding the commonly accepted threshold of 0.70 for acceptable reliability (Taber, 2018). These findings indicate that the scales used in this study are statistically reliable and suitable for the intended research purpose. With the normality test, the entire dataset was also noted to be non-parametric using Kolmogorov-Smirnov(K-S) (P-value<0.000) due to the sample size ≤50 (Mishra *et al.*, 2019).

4.1.1 Level of Agreement on the Potential QS Enablers for ECA

The descriptive statistics show that QS in the construction industry strongly supports a range of enablers designed to facilitate the adoption of ECA. Most respondents endorsed digital tools such as BIM and LCA software (*f* = 83 or 78.3%), carbon-integrated procurement (*f* = 85 or 80.2%), and embedding carbon metrics in cost planning (*f* = 89 or 84.0%), confirming technology as central to ECA adoption. Over *f* = 86 or 80% stressed the need for training and capacity building, while *f* = 87 or 82% agreed that client awareness is vital. Reservations emerged around specialised ECA QS, cross-industry communication, and database sharing (*f* = 13-38 or 12–35% neutral/disagree). Still, with strong disagreement below *f* = 3 or 3%, results indicate a broad consensus on systemic, technological and educational enablers for low-carbon practice (refer to Table 2).

Table 2: Perceived Enablers for ECA Adoption by QS (1= Strongly disagree; 2=Disagree; 3=Moderate; 4=Agree; 5=Strongly agree)

Code	Enablers	Strongly Disagree (%[f])	Disagree (%[f])	Moderate (%[f])	Agree (%[f])	Strongly agree (%[f])
E1	Adoption of digital tools (e.g. BIM, LCA software)	0.00%[0]	4.70%[5]	17%[18]	52.80%[56]	25.50%[27]
E2	Centralised Environmental Product Declarations EPD for easy access	0.00%[0]	7.50%[8]	30%[32]	41.50%[44]	20.80%[22]
E3	Integration of carbon data with procurement systems	0.90%[1]	5.70%[6]	13%[14]	43.40%[46]	36.80%[39]
E4	Inclusion of carbon metrics in cost planning	1.90%[2]	3.80%[4]	10%[11]	45.30%[48]	38.70%[41]
E5	Use of Life Cycle Assessment (LCA) methodologies	0.00%[0]	5.70%[6]	23%p[24]	44.30%[47]	27.40%[29]
E6	Availability of RICS WLCA and other frameworks	1.90%[2]	4.70%[5]	29%[31]	45.30%[48]	18.90%[20]
E7	Internal Training	0.00%[0]	7.50%[8]	11%[12]	41.50%[44]	39.60%[42]
E8	External Training (Academic)	0.00%[0]	6.60%[7]	30%[32]	37.70%[40]	25.50%[27]
E9	Cross-Industry training (Learning from other sectors)	0.90%[1]	10.40%[11]	27%[29]	33.00%[35]	28.30%[30]
E10	Carbon Accounting QS (Specialised QS)	1.90%[2]	20.80%[22]	28%[30]	27.40%[29]	21.70%[23]
E11	Cross-Industry systems communications	0.90%[1]	12.30%[13]	35%[37]	35.80%[38]	16.00%[17]
E12	Database sharing with other industries (Manufacturing Sector)	2.80%[3]	16.00%[17]	24%[25]	36.80%[39]	20.80%[22]
E13	Industry-wide collaboration (QSs, designers, consultants)	0.00%[0]	6.60%[7]	16%[17]	40.60%[43]	36.80%[39]
E14	Knowledge-based intelligent skilling	0.00%[0]	6.60%[7]	22%[23]	45.30%[48]	26.40%[28]
E15	Client awareness of carbon-related cost implications	1.90%[2]	2.80%[3]	13%[14]	39.60%[42]	42.50%[45]
E16	Government or policy-driven mandates for EC accounting	2.80%[3]	5.70%[6]	21%[22]	34.90%[37]	35.80%[38]

f = frequency

PCFA with Maximum Likelihood extraction with Varimax rotation was conducted to identify the underlying dimensions regarding the enablers and strategies for QS in relation to ECA, using eigenvalues >1. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.891, and Bartlett's Test of Sphericity was significant, $\chi^2(120) = 938.741$, $p < .001$, indicating the data were appropriate for factor analysis. The analysis initially extracted three factors with eigenvalues >1, explaining a cumulative 56%

of the total variance before rotation. After rotation, three interpretable factors remained, with the first three rotated components explaining 26%, 18% and 12% of the variance, respectively (refer to Table 3).

Table 3: Factor Analysis of the Enablers for QS in Adopting ECA.

Initial Eigenvalues				**Rotation Sums of Squared Loadings**		
Factor	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
E1	7.41	46.34	46.34	4.23	26.43	26.43
E2	1.61	10.06	56.39	2.81	17.57	44.00
E3	1.17	7.30	63.69	1.91	11.96	55.95
E4	0.95	5.93	69.62			
E5	0.78	4.88	74.50			
E6	0.62	3.84	78.35			
E7	0.54	3.38	81.72			
E8	0.50	3.13	84.85			
E9	0.46	2.89	87.74			
E10	0.40	2.50	90.24			
E11	0.37	2.32	92.56			
E12	0.35	2.17	94.73			
E13	0.28	1.72	96.45			
E14	0.22	1.35	97.80			
E15	0.19	1.17	98.97			
E16	0.16	1.03	100.00			

(a) Factor 1: Industry Collaboration and Knowledge Sharing (26% variance)

This factor included high loadings on cross-industry systems communication (0.84), cross-industry training (0.83), knowledge-based intelligent skilling (0.67), external training (0.65), database sharing with other industries (0.64), industry-wide collaboration (0.56), carbon accounting QS/Specialised QS (0.55) and Client awareness of carbon-related cost implications (0.53). This dimension emphasises the importance of interdisciplinary learning, data sharing and sector-wide upskilling.

(b) Factor 2: Tools, Frameworks, and Policy Infrastructure (18% variance)

This factor loaded on items such as Life Cycle Assessment (LCA) methodologies (0.68), RICS WLCA frameworks (0.64) and BIM/LCA software adoption (0.53), reflecting the need for technological and policy-related enablers.

(c) Factor 3: Data Integration and ECA Cost Planning (12% variance)

Variables included integration of carbon data with procurement systems (0.96) and inclusion of carbon metrics in cost planning (0.57), highlighting the value of operational and technological integration into existing QS practices.

Table 4 offers insight into the perceived importance of specific skills needed for effective ECA among QS professionals in the construction industry, and these contribute to shaping the enablers. Findings reveal broad agreement on essential QS competencies for ECA. Knowledge of LCA was rated important (*f* = 52 or 49.1%) or extremely important (*f* = 33 or 31.1%), with no negative responses. Carbon VE achieved similar recognition (*f* = 82 or 77.3%). Over 70% valued competencies such as interpreting EPDs, green procurement, and cost–carbon trade-off modelling. Digital skills also ranked highly, with BIM and tracking tools considered important by *f* = 48 or 45.3% and extremely important by *f* = 24 or 22.6%. Communicating carbon impacts to clients was endorsed by *f* = 91, or 85.8%, while f = 88, or over 80%, supported the importance of using estimation tools and centralised databases. Overall, the results highlight strong industry readiness for carbon-informed QS practice.

Table 4: Skills Required for Effective ECA Adoption by the QS (1=Not needed; 2=low; 3=Moderately; 4=Important; 5= Extremely Important).

Skills	Not needed (%[f])	Low (%[f])	Moderately (%[f])	Important (%[f])	Extremely important (%[f])
LCA knowledge	0.00%[0]	0.90%[1]	19%[20]	49.10%[52]	31.10%[33]
Carbon value engineering	0.00%[0]	0.90%[1]	22%[23]	44.30%[47]	33.00%[35]
Interpreting EPDs	0.00%[0]	1.90%[2]	23%[24]	44.30%[47]	31.10%[33]
Green procurement principles	0.00%[0]	3.80%[4]	25%[27]	45.30%[47]	26.40%[28]
Cost–carbon trade-off modelling	0.00%[0]	6.60%[7]	25%[27]	43.40%[45]	25.50%[27]
BIM and digital proficiency for carbon tracking	0.90%[1]	6.60%[7]	25%[27]	45.30%[48]	22.60%[24]
Communication of carbon impact to clients	0.00%[0]	2.80%[3]	11%[12]	48.10%[51]	37.70%[40]
Use of carbon estimation tools	0.00%[0]	3.80%[4]	13%[14]	52.80%[56]	30.20%[32]
Access Centralised EC Database	0.00%[0]	2.80%[3]	19%[20]	49.10%[52]	29.20%[31]

f = frequency

4.1.2 Level of Importance of the Proposed Strategies for ECA Adoption by QS

Descriptive statistics in Table 5 reflect QSs' perceptions of the effectiveness of various strategies in supporting the adoption of ECA within the construction sector. Respondents rated most of the twelve strategies positively. Contractual requirement and digital tool integration were strongest (*f* = 97 or 91.5%), while client communication (*f* = 95 or 89.6%) and interdisciplinary collaboration (55.7%) also scored well. Education-focused measures, such as curriculum inclusion (*f* = 77 or 72.2%) and CPD/certification (*f* = 89 or 84%), were widely supported. Incentives from government and employers (*f* = 95 or 90%) and (*f* = 95 or 89%), respectively, reinforced the role of institutional backing. Opinions on specialised carbon QS were mixed, with *f* = 24 or 22.6% rating it moderate or ineffective. Overall, results highlight consensus that a multifaceted approach, including policy, education, incentives, technology and collaboration, is essential for mainstreaming QS involvement in ECA.

Table 5: Perceived Strategies to Support ECA Adoption by QS (1=Not at all effective; 2=Slightly effective; 3=Moderately effective; 4=Very effective; 5= Extremely effective).

Code	Strategies	Not at all effective (%[f])	Moderately effective (%[f])	Effective (%[f])	Very effective (%[f])	Extremely effective (%[f])
S1	University curriculum inclusion	5.70%[6]	21.70%[23]	37%[39]	21.70%[23]	14.20%[15]
S2	CPD and professional certifications	2.80%[3]	13.20%[14]	41%[43]	29.20%[31]	14.20%[15]
S3	Carbon value engineering	1.90%[2]	9.40%[10]	35%[37]	37.70%[40]	16.00%[17]
S4	Mandatory carbon reporting policies	1.90%[2]	9.40%[10]	26%[28]	44.30%[47]	17.90%[19]
S5	Client education and awareness	2.80%[3]	5.70%[6]	25%[27]	37.70%[40]	29.20%[31]
S6	Interdisciplinary collaboration	2.80%[3]	8.50%[9]	33%[35]	38.70%[41]	17.00%[18]
S7	Digital tool integration	0.90%[1]	7.50%[8]	37%[39]	35.80%[38]	18.90%[20]
S8	Communication of carbon impact to clients	2.80%[3]	7.50%[8]	23%[24]	36.80%[39]	30.20%[32]
S9	Emergence of Specialised Carbon Accounting QS	6.60%[7]	16.00%[17]	34%[36]	33.00%[35]	10.40%[11]
S10	Government Incentive	3.80%[4]	6.60%[7]	29%[31]	30.20%[32]	30.20%[32]
S11	Employer Incentives	2.80%[3]	8.50%[9]	25%[27]	40.60%[43]	23.10%[24]
S12	Contractual requirement	0.90%[1]	7.50%[8]	10%[11]	46.20%[49]	34.90%[37]

f = frequency

To assess the strategies for ECA adoption, a PCFA was conducted on the 12 strategy variables. The KMO statistic was 0.88, indicating excellent sampling adequacy, and Bartlett's test was significant, $\chi^2(66) = 608.78$, $p < 0.001$. Two factors were extracted, accounting for 51.9% of the total variance (refer to Table 6).

Table 6: Factor Analysis of the Strategies for QS Adopting ECA.

	Initial Eigenvalues			**Rotation Sums of Squared Loadings**		
Factor	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
S1	5.82	48.50	48.50	3.80	31.66	31.66
S2	1.32	10.97	59.46	2.43	20.21	51.87
S3	0.87	7.22	66.68			
S4	0.77	6.41	73.09			
S5	0.63	5.24	78.33			
S6	0.54	4.48	82.81			
S7	0.44	3.68	86.49			
S8	0.43	3.54	90.03			
S9	0.41	3.38	93.40			
S10	0.32	2.68	96.08			
S11	0.26	2.19	98.28			
S12	0.21	1.73	100.00			

(a) Factor 1: Technical and Professional Integration (31.7%)

This factor loaded on interdisciplinary collaboration (0.74), mandatory reporting (0.69), CPD (0.68), carbon value engineering (0.67) and digital tool use (0.64). Other contributors included curriculum inclusion (0.61), client awareness (0.57), communication of carbon impacts (0.55) and specialised Carbon QS roles (0.55). It reflects strategies centred on skills, training, reporting and collaboration.

Factor 2: Policy and Market Incentives (20.2%)

This factor included government incentives (0.81), employer incentives (0.79) and contractual requirements (0.53), emphasising regulatory and economic motivators.

Spearman's Correlation Analysis

Table 7 summarises correlations for 12 items measuring ECA strategies for QS. Mean scores ranged from 3.17 to 4.09, showing general agreement on their importance. The highest-rated were integration of carbon data with procurement systems (M = 4.09, SD = 0.90) and contractual requirements (M = 4.07, SD = 0.92), underscoring their central role. The lowest ratings were for university curriculum inclusion (M = 3.17, SD = 1.10) and specialised carbon QS (M = 3.25, SD = 1.06), reflecting caution around education and specialisation. Due to the non-parametric dataset, Spearman's correlation analysis revealed strong links between employer and government incentives ($r = 0.70$, $p < 0.001$), CPD/certification and University curriculum inclusion ($r = 0.63$, $p < 0.001$), and mandatory carbon reporting and client awareness ($r = 0.63$, $p < 0.001$), showing that policy, education and client strategies are closely connected.

Table 7: Intercorrelations of effective strategy for QS in ECA.

Item	**M**	**SD**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
S1	3.17	1.1	—											
S2	3.39	0.98	0.62***	—										
S3	3.57	0.94	0.52***	0.64***	—									
S4	3.67	0.94	0.49***	0.52***	0.58***	—								
S5	3.85	1.00	0.33***	0.49***	0.48***	0.63***	—							
S6	3.58	0.97	0.42***	0.50***	0.51***	0.60***	0.48***	—						
S7	3.64	0.91	0.44***	0.48***	0.52***	0.53***	0.42***	0.58***	—					
S8	3.84	1.03	0.28**	0.44***	0.53***	0.54***	0.61***	0.59***	0.48***	—				
S9	3.25	1.06	0.37***	0.36***	0.36***	0.44***	0.34***	0.50***	.044***	0.29**	—			
S10	3.76	1.07	0.28**	0.39***	0.47***	0.52***	0.43***	0.37***	0.39***	0.53***	0.24*	—		
S11	3.74	1.01	0.29**	0.37***	0.39***	0.39***	0.44***	0.26**	0.38***	0.43***	0.24*	0.70***	—	
S12	4.07	0.92	0.18	0.30**	0.29**	0.42**	0.31**	0.30**	0.38**	0.38**	0.19	0.48**	0.48**	—

Note. M = Mean; SD = Standard Deviation. p < .05. ** p < .01. *** p < .001 (two-tailed).

4.2 Qualitative Data Analysis: Thematic Analysis of QS Role in ECA

This study explored how QSs engage with ECA and how their roles can be enhanced to support the construction industry's transition toward net-zero targets. Using thematic analysis (Braun & Clarke, 2021), the qualitative data were analysed in alignment with the study's three objectives. Supplementary Information S4 shows the participants' background information, whilst Supplementary Information S5 shows the thematic insight from the interviews.

Theme 1: Limited Engagement and Perceived Boundaries of the QS Role

Across the sample, QSs were often reported to have a marginal role in ECA, mostly limited to supplying quantity data. For instance, *Participant 12* (Head of Sustainable Design) stated: "*They [QSs] don't really participate in this process. They provide quantities in the same form as they use for calculating cost*," while *Participant 1* (Head of Sustainability) confirmed that: "*They [quantity surveyors] do not play a key role at present time.*" A recurring view was that ECA responsibilities fall to the sustainability team, with *Participant 1* adding: "*It is perceived that EC sits solely with the sustainability team, so there is a lack of awareness and interest among QS.*" Some recognised a potential for QSs to expand their role, as *Participant 5* noted: "*The QS professional plays a vital role in ensuring our supply chain charter is followed... not just the best value from a commercial perspective but aligned with our ESMP and ESG standards.*"

Theme 2: Inconsistent Tool Use and Lack of Standardisation

Many participants referred to OneClick LCA as the most used tool, though several acknowledged that it is not without limitations. *Participant 2* (Carbon Lead) remarked: "*OneClick LCA is the most used so far, but not the most effective... there are a lot of bespoke tools developed by companies, but they are not all aligned.*" Others highlighted the lack of tools for as-built data, with *Participant 12* noting: "*There are no tools that help with collating as-built data. We tend to use spreadsheets. All current tools are focused around design.*" Several participants referenced the RICS WLCA methodology as the industry baseline, yet some suggested that it is not always fully applied in practice. *Participant 1* explained: "*We use a range of tools... but the RICS v2 methodology is not always followed completely—only roughly.*"

Theme 3: Skills and Knowledge Gaps Among QS

A prevalent concern was the lack of carbon-specific knowledge among QS. *Participant 6* (Consultant Partner) emphasised that: "*We are not knowledgeable enough on EC in the construction process*," while *Participant 7* observed that "*QSs are perceived as only dealing with costs and not as contributors to sustainability goals.*" Key technical skills mentioned include LCA, EPD interpretation, carbon estimation, and BIM. For example, *Participant 2* stressed the need for: "*a thorough knowledge of building systems and RICS WLCA methodology, as well as TM65 and CWCT.*" And Participant 11 stated that: "*QSs will need to catch up to the knowledge base of sustainability consultants/engineers.*" In addition to technical competencies, *Participant 9* emphasised the importance of behavioural and collaborative skills, stating: "*QS professionals are pivotal people who bring disciplines together; behavioural and collaborative practice is key to make the process happen.*"

Theme 4: Mixed Perceptions of the QS Role in ECA Net-Zero Targets

Perceptions varied on whether QS professionals are seen as key players in achieving net-zero. Some respondents, such as *Participant 9*, viewed them as central figures: "*QS professionals are often the 'oracle' of projects. If the PQS [Prime Quantity Surveyor] has budget clarity, it influences procurement and behaviour throughout.*" In contrast, *Participant 12* asserted: "*No—they offer very little skill or expertise in this area,*" reflecting a more critical view. *Participant 4* added that net-zero is a: "*joint responsibility,*" but QSs are: "*...not yet front and centre*." Still, many agreed that QS professionals could play a larger role.

Theme 5: Strategies to Strengthen the QS Role in ECA

Several participants proposed strategies for integrating ECA into QS practice, including professional training, early-stage collaboration and policy reform. *Participant 2* advocated for industry alignment: "*The important thing is to agree first on a common methodology.*" *Participant 3* emphasised the importance of contractual requirements, stating: "*A quantity surveyor must ensure that the subcontractor has signed up to achieve an EC target.*" Regulatory and educational interventions were also widely recommended. *Participant 9* suggested that RICS and university curricula need to evolve, adding: "*Education is a key time to change mindsets of quantity surveyors coming through the ranks.*" Furthermore, many pointed to digital tools, particularly BIM, as enablers of better data integration and automation. *Participant 5* observed: "*Smart design through the BIM process is an effective tool for the QS to monitor and record change.*" Notably, opinions on whether a specialised "Carbon quantity surveyor" is needed were divided. *Participant 8* argued that: "*QS practices should have EC specialists employed directly,*" and *Participant 10* stated: "*100%, most quantity surveyors won't have experience in this*", whereas *Participant 6* disagreed, suggesting that: *"It is more a learning exercise to re-skill quantity surveyors, not to create a new specialisation."*

5 Discussion

Stakeholders expressed mixed perceptions about the QSs' role in ECA. This study showed that *f* = 50 or 47% agreed or strongly agreed that QSs play an active role, *f* = 36 or 34% were neutral, and *f* = 20 or 19% disagreed. Further, when asked if QSs should lead the ECA process for Net-Zero achievement, *f* = 33 or 31% disagreed, indicating overall optimism tempered by scepticism. A key debate concerned the idea of a dedicated *"Carbon quantity surveyor."* Participant 8 argued that ECA demands: *"a different type of skill"* and warrants specialisation, while others, including Participants 5, 7 and 12, favoured integrating carbon literacy into the broader quantity surveyor skill set. Participant 3 stressed that: *"all surveyors should be fully aware of the measurement requirements to inform carbon data software and maximise accuracy."* This reflects literature suggesting that specialisation risks fragmenting practice, while integration could mainstream carbon expertise (Victoria, 2025). Stakeholders also linked perceptions to *current skills and resources*. This study highlighted QS's expertise in cost management as a foundation for expanding into ECA, provided adequate training is offered. More cautious views pointed to limitations in tools, knowledge and mandates for ECA adoption by QS. Literature reinforces this, emphasising the potential of QS in EC reduction but noting constraints without *upskilling and institutional support* (Mohd Hafir, 2019).

Education emerged as a recurring theme. Participant 9 recalled: "My degree was completed in 2013. At this time, even the sustainability agenda was limited… if not, it should [now include decarbonisation modules]." This reflects calls for curricula reform to embed ECA and LCA at the undergraduate level (Li et al., 2022). Without updated training pipelines, confidence in the profession's readiness remains divided. Finally, many stakeholders tied quantity surveyors' involvement to broader industry drivers. Participant 4 argued that engagement depends on procurement requirements, while Participant 9 stressed that government incentives and policies are critical to legitimising QS-led carbon management.

5.1 Construction Industry's Tools, Frameworks, and Methodologies for ECA

The study revealed awareness of ECA frameworks but inconsistent adoption. Only *f* =7 or *7% strongly agreed* that reliable frameworks exist, *f* = 50 or 47% rated them as *moderately reliable*, *f* = 30 or 28% agreed, and *f* = 19 or 18% disagreed. This indicates widespread uncertainty about the robustness and applicability of current methods. PCFA confirmed the importance of *Tools, Frameworks, and Policy Infrastructure* (18%) and *Data Integration with Cost Planning* (12%) as key enablers. Most participants (*f* = 88 or 83%) stressed proficiency in *carbon estimation tools,* and *f* = 80 or 75.4% emphasised *EPD interpretation* as a critical skill. These findings align with studies positioning the *RICS WLCA*, aligned with *BS EN 15978*, as the most comprehensive framework (UKGBC, 2021; RICS, 2023). Participant 12 reflected this, noting: *"Our team uses CWCT methodology, aligned with RICS WLCA, to calculate and benchmark façade EC."*

Support for digital tools was strong: *f* = 72 or 67.9% viewed *BIM-linked LCA software* as effective. Participants described BIM as both promising and limited. Participant 12 stated: *"BIM is the answer to collating data for EC,"* but others stressed that accuracy depends on model detail. Interoperability issues persist, with research showing that only *11% of carbon data comes from BIM quantity extraction*, the rest relying on 2D drawings (Scagliotti *et al.,* 2025). Emerging technologies such as *blockchain, IoT-enabled BIM, and integrated platforms like One Click LCA* were also cited as promising for transparency and efficiency (Mofatteh *et al.,* 2024). Participant 6 observed: *"One Click seems to be the default software,"* though Participant 2 noted inconsistent application: *"We use RICS v2, but often only roughly."* This reflects broader challenges of data gaps and reliance on generic datasets, sometimes substituted with TM65 embodied carbon calculations. Overall, the findings show strong recognition of tools and frameworks but limited *standardisation and interoperability*. While platforms such as BIM and One Click LCA offer opportunities, outcomes depend heavily on input quality and consistent methodology. Achieving consensus on standard frameworks remains essential for ensuring reliable and comparable ECA outputs (Sinha *et al.,* 2016).

5.2 Enablers of ECA in the QS Profession

The study revealed broad support for *technological integration* and *capacity building* as enablers. With *f* = 83 or over 78% of participants endorsing the use of *BIM and LCA tools*, *f* = 85 or 80% supported integration of carbon data with procurement and *f* = 89 or 84% agreed on embedding carbon metrics in cost planning. Similarly, *f* = 86 or over 80% highlighted *internal training* as vital, while *f* = 87 or 82% stressed *client awareness* of carbon costs. Qualitative insights echoed these results. Participant 5 emphasised that: *"smart design through the BIM process is an effective tool for quantity surveyors to monitor and record change"*. Others highlighted the role of contractual reinforcement and policy alignment, with Participant 3 noting that: *"a quantity surveyor must ensure subcontractors sign up to achieve carbon targets."* Education was also raised, with Participant 9 arguing that: *"Curriculum reform is a key time to change mindsets of quantity surveyors coming through the ranks."* These findings aligned with Greene & Bateman (2023) who identified *digital innovation, client demand and policy frameworks* as critical enablers. Overall, the evidence indicates that *technology, training, policy incentives and informed clients* create an ecosystem where QSs can expand their role from *traditional cost managers* to *strategic sustainability advisors*. Without such enablers, QS's contributions to carbon reduction could remain constrained.

5.3 Skills and Knowledge Required by QS to Contribute to ECA Effectively

The findings emphasised that QS professionals need a blend of *technical expertise, digital proficiency, and communication skills* to contribute effectively to ECA. Statistically, *LCA knowledge* was rated important or very important by *f* = 85 or 80% of respondents, *carbon value engineering* by *f* = 82 or 77% and *EPD interpretation* by *f* = 80 or over 70%. The most critical competency was *communicating carbon impacts to clients* (*f* = 91 or 85.8%), showing that carbon literacy must extend beyond technical analysis to influence procurement and design choices. These results align with literature stressing the QS's potential in sustainability if supported by structured training and standardised tools (Omotayo *et al.,* 2023; Celik *et al.,* 2023). Participant 4 argued carbon assessment should be: *"as natural for QS as pricing,"* while Participant 5 noted that BIM familiarity linked to carbon measurement is: *"not yet standard practice."* Such perspectives reflect emerging research positioning *BIM and One Click LCA* as vital for embedding carbon data into QS workflows.

Overall, the essential skills and knowledge for QS in improving ECA efficiency include: mastery of LCA and WLCA methodologies; application of carbon value engineering in design optimisation; proficiency in EPD interpretation; digital literacy, such as One Click LCA, CostX and BIM with ECA integration; and the ability to translate carbon data into client-focused decision-making. The implication is that ECA adoption by QSs is unlikely to be achieved solely through technical training. A broader cultural and systemic shift, driven by policy frameworks, industry standards and collaborative practices, is necessary to embed carbon literacy into the QS profession at the same level as cost management (Modiba & Harinarain, 2024).

5.4 Strategies for Integrating ECA into the QS Profession

Integrating ECA into the QS profession expands the profession's cost-focused remit and positions its practice as an active contributor to carbon reduction. Embedding carbon metrics in cost data enables influence over materials, procurement and design decisions, stages where most emissions are determined. This aligns with industry guidance (UKGBC, 2021; RICS, 2023), advocating early, data-driven interventions. The survey results showed f = 73 or 69% moderate to strong agreement that ECA should be a QS-led, while qualitative data collection results show f = 12 or 100% agreement that ECA should be a quantity surveyor's responsibility, though some participants highlight that cultural and procedural changes are still needed. Recommendations of strategies to be adopted can be categorised into "*technical and professional integration" and "policy and market incentives"*. Incorporating ECA into QS practice does not redefine the profession but instead expands its scope to measure, manage and report EC with the same rigour as cost, thereby embedding sustainability into construction decisions. The two categories synthesise with the qualitative results to recommend five key strategies viz.:

5.4.1 Formalised Training and Upskilling

Findings emphasise *carbon literacy* as foundational. CPD on WLCA, EPDs and carbon–cost integration is required, supported by curriculum reform to address skills gaps (Kuittinen *et al.,* 2023). Training should extend to *clients*, whose awareness of reputational and financial benefits can accelerate low-carbon adoption (Zhao *et al.*, 2025).

5.4.2 Embedding Carbon into Existing QS Workflows

Integrating carbon data into cost plans, BOQs and procurement documentation emerged as a priority. This approach leverages established QS processes to normalise carbon considerations, ensuring it is addressed in client discussions. The WLCA framework leverages NRM methods, which offer a structured approach for carbon reporting and is familiar with QS cost planning methods.

5.4.3 Digital Tool Integration

Key issues include technical knowledge gaps and a lack of frameworks. Linking *BIM with LCA software* for carbon tracking was endorsed by f = 72 or 68% of participants as an important or extremely important strategy for improving accuracy and efficiency when data is reliable. Advanced tools such as *blockchain-enabled BIM* are proposed to enhance *transparency and data security* (Körner *et al.,* 2023). Integration with platforms like *One Click LCA* also supports smoother adoption within familiar QS systems.

5.4.4 Early-Stage Project Involvement

Stakeholders repeatedly emphasised the importance of QSs' engagement during concept design because this is where material and specification decisions significantly impact the project's overall EC emissions. This aligns with Siriwardhana *et al. (*2024), who emphasised the importance of early intervention in achieving low-carbon outcomes. In cases where BIM is underused in the early phases (cf. Scagliotti *et al.,* 2025), early QS involvement, combined with their expertise in contract administration and procurement management, can influence the process from the outset and help establish EC contractual requirements from the project's inception.

5.4.5 Policy and Client-Led Requirements

Mandatory carbon reporting, WLCA submissions at planning and client procurement rules requiring carbon data alongside costs could formalise QS roles. Participants emphasised that clear client vision and government incentives are key drivers. Literature similarly supports policy measures such as tax incentives, CPD updates and contractual obligations to shift ECA from voluntary to standard practice (RICS, 2023).

5.5 Study Implications

This study expands the theoretical understanding of how the QS profession can transition from its traditional focus on costs to a dual custodianship model that encompasses both cost management and carbon oversight. It advances the conceptual integration of ECA within established cost management theories, suggesting that carbon can be measured, forecasted and optimised alongside cost parameters through shared data frameworks. The research enhances the theoretical discussion on role evolution, proposing that QS can become key agents of sustainability by adopting lifecycle thinking and digital integration (e.g. BIM–LCA interoperability) in construction decision-making. Moreover, it emphasises the need for academic theory to reframe QS identity with a focus on capacity-building, carbon literacy and professional agility, positioning QSs as essential in achieving net-zero carbon transitions.

Practically, this study shows that including carbon considerations in QSs' workflows is both feasible and essential for the profession's future relevance. The findings support the implementation of mandatory CPD on ECA, incorporating carbon metrics into cost plans and procurement documents, and utilising advanced technology and BIM-linked LCA tools to facilitate seamless data exchange between design and cost systems. The study also highlights the importance of early-stage QSs involvement in project planning to influence material choices and design decisions before significant carbon commitments are made. Additionally, it urges policy and client-driven mandates, such as carbon reporting during planning and procurement incentives for low-carbon solutions, to institutionalise QS-led carbon management practices. The study also highlights the importance of client awareness as a key driver for ECA implication in the QS profession. Together, these implications offer a clear pathway for integrating carbon awareness into everyday QS activities and industry standards.

6 Conclusions

EC accounts for approximately 40–70% of the total carbon emissions in new buildings over their whole life cycle. Although international agreements, such as the Paris Agreement and UK frameworks, like the WLCA, have sparked interest in carbon reduction, the focus remains primarily on operational carbon, thereby limiting the consideration of EC. QSs possess relevant skills in cost planning, procurement and VE that can be applied to ECA; however, the integration of EC into the QS profession has not been given enough attention. Thus, this study aimed to address the gaps by examining the role of QS in ECA, using a mixed-method approach. The study found that while QS professionals possess transferable skills relevant to carbon management, such as cost planning, procurement and VE, their actual involvement in ECA is limited by skill gaps, fragmented frameworks, inconsistent tool usage and inadequate policy enforcement. It is revealed that enablers, such as digital tools, training, policy incentives and client awareness, have a greater influence on the success of ECA. Qualitative insights confirmed these findings, indicating that QSs are optimistic about their potential role in carbon reduction but need structured upskilling, clearer expectations, better-integrated tools and client- and stakeholder-driven approaches.

This study recommends aligning ECA frameworks with established QS cost management systems to create unified cost–carbon standards. It encourages higher education institutions to incorporate carbon literacy, EPD interpretation and BIM-LCA integration into QS curricula. Professionally, RICS and other bodies should enforce CPD modules on carbon management and include carbon data reporting in standard QS deliverables. Increasing client and key stakeholder training on the long-term benefits of EC in project planning can foster more cautious project uptake. Government and client organisations should mandate carbon reporting at the planning stage and provide procurement incentives for low-carbon outcomes. Finally, early QSs' involvement in design and greater use of digital tools like BIM-linked LCA are essential for mainstreaming carbon-focused cost planning.

Although this mixed-methods study provided valuable insights, limitations include potential survey bias due to the researcher's limited reach in recruiting participants. Additionally, the role of QS in ECA has not been extensively researched by others, resulting in limited secondary data on the topic. Furthermore, the difficulty in securing interviews with senior professionals may have restricted the depth of qualitative perspectives. Future research should empirically evaluate the long-term effectiveness of QS-led ECA interventions in achieving measurable reductions in carbon emissions. It should also investigate digital integration models that enhance interoperability between BIM, LCA and cost databases, potentially using AI automation. Additional research into client behaviour and incentive structures could provide crucial insights into promoting wider adoption of QS-led ECA practices across the construction industry.

Acknowledgements
The authors would like to thank all the research participants who devoted their time and effort during the survey and interviews to make this study a success. We also appreciate the efforts of the reviewers.

Funding
No external funding was received.

Ethical Approval Declaration
The LSBU College of Technology and Environment Ethics and Integrity Panel examined and approved this study in accordance with the Light Touch Ethics Form, which involved human participants via survey and interview. No personal data was taken from the research participants.

Informed Consent Statement
All participants provided informed consent before participating in the study.

Data Availability Statement
Data can be made available upon request to the corresponding author.

Conflicts of Interest
The authors declare no conflict of interest.

References

2050-materials. (n.d.). *Quantity surveying and carbon: Integrating sustainability into cost management*. Retrieved December 20, 2025, from https://2050-materials.com/blog/quantity-surveying-and-carbon-integrating-sustainability-into-cost-management/

Adabre, M. A., Chan, A. P., Darko, A., Osei-Kyei, R., Abidoye, R., & Adjei-Kumi, T. (2020). Critical barriers to sustainability attainment in affordable housing: International construction professionals' perspective. *Journal of Cleaner Production, 253*, 119995.

Al-Mazeedi, A. S. (2025). The evolution of quantity surveying: Emerging tools for architects and draftsmen in construction. *International Journal of Novel Research in Civil Structural and Earth Sciences, 12*(1), 20–23. https://doi.org/10.5281/zenodo.15039716

Amarasinghe, I., Liu, T., Stewart, R. A., & Mostafa, S. (2024). Paving the way for lowering embodied carbon emissions in the building and construction sector. *Clean Technologies and Environmental Policy*. https://doi.org/10.1007/s10098-024-03023-6

Bayramova, A., Edwards, D. J., & Roberts, C. (2021). The role of blockchain technology in augmenting supply chain resilience to cybercrime. *Buildings, 11*(7). https://doi.org/10.3390/buildings11070283

Blumberg, G., & Sibilla, M. (2023). A carbon accounting and trading platform for the UK construction industry. *Energies, 16*(4). https://doi.org/10.3390/en16041566

Bolade-Oladepo, F. A., Oladipo, F. O., & Fasuyi, O. A. (2020). Sustainable built environment: The role of quantity surveyors. *IOSR Journal of Engineering, 10*(1), 1–6.

Brandao, R., Edwards, D. J., Melo, A. C. S., & Macedo, A. N. (2023). Reverse supply chain practices for construction and demolition waste in the Brazilian Amazon: A multi-stakeholder view. *Journal of Material Cycles and Waste Management, 25*, 2245–2261. https://doi.org/10.1007/s10163-023-01680-1

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health, 11*(4), 589–597.

Braun, V., & Clarke, V. (2021). One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology, 18*(3), 328–352.

Butterick, D. (2021). *Design standardisation and the impact on cost—A quantity surveyor's perspective*. Retrieved October 8, 2025, from https://www.linkedin.com/pulse/design-standardisation-impact-cost-quantity-butterick-mrics-/

Celik, Y., Petri, I., & Rezgui, Y. (2023). Integrating BIM and blockchain across construction lifecycle and supply chains. *Computers in Industry, 148*, 103886. https://doi.org/10.1016/j.compind.2023.103886

Chamikara, P. B. S., Perera, B. A. K. S., & Rodrigo, M. N. N. (2018). Competencies of the quantity surveyor in performing for sustainable construction. *International Journal of Construction Management, 20*(3), 237–251.

Chan, A. P. C., Darko, A., & Ameyaw, E. E. (2017). Strategies for promoting green building technologies adoption in the construction industry—An international study. *Sustainability, 9*(6), 969.

Davies, H. K., Posillico, J. J., & Edwards, D. J. (2025). Soft skills for teams in public linear infrastructure: The development of a decision support tool. *Buildings, 15*(7), 1197. https://doi.org/10.3390/buildings15071197

Dhanasekar, Y., Anandh, K. S., & Szostak, M. (2023). Development of the diversity concept for the construction sector: A bibliometric analysis. *Sustainability, 15*(21), 15424.

Dworkin, S. L. (2012). Sample size policy for qualitative studies using in-depth interviews. *Archives of Sexual Behaviour, 41*(6), 1319–1320.

de Bortoli, A., Bjørn, A., Saunier, F., & Margni, M. (2023). Planning sustainable carbon neutrality pathways: Accounting challenges experienced by organisations and solutions from industrial ecology. *International Journal of Life Cycle Assessment, 28*(7), 746–770. https://doi.org/10.1007/s11367-023-02147-z

Elghaish, F., Matarneh, S. T., Edwards, D. J., Pour Rahimian, F., El-Gohary, H., & Ejohwomu, O. (2022). Applications of Industry 4.0 digital technologies towards a construction circular economy: Gap analysis and conceptual framework. *Construction Innovation, 22*(3), 647–670. https://doi.org/10.1108/CI-03-2022-0062

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics, 5*(1), 1–4.

Fisher, L., Edwards, D. J., Pärn, E. A., & Aigbavboa, C. O. (2018). Building design for people with dementia: A case study of a UK care home. *Facilities, 36*(7–8), 349–368. https://doi.org/10.1108/F-06-2017-0062

Fischer, E., & Guzel, G. T. (2023). The case for qualitative research. *Journal of Consumer Psychology, 33*(1), 259–272. https://doi.org/10.1002/jcpy.1300

Flick, U. (2022). *An introduction to qualitative research*. Sage.

Ghanad, A. (2023). An overview of quantitative research methods. *International Journal of Multidisciplinary Research and Analysis, 6*(08), 3794–3803.

Ghansah, F. A., & Lu, W. (2024). Major opportunities of digital twins for smart buildings: A scientometric and content analysis. *Smart and Sustainable Built Environment, 13*(1), 63–84.

Ghosh, A., Edwards, D. J., & Hosseini, M. Reza. (2020). Patterns and trends in Internet of Things (IoT) research: Future applications in the construction industry. *Engineering, Construction and Architectural Management, 28*(2), 457–481. https://doi.org/10.1108/ECAM-04-2020-0271

Greene, S., & Bateman, A. (2023). Getting to 2050: Transparency for setting and reaching supply chain climate goals. In *Handbook of business and climate change* (pp. 340–358). Edward Elgar Publishing.

Hamilton, I., Rapf, O., Kockat, D. J., Zuhaib, D. S., Abergel, T., Oppermann, M., Otto, M., Loran, S., Fagotto, I., & Steurer, N. (2020). *Global status report for buildings and construction*. United Nations Environmental Programme. Retrieved October 8, 2025, from https://globalabc.org/resources/publications/2020-global-status-report-buildings-and-construction

Hart, J., Adams, K., Giesekam, J., Densley Tingley, D., & Pomponi, F. (2019). Barriers and drivers in a circular economy: The case of the built environment. *Procedia CIRP, 80*, 619–624. https://doi.org/10.1016/j.procir.2018.12.015

Hosamo, H., Coelho, G. B., Buvik, E., Drissi, S., & Kraniotis, D. (2024). Building sustainability through a novel exploration of dynamic LCA uncertainty: Overview and state of the art. *Building and Environment*, 111922.

Hu, M. (2020). A building life-cycle embodied performance index—The relationship between embodied energy, embodied carbon and environmental impact. *Energies, 13*(8). https://doi.org/10.3390/en13081905

Islam, S., & Aldaihani, F. M. (2021). Justification for adopting qualitative research method, research approaches, sampling strategy, sample size, interview method, saturation, and data analysis. *Journal of International Business and Management*. https://doi.org/10.37227/jibm-2021-09-1494

Janse, R. J., Hoekstra, T., Jager, K. J., Zoccali, C., Tripepi, G., Dekker, F. W., & van Diepen, M. (2021). Conducting correlation analysis: Important limitations and pitfalls. *Clinical Kidney Journal, 14*(11), 2332–2337.

Jolliffe, I. T. (1986). Principal component analysis and factor analysis. In *Principal component analysis* (pp. 115–128). Springer New York.

Kaur, R., Patsavellas, J., Haddad, Y., & Salonitis, K. (2022). Carbon accounting management in complex manufacturing supply chains: A structured framework approach. *Procedia CIRP, 107*, 869–875. https://doi.org/10.1016/j.procir.2022.05.077

Keyhani, M., Bahadori-Jahromi, A., Fu, C., Godfrey, P., & l, H. (2024). Whole-life embodied carbon reduction strategies in UK buildings: A comprehensive analysis. *Energy Science & Engineering, 12*(12), 5370–5384.

Khan, L., Tong, N., & Phung, Q. (2024). Isn't it time for quantity surveyors to contribute to sustainability? *International Journal of Sustainable Construction Engineering and Technology, 15*(3), 1–10.

Khan, T. H., & MacEachen, E. (2022). An alternative method of interviewing: Critical reflections on videoconference interviews for qualitative data collection. *International Journal of Qualitative Methods, 21*. https://doi.org/10.1177/16094069221090063

Kuittinen, M., Zernicke, C., Slabik, S., & Hafner, A. (2023). How can carbon be stored in the built environment? A review of potential options. *Architectural Science Review, 66*(2), 91–107.

Körner, M., Schober, M., Ströher, T., & Strüker, J. (2023). Digital carbon accounting for accelerating decarbonization: Characteristics of IS-enabled system architectures. In *AMCIS 2023 proceedings* (p. 2). https://aisel.aisnet.org/amcis2023/sig_green/sig_green/2/

Labaran, Y. H., Mathur, V. S., & Farouq, M. M. (2021). The carbon footprint of construction industry: A review of direct and indirect emissions. *Journal of Sustainable Construction Materials and Technologies, 6*(3), 101–115. https://doi.org/10.29187/jscmt.2021.66

Lackner, K. S., Arcusa, S. H., Azarabadi, H., Sriramprasad, V., & Page, R. (2023). Carbon accounting without life cycle analysis. *Energy & Environmental Science, 16*(11), 4968–4982.

Li, X., Wang, C., Kassem, M. A., Wu, S. Y., & Wei, T. B. (2022). Case study on carbon footprint life-cycle assessment for construction delivery stage in China. *Sustainability, 14*(9), 5180.

Lützkendorf, T., & Balouktsi, M. (2022). Embodied carbon emissions in buildings: Explanations, interpretations, recommendations. *Buildings and Cities, 3*(1), 964–973.

Mallawaarachchi, B. C., De Silva, P. V., Fonseka, P., & Ratnaweera, R. (2025). Assessment of construct of the parent/teacher disruptive behaviour disorder (DBD) rating scale–Sinhala by principal component factor analysis (PCA). *Sri Lanka Journal of Medicine, 34*(2).

Marshall, G. (2005). The purpose, design and administration of a questionnaire for data collection. *Radiography, 11*(2), 131–136.

Mastt. (2025). *Quantity surveying guide: Functions, process, and techniques*. Retrieved December 28, 2025, from https://www.mastt.com/guide/quantity-surveying

Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of Cardiac Anaesthesia, 22*(1), 67–72.

Modiba, M., & Harinarain, N. (2024). Building resilience: Quantity surveyors in the face of future pandemics. *Journal of Construction Project Management and Innovation, 14*(1), 1–12.

Mofatteh, M. Y., Davallou, R., Ishimwe, C. N., Divekar, S. S., & Valilai, O. F. (2024). Developing a blockchain-based supply chain CO2 footprint tracking framework enabled by IoT. *International Journal of Advanced*

Computer Science and Applications (IJACSA), 15(10). http://dx.doi.org/10.14569/IJACSA.2024.0151002
Mohd Hafir, N. H. B. (2019). *The investigation of the interplay between professional identity and attitudes towards sustainability for more sustainability practices in the built environment sector* (Doctoral dissertation, University of Reading, United Kingdom).
Mulisa, F. (2022). When does a researcher choose a quantitative, qualitative, or mixed research approach? *Interchange, 53*(1), 113–131.
Naeem, M., Ozuem, W., Howell, K., & Ranfagni, S. (2023). A step-by-step process of thematic analysis to develop a conceptual model in qualitative research. *International Journal of Qualitative Methods, 22*, 1–18.
Newman, C., Edwards, D. J., Martek, I., Lai, J., & Thwala, W. D. (2021). Industry 4.0 deployment in the construction industry: A bibliometric literature review and UK-based case study. *Smart and Sustainable Built Environment, 10*(4), 557–580. https://doi.org/10.1108/SASBE-02-2020-0016
Nyamekye, C. A., Fugar, F. F., & Nani, G. (2023). Exploring the role of quantity surveyors in mechanical and electrical services cost estimation—Challenges, and client implications. *International Journal for Multidisciplinary Research, 5*(6), 1–14.
Ogunseiju, O., Odeyinka, H. A., & Yusuf, A. O. (2023). Usage of building information modelling in quantity surveying firms in Nigeria. *Journal of Construction Business and Management, 6*(2), 27–37.
Omotayo, D. T., Tan, S. W., & Ekundayo, D. (2023). Sustainable construction and the versatility of the quantity surveying profession in Singapore. *Smart and Sustainable Built Environment, 12*(2), 435–457.
Ott, R. L., & Longnecker, M. T. (2015). *An introduction to statistical methods and data analysis*. Nelson Education, Cengage Learning Inc.
Owusu-Manu, D. G., Ghansah, F. A., Parn, E., & Edwards, D. J. (2018, September). Insights into the push factors of innovation adoption of professional services firms: The case of Ghanaian quantity surveying firms (QSF). In *Proceedings of 42nd AUBEA Conference 2018: Educating Building Professionals for the Future in the Globalised World*.
Owusu-Manu, D. G., Ghansah, F. A., Boateng, F., Asumadu, G., & Edwards, D. J. (2020). The strategic benefits of innovation adoption in construction consultancy firms: The role of quantity surveyors. In *Supporting inclusive growth and sustainable development in Africa—Volume II: Transforming infrastructure development* (pp. 49–64). Springer International Publishing.
Phillips, M. J. (2023). Towards a social constructionist, criticalist, Foucauldian-informed qualitative research approach: Opportunities and challenges. *SN Social Sciences, 3*(10), 175.
Reddy, B. C., Nanyam, V. P. S. N., & Haldankar, M. (2022). The role of a quantity surveyor throughout the lifecycle of a construction project. In B. Laishram & A. Tawalare (Eds.), *Recent advancements in civil engineering* (Lecture Notes in Civil Engineering, Vol. 172). Springer, Singapore. https://doi.org/10.1007/978-981-16-4396-5_5
RICS. (2023). *Whole life carbon assessment for the built environment* (2nd ed.). Royal Institution of Chartered Surveyors. Retrieved February 20, 2025, from https://www.rics.org/content/dam/ricsglobal/documents/standards/Whole_life_carbon_assessment_PS_Sept23.pdf
RICS. (2024). *RICS response to manifesto announcements regarding construction, infrastructure and skills*. Royal Institution of Chartered Surveyors. Retrieved October 8, 2025, from https://www.rics.org/news-insights/manifesto-response-construction-infrastructure
Robati, M., Oldfield, P., Nezhad, A. A., Carmichael, D. G., & Kuru, A. (2021). Carbon value engineering: A framework for integrating embodied carbon and cost reduction strategies in building design. *Building and Environment, 192*, 107620. https://doi.org/10.1016/j.buildenv.2021.107620
Salleh, N. M., Husien, E., Husin, S. N., Muhammad, N. H., & Alang, N. (2020). Quantity surveyors' roles and responsibilities in different job sectors. *International Journal of Academic Research in Business and Social Sciences, 10*(10), 1090–1101.
Savage, C. (2022). *Reducing carbon in buildings*. Retrieved December 28, 2025, from https://www.jlconline.com/how-to/reducing-carbon_o
Scagliotti, G., & Fischer, M. (2025). Practical challenges in assessing embodied carbon and cost trade-offs in the design phase: Insights from a residential building project. *CIB Conferences, 1*(40). https://doi.org/10.7771/3067-4883.2048
Seeley, I. H. (1988). General introduction. In *Building quantities explained*. Palgrave. https://doi.org/10.1007/978-1-349-19343-1_1

Seidu, R. D., Young, B. E., Thayaparan, M., Rodmell, S., & Robinson, H. (2019, November). Mechanical and electrical (M&E) training for quantity surveyors to contribute to carbon reduction in buildings. In *Proceedings of the 8th World Construction Symposium*. University of Moratuwa.

Sinha, R., Lennartsson, M., & Frostell, B. (2016). Environmental footprint assessment of building structures: A comparative study. *Building and Environment, 104*, 162–171.

Siriwardhana, S. D., Samarakkody, A. L., Wimalaratne, I., Mahinkanda, M., Kulatunga, U., & Rathnayake, L. (2024). Quantity surveyors' adaptability to technology: The last frontier of job displacement challenge. *Built-Environment Sri Lanka, 14*(1).

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education, 48*(6), 1273–1296.

Taherdoost, H. (2022). What are different research approaches? Comprehensive review of qualitative, quantitative, and mixed method research, their applications, types, and limitations. *Journal of Management Science & Engineering Research, 2022*(1), 53–63.

Trading Economics. (n.d.). *UK construction output*. Trading Economics. Retrieved February 10, 2025, from https://tradingeconomics.com/united-kingdom/construction-output

Tukker, A., Pollitt, H., & Henkemans, M. (2020). Consumption-based carbon accounting: Sense and sensibility. *Climate Policy, 20*(sup1), S1–S13.

Tunley Environmental. (2025). *Embodied carbon in construction materials*. Retrieved October 8, 2025, from https://www.tunley-environmental.com/en/insights/embodied-carbon-in-construction-materials?hs_amp=true

UKGBC. (2021). *Net zero whole life carbon roadmap: A pathway to net zero for the UK built environment*. Retrieved July 20, 2025, from https://ukgbc.org/wp-content/uploads/2021/11/UKGBC-Whole-Life-Carbon-Roadmap-A-Pathway-to-Net-Zero.pdf

United Nations Environment Programme. (2024). *Global status report for buildings and construction—Beyond foundations: Mainstreaming sustainable solutions to cut emissions from the buildings sector*. Retrieved December 29, 2025, from https://wedocs.unep.org/items/fa8f1650-2259-4c77-b2ad-07cca2e72a7f

Victar, H. C., Perera, B. A. K. S., Palihakkara, A. D., & Dewagod, K. G. (2024). Roles and competencies of quantity surveyors in achieving a circular built environment: An investigation according to 3R principles. *Smart and Sustainable Built Environment, 13*(4), 1015–1040.

Victoria, M. F. (2025). Integrating embodied carbon estimating in quantity surveying curriculum: A case study. In M. F. Victoria, R. A. Laing, & W. J. Bevan (Eds.), *Embedding sustainability in built environment curricula: Opportunities and challenges* (pp. 191–207). Springer. https://doi.org/10.1007/978-3-031-96909-6_12

Vieira, L. C., Longo, M., & Mura, M. (2024). Impact pathways: The hidden challenges of scope 3 emissions measurement and management. *International Journal of Operations & Production Management, 44*(13), 326–334.

Wang, G., Luo, T., Luo, H., Liu, R., Liu, Y., & Liu, Z. (2024). A comprehensive review of building lifecycle carbon emissions and reduction approaches. *City and Built Environment, 2*(1), 12.

Yamamoto, K. (2023). GHG verification: Introduction to supply chain emissions (scope 1, 2, 3). *ClassNK Technical Journal, 2023*(2), 31–39. Retrieved December 29, 2025, from https://www.classnk.or.jp/hp/pdf/research/rd/2023/08_e05.pdf

Zhao, Y., Ma, Y., & Zhong, F. (2025). Sustaining green building incentives: A tripartite evolutionary game analysis and the synergistic "technology–reputation–policy" pathway. *Buildings, 15*(9), 1537. https://doi.org/10.3390/buildings15091537