GLOBAL PRACTICES OF NET ZERO CARBON BUILDING DESIGN AND CONSTRUCTION

2025

Task Group 124

International Council
for Research and Innovation
in Building and Construction

GLOBAL PRACTICES OF NET ZERO CARBON BUILDING DESIGN AND CONSTRUCTION

Principal Investigators

Associate Professor Sepani Senaratne, Centre for Smart Modern Construction, Western Sydney University, Australia
Associate Professor Niluka Domingo, Massey University, Australia
Professor Srinath Perera, Centre for Smart Modern Construction, Western Sydney University, Australia

Country/Region Coordinators

Australia - Associate Professor Sepani Senaratne, Western Sydney University
New Zealand - Associate Professor Niluka Domingo, Massey University
Italy - Professor Patrizia Lombardi and Assistant Professor Sara Torabi, Politecnico di Torino
United Kingdom - Dr. Gabriela Zapata-Lancaster, Cardiff University
South Africa - Dr. Coralie Van Reenen, Council for Scientific and Industrial Research (CSIR)
Hong Kong - Professor Joseph Lai and Associate Professor Daniel Chan, The Hong Kong Polytechnic University (PolyU)
Sri Lanka - Dr. Harshini Mallawaarachchi, University of Maratuwa

Research Assistants

Australia - Ms. Malka Nadeeshani, Western Sydney University
New Zealand - Ms. Jiaxin Liang, Massey University
Italy - Mr. Belal Neazi, Politecnico di Torino
Sri Lanka - Ms. Kavishka Jayakodi, University of Moratuwa

International Council
for Research and Innovation
in Building and Construction

PREFACE

The construction industry is one of the main contributors to carbon emissions. The construction industry has a significant role to play in emission reduction. Both the new and existing buildings need to be redesigned to account for the emissions that they produce. Globally, 196 countries committed to reducing carbon emissions by signing the Paris Agreement in 2015. The goals were set to achieve net zero carbon buildings (NZCB) and infrastructure by mid-century. This needs changes in thinking, processes, products, technology and people.

CIB Task Group 124 is focused on uniting the construction industry with various experts to discuss, research, and reduce global carbon emissions in the sector. Their efforts include international collaborations, discussion forums, and research studies aimed at achieving net-zero carbon in construction. This report presents the findings of a global survey conducted as part of CIB Task Group 124. The aim of the study was to explore global practices related to net-zero carbon building design and construction, including the enablers and barriers to implementation. To achieve this aim, a global survey (an online questionnaire) was designed and conducted, involving participation from seven countries/regions: Australia, New Zealand, the United Kingdom, Italy, South Africa, Sri Lanka, and Hong Kong. The study was funded by the *CIB vistas Programme* and the authors greatly appreciate the funding received through the programme.

Edited by

A/ Professor Sepani Senaratne, A/ Professor Niluka Domingo, Professor Srinath Perera and Ms. Malka Nadeeshani

EXECUTIVE SUMMARY

This report presents the key survey results from six countries/regions: Australia, New Zealand, Italy, South Africa, Sri Lanka, and Hong Kong, aiming to investigate current net zero carbon practices worldwide. The survey primarily targeted low-carbon building technologies, carbon estimating, and the enablers and barriers related to net zero-carbon buildings (NZCBs). A consistent survey template and content were used across all participating countries/regions, with only minor adjustments made by the country/region coordinators to suit their specific contexts. The questionnaire was distributed to construction professionals in each country/region within a similar timeframe, and the results were collected and reported by each country/region coordinator and their team. Although a survey was initiated in the United Kingdom, the results are not reported due to very low industry participation. Instead, a brief literature review highlighting the current status and issues relevant to NZCBs in the UK is included in the report.

The report is structured based on each country/region's results and sub-categorised into three main areas: low carbon building technologies; carbon estimating; and enablers and barriers of NZCBs within each country/region context. Each country/region had a unique number of respondents, used different survey distribution tools (such as Qualtrics or SurveyMonkey), and obtained relevant ethical approvals, all of which were handled by the respective country/region coordinators.

The results show a growing trend in the adoption of low-carbon building technologies worldwide. Energy-efficient systems, passive technologies, and renewable energy systems are the most common low-carbon building technologies globally. However, carbon estimation practices remain consistently low across all participating countries/regions. While some carbon estimation tools are well-known in certain countries, their application is limited. The enablers and barriers to achieving NZCBs also vary across countries/regions, but most face a similar set of significant challenges. These barriers include the lack of financial incentives, inadequate policies and legislation to support low-carbon buildings, and the prioritisation of cost savings over sustainability impacts.

CONTENTS

NZCB Practices – Australia 06

NZCB Practices – New Zealand 10

NZCB Practices – Italy 14

NZCB Practices – South Africa 18

NZCB Practices – Sri Lanka 22

NZCB Practices – Hong Kong 26

NZCB Practices – United Kingdom 30

Conclusions..34

NZCB Practices - Australia

The Australian construction sector accounts for 21% of the country's total emissions. Researchers, industry practitioners, and government organisations are actively exploring methods and pathways to achieve net-zero carbon buildings. The Australian government enacted the Climate Change Act 2022, which sets a target to achieve net zero emissions by 2050 (Australian Government, 2022). According to the government, transitioning to low-emission electricity is a key strategy for reducing carbon emissions in the building sector. To support this transition, the use of on-site renewable energy sources and highly efficient appliances is recommended. Industry reports indicate that reducing embodied carbon and improving energy efficiency are the two primary areas to focus on to achieve carbon neutrality in the Australian construction sector. Current industry practices for NZCBs, including these areas, are presented here based on the survey results.

Profile of Survey Respondents

The online questionnaire survey received 85 responses from construction professionals in Australia. Most of the professionals are Quantity surveyors (32%), followed by Engineers (22%) and other professionals (19%). When considering the services they provide, majority are working for contracting firms (36%) and consulting firms (26%), respectively. Most of the respondents are from the commercial sector, while having 1-5 years of industry experience (42%). Majority of the project experiences lie within 0-5 projects that are identified as low/zero or net zero carbon projects as per Figure 1.

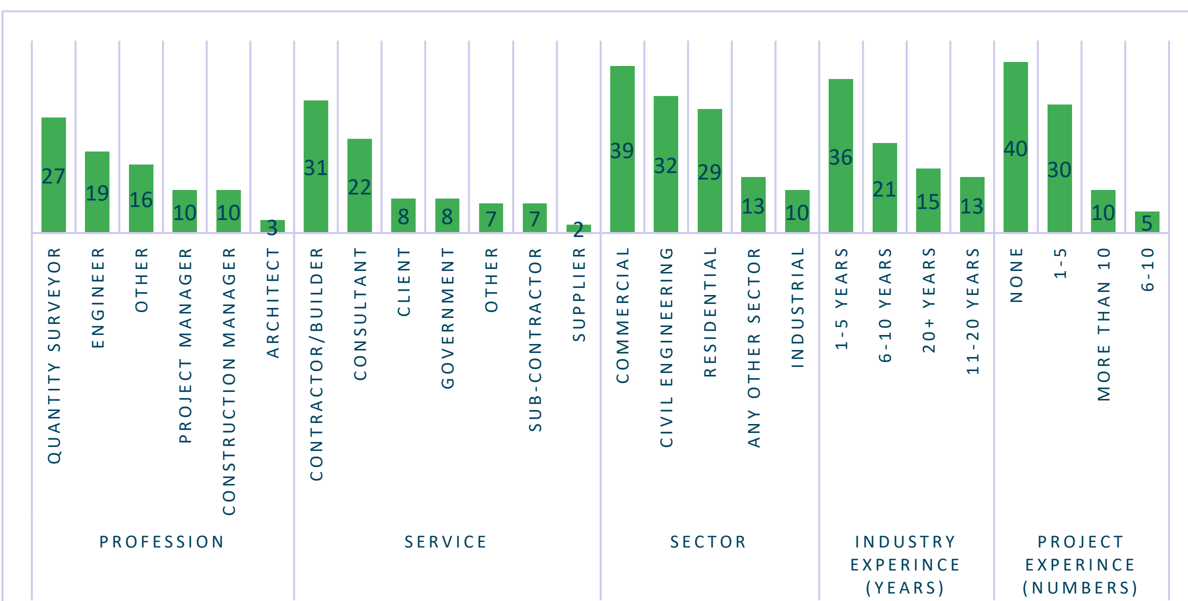

Figure 1: Profile of respondents in Australia

Low Carbon Building Technologies

Low-carbon materials and technologies are essential in reducing carbon emissions. In Australia, high-strength concrete is the most popular low-carbon material, followed by engineered timber. A few respondents have mentioned recycled aggregates as an alternative for carbon reduction. Prefabricated modular systems are being used to a moderate extent in Australia, while geopolymer concrete—a suggested alternative by the Australian government—seemed rarely used in the industry. Additionally, applications of passive design and technology are used moderately within the industry.

Energy efficient systems are the most commonly used low-carbon building practices in Australia. Upgrades to LED lighting and the installation of energy-efficient HVAC systems are among the most popular options. Also, photovoltaic (PV) solar panels are frequently used as a renewable energy source within industry. Australia, already being a global solar superpower, this level of popularity is not surprising but upscaling this usage to a most frequent level is possible. Although energy storage systems and carbon trading are not widely used, they are still employed at a moderate level within the industry. Currently, batteries are the primary type of energy storage system in use. A summarised table, indicating the top three practices for each low carbon technology, based on survey results, is presented in Table 1.

Table 1: Overview of low carbon building practices in Australia

Low Carbon Building Technologies	Mean	Rank
Low carbon materials, components and technologies		
High strength concrete and steel	2.89	1
Prefabricated and modular systems	2.76	2
Engineered timber instead of steel	2.60	3
Passive energy and technology applications		
Sun shading methods (i.e. use of balconies, hoods, overhangs to façade, louvers)	3.05	1
Natural ventilation in buildings (i.e. courtyards, grill panels etc.)	3.00	2
Daylighting devices to get daylight inside the building (i.e. light tubes, rooflights, etc.)	2.69	3
Passive design applications		
Appropriate window placement and shading	3.00	1
Thermal insulation (i.e. insulation blocks, cavity insulation, etc.)	2.99	2
Orientation towards higher solar gain	2.82	3
Energy efficient systems		
LED lighting upgrades	3.42	1
Energy efficient HVAC systems	3.41	2
Energy efficient lifts	2.79	3
Renewable energy systems		
Solar photovoltaics (i.e. PV solar panels)	2.89	1
Solar thermal (i.e. use solar thermal energy collectors)	2.42	2
Geothermal systems (i.e. use thermal energy trapped below the outer surface of earth)	1.99	3
Energy storage systems		
Batteries	2.65	1
Pumped hydro storage	1.72	2
Thermal energy storage (TES)	1.67	3
Carbon allowances and carbon trading systems		
Australian Carbon Credit Unit (ACCU) Scheme	1.94	n/a

Carbon Estimating Tools

Carbon estimation, particularly the reduction of embodied carbon, which is often referred to as upfront carbon, is a significant concern in the Australian construction industry. However, current practices for carbon estimating are significantly low. More than half of the respondents have never applied the common carbon estimating tools in practice. However, some respondents provided valuable insights into the reasons for this low adoption of carbon estimating tools. Key factors include a general lack of awareness about these tools, future plans to adopt these tools and, carbon estimation being outside their job scope.

Those who stated that carbon estimation is not within their job responsibilities, explained that this task is typically handled by sustainability officers, either internal or external to the organisation. Additionally, some respondents shared other tools they are currently using to estimate carbon emissions; these include CostX, a bespoke GHG estimation tool, the ISC materials calculator, NatHERS for residential assessments, and Green Star. Despite the slow adoption, eTool is identified as the most popular estimating tool for embodied carbon, while EnergyPlus and BERS are the popular options for operational carbon tools, according to the survey results shown in Figure 2.

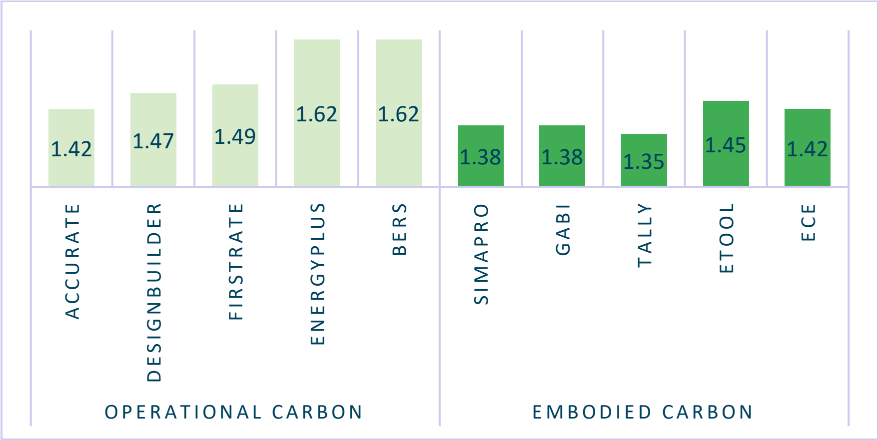

Figure 2: Use of Carbon Estimating Tools according to their mean values

Enablers and Barriers to NZCBs

In the Australian construction industry, cost savings are often prioritised over sustainability impacts, which has become the primary barrier to implementing NZCBs. Additionally, the lack of direct financial investment from the government hinders the successful implementation of NZCBs. Some respondents noted that the heavy price dependency of public sector projects in Australia works against carbon reduction efforts and demotivates environmental initiatives. Insufficient data on embodied carbon is also among the top five barriers. Since addressing embodied carbon is one of the areas focused on achieving net zero emissions in Australia, strategies to overcome this barrier are urgently needed.

Most respondents agreed that enhancing financial benefits and prioritising sustainability impacts are the leading enablers for their projects in achieving NZCBs. However, industry resistance to change and technology adoption is challenging across all sectors. Therefore, integrating digital technologies into building processes ranks among the top three enablers in the Australian construction industry. In contrast, the use of advanced carbon estimating standards and building codes ranked as the least important enabler. A list of enablers and barriers in the implementation of NZCBs in Australia, which ranked according to the survey results, is presented in Table 2.

Table 2: Barriers and enablers to implementation of NZCBs in Australia

Barriers	Rank	Enablers	Rank
Prioritisation of saving costs over sustainability impacts	1	Enhanced financial and investment opportunities	1
Lack of direct financial incentives from the government	2	Prioritisation of sustainability impacts over saving costs	2
Lack of stakeholder collaboration and integration, acting in their own silos with very little knowledge exchange	3	Integrated digital technologies (eg- BIM, IOT, Digital Twins, AI) for building processes	3
Inadequate or inconsistent understanding of net zero concepts among stakeholders	4	Adaption of sustainability principles throughout the building lifecycle	4
Insufficient data/ information about embodied carbon of construction materials	5	Increased awareness of low carbon practices by the stakeholders	5
Industry actors lacking knowledge and skills on low carbon building design and construction methods	6	Effective stakeholder integration and collaboration throughout the building lifecycle	6
Undeveloped or unclear building codes about low carbon buildings	7	Incentives for innovation and active research	7
Low and uncertain return on investment with higher initial costs	8	Robust policies and clear goals for low carbon buildings	8
Lack of common standards and methods for carbon estimating	9	Enhanced expertise for low carbon practices by building professionals	9
Lack of legislation and policies to support low carbon buildings	10	Mandatory disclosure of building efficiencies	10
Inadequate application of low carbon material and technologies	11	Transparent mechanism of sharing data and information	11
Lack of innovation towards use of less carbon intensive construction materials	12	Use of advanced carbon estimating standards and latest building codes	12
Lack of prioritisation of low carbon research and innovation	13		
Ineffective supply chain practices	14		
Ineffective waste management practices	15		

NZCB Practices – New Zealand

To reduce net emissions of all greenhouse gases to zero by 2050, the New Zealand government enacted the Climate Change Response (Zero Carbon) Act 2019 (Ministry for the Environment, 2019). The construction sector in New Zealand accounts for approximately 20% of the country's total carbon footprint, making construction decarbonisation essential to achieving the 2050 targets. Researchers, industry professionals, and policymakers are actively exploring ways to accelerate the decarbonisation of the construction sector. For example, in 2021, the government released guidelines on reducing the carbon footprint of construction procurement practices. However, construction decarbonisation remains in its early stages, and there is an urgent need to assess the current state of the low-carbon construction industry, identify barriers, and implement effective measures to accelerate progress. This report presents the findings of a survey conducted to explore the most commonly used low-carbon technologies and tools in the construction industry, as well as the key enablers and barriers to carbon reduction in New Zealand.

Profile of Survey Respondents

This report presents data collected from 49 respondents in the New Zealand construction sector. Among them, 22% are architects, followed by 20% who are quantity surveyors. Additionally, 4% are engineers and project managers, while 41% hold other professional roles, such as carbon consultants and commercial managers. The majority of participants provide consultancy services (47%), followed by contractor/builder roles (20%). The respondents primarily work in four key sectors: commercial and residential construction, which together account for more than 70% of the participants, followed by civil engineering and the industrial sector, each representing approximately 12% of the total. Furthermore, most respondents have over 11 years of industry experience and have worked on at least one low-carbon or net-zero-carbon project, as illustrated in Figure 3.

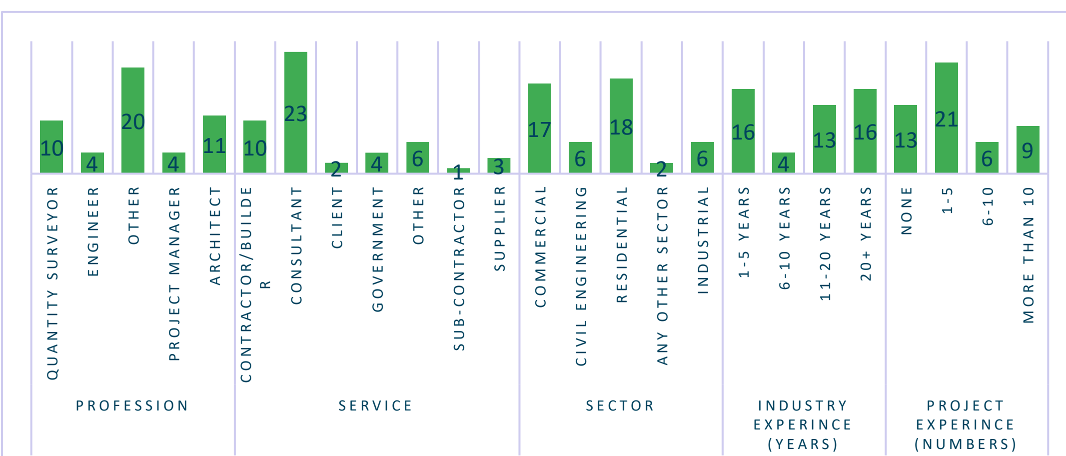

Figure 3: Profile of respondents in New Zealand

Low Carbon Building Technologies

Low-carbon building technologies play a crucial role in reducing carbon emissions in the construction sector. The questionnaire covered seven categories of practices, with the top three in each category presented in Table 3. In New Zealand, the most commonly used low-carbon material is engineered timber, followed by prefabricated and modular systems. For passive energy and technology applications, sun shading methods rank first, closely followed by natural ventilation. Passive design approaches are the most widely adopted low-carbon building practices, with thermal insulation ranking first, followed by window placement and shading strategies.

Energy-efficient systems also play a vital role in supporting low-carbon building practices. LED lighting upgrades are the most widely used method to improve building energy performance, followed by energy-efficient HVAC systems and heat recovery systems. The most common form of renewable energy application is solar photovoltaics. Exploring additional ways to harness solar energy and alternative renewable sources presents a promising area for future development.

Table 3: Overview of low carbon building practices in New Zealand

Low Carbon Building Technologies	Mean	Rank
Low carbon materials, components and technologies		
Use of engineered timber instead of steel	2.77	1
Use of prefabricated and modular systems	2.57	2
Replace Portland Cement with supplementary cementitious materials (SCMs)	2.40	3
Passive energy and technology applications		
Sun shading methods (i.e. use of balconies, hoods, overhangs to façade, louvers)	3.10	1
Use natural ventilation in buildings (i.e courtyards, grill panels etc.)	3.03	2
Use daylighting devices to get daylight inside the building (i.e. light tubes, rooflights, etc.)	2.90	3
Passive design applications		
Use thermal insulation (i.e insulation blocks, cavity insulation, etc.)	3.60	1
Appropriate window placement and shading	3.43	2
Orientation towards higher solar gain	3.20	3
Energy efficient systems		
LED lighting upgrades	3.55	1
Energy efficient HVAC systems	3.03	2
Heat recovery systems	3.00	3
Renewable energy systems		
Solar photovoltaics (i.e. PV solar panels)	2.79	1
Use solar thermal (i.e. use solar thermal energy collectors)	2.17	2
Use geothermal systems (i.e. use thermal energy trapped below the outer surface of earth)	1.69	3
Energy storage systems		
Batteries	2.20	1
Thermal energy storage (TES)	1.59	2
Pumped hydro storage	1.38	3
Carbon allowances and carbon trading systems		
New Zealand Emissions Trading Scheme (NZ ETS)	1.52	n/a

Carbon Estimating Tools

Carbon estimation is a critical process in quantifying emissions from construction across the entire life cycle. Emissions are typically categorised as operational carbon and embodied carbon. In New Zealand, the use of carbon estimation tools remains limited for both. According to the survey results shown in Figure 4, all mean scores for various carbon estimation tools were below 2.00, indicating limited adoption in low-carbon construction practices.

Among tools used for operational carbon estimation, EnergyPlus and BERS were more frequently adopted than others, such as Accurate or DesignBuilder. For embodied carbon estimation, eTool and ECE were the most selected. Additionally, some respondents reported using ECCHO and the Green Star Embodied Carbon Calculator. Feedback from several participants indicated that estimation tools often fail to meet project-specific requirements. Moreover, many respondents reported limited awareness of available estimation tools. For example, one participant noted the difficulty in determining which tool was most appropriate for their project. The low usage rate may also stem from limited applicability, as several tools lack New Zealand-specific datasets. The issues raised by respondents should be addressed in the future.

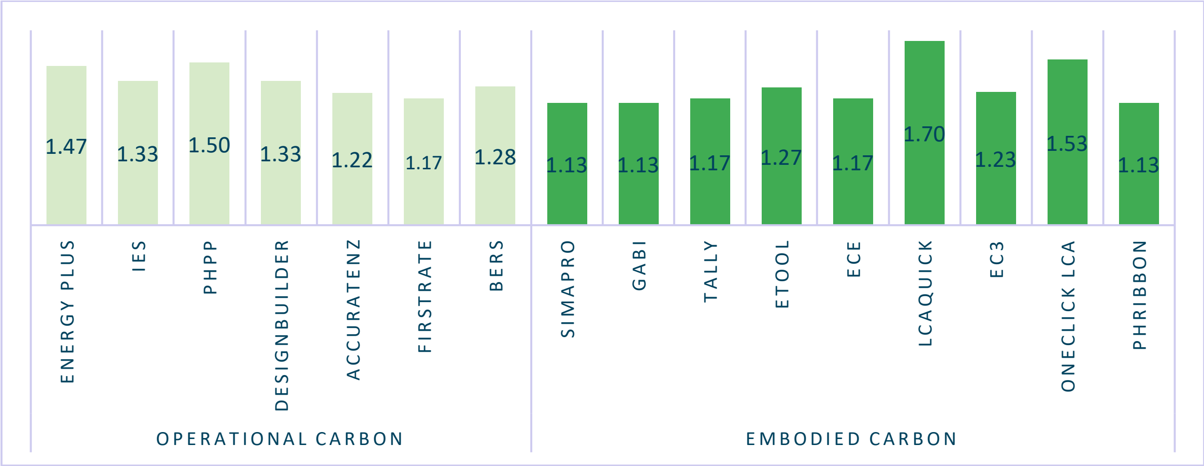

Figure 4: Use of Carbon Estimating Tools according to their mean values

Enablers and Barriers to NZCBs

In New Zealand, the top two barriers to low-carbon construction are both financial-related. The highest-ranking barrier is the prioritisation of cost savings over sustainability impacts, followed by the lack of direct financial incentives from the government. One respondent noted that cost is the primary factor influencing the adoption of sustainable practices in New Zealand and that sustainability is mostly discussed in academic settings. Additionally, the lack of knowledge and skills in low-carbon building design received the same score as the lack of financial incentives, ranking second. This finding aligns with the low adoption rate of carbon estimation tools, as many people are unsure which tools are appropriate.

Among the enablers, increased awareness of low-carbon practices ranks highest, followed by the use of advanced standards and building codes and the integration of sustainability principles throughout the building lifecycle. Robust policies and clear goals are considered the third most significant enabler, aligning with the third-ranked barrier. In contrast, incentives for innovation and active research rank as the least significant enablers. Notably, while cost savings over sustainability is identified as the top barrier, prioritising sustainability impacts over cost ranks only fifth among all enablers. A ranked list of barriers and enablers in New Zealand is shown in Table 4.

Table 4: Barriers and enablers to implementation of NZCBs in New Zealand

Barriers	Rank	Enablers	Rank
Prioritisation of saving costs over sustainability impacts	1	Increased awareness of low carbon practices by the stakeholders	1
Lack of direct financial incentives from the government	2	Use of advanced carbon estimating standards and latest building codes	2
Industry actors lacking knowledge and skills on low carbon building design	2	Adaption of sustainability principles throughout the building lifecycle	2
Lack of legislation and policies to support low carbon buildings	3	Robust policies and clear goals for low carbon buildings	3
Inadequate or inconsistent understanding of net zero concepts among stakeholders	3	Mandatory disclosure of building efficiencies	3
Undeveloped or unclear building codes about low carbon buildings	4	Transparent mechanism of sharing data and information	4
Lack of stakeholder collaboration and integration, acting in their own silos with very little knowledge exchange	4	Enhanced expertise for low carbon practices by building professionals	4
Lack of common standards and methods for carbon estimating	5	Prioritisation of sustainability impacts over saving costs	5
Low and uncertain return on investment with higher initial costs	6	Effective stakeholder integration and collaboration throughout the building lifecycle	6
Ineffective waste management practices	7	Enhanced financial and investment opportunities	7
Lack of prioritisation of low carbon research and innovation	8	Integrated digital technologies (eg- BIM, IOT, Digital Twins, AI) for building processes	8
Inadequate application of low carbon material and technologies	8	Incentives for innovation and active research	9
Insufficient data/ information about embodied carbon of construction materials	8		
Lack of innovation towards use of less carbon intensive construction materials	9		
Ineffective supply chain practices	10		

NZCB Practices – Italy

In 2020, energy use in the Italian manufacturing and construction sector accounted for 14.8% of national CO_2 emissions, 0.6% of CH_4, and 3.6% of N_2O (ISPRA, 2022). Compared to the 1990 level, in 2022, carbon intensity (t CO2eq/toe) declined by 17.8%, GHGs per GDP fell by 34.9%, and energy emissions from primary energy dropped by 16.8% (ISPRA, 2024). Net-zero carbon buildings are necessary to achieve sustainability goals and reduce carbon emissions. European Green Deal is an important aspect which targets climate neutrality by 2050 – a continent with net-zero greenhouse gas emissions. To achieve this goal, Italy is playing its part with the help of the National Recovery and Resilience Plan (NRRP), which allocates €194.4 billion (10.8% of 2019 GDP), with 39% of the amount dedicated to climate action with the REPowerEU update. This plan has €16.9 billion for energy efficiency in residential and public buildings. Current construction industry practices for NZCBs, are analysed here based on survey results.

Profile of Survey Respondents

The online questionnaire survey received a total of 58 responses from professionals in Italy. The majority of the professionals were identified as architects (39.66%), followed by engineers (36.21%), surveyors (1.72%) and other professional roles (29%). Some respondents even indicated multiple professional roles. Regarding the services they provide, most respondents reported working for consulting firms (37.93%), followed by general contractors (18.97%), and various other services (22.41%). Most of the respondents (67.24%) work in the residential sector, while a significant portion also reported working in the commercial (43.1%) and industrial sectors (27.59%). Moving on to professional experience, 62.07% of the respondents possess between 1 and 5 years of industry experience, while 15.52 % each reported 6 to 10 years and 11 to 20 years of experience. Lastly, most of the respondents (70.69%) reported involvement in 1 to 5 projects categorised as low/zero or net zero. All graphs are illustrated in Figure 5.

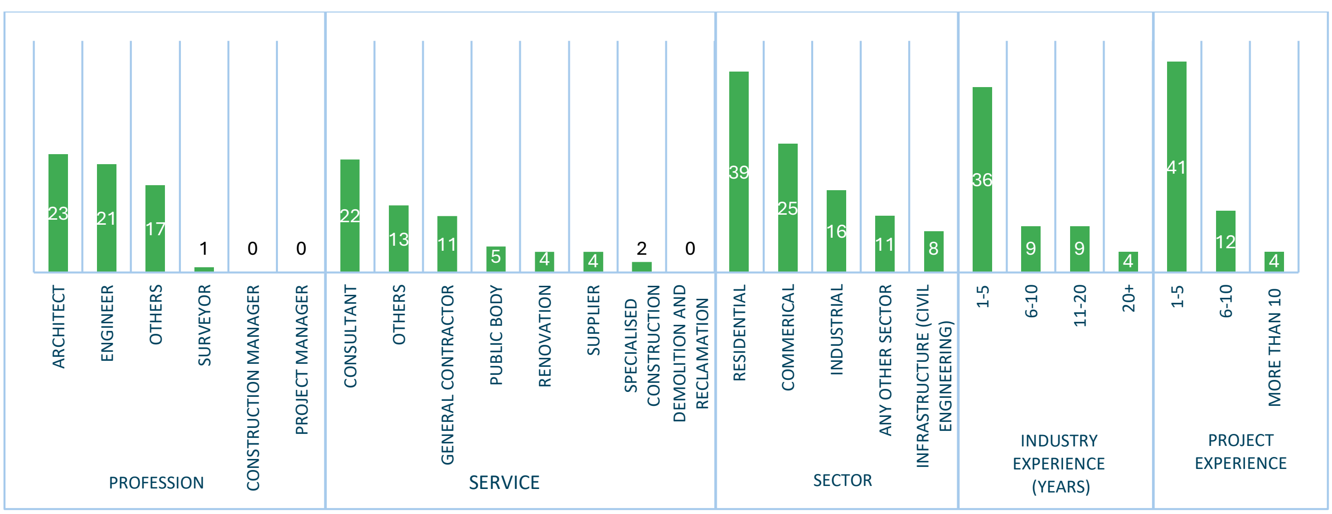

Figure 5: Profile of respondents in Italy

Low Carbon Building Technologies

The adoption of low-carbon materials and technologies is essential to reduce carbon emissions and achieve sustainability goals. In Italy, prefabricated and modular systems represent the most popular low-carbon component, followed by recycled aluminium products. Natural insulation materials including cork, hemp and sheep wool, along with recycled steel frames are also mentioned by many respondents as effective materials for carbon reduction. Portland cement with supplementary cementitious materials (SCMs) is moderately utilised in the Italian construction industry, whereas advanced technologies like carbon sequestration through algae and carbon stores, are rarely utilised in Italy.

Among the low-carbon building practices used in Italy, passive design applications are the most common. Thermal insulation upgrades (i.e. insulation blocks, cavity insulation, etc.), closely followed by high-performance glazing systems (i.e. triple glazing, low emissivity glazing, transparent insulation materials, etc.) are the most widely adopted practices in Italy, which could be largely due to older building stock which is undergoing renovation. Moreover, renewable energy technologies like solar photovoltaics and solar thermal panels are frequently implemented, which could be an influence of the NRPP, which emphasises the use of renewable energy. Other energy-efficient systems used include efficient lighting systems (LEDs, and motion sensors), energy-efficient HVAC systems and energy-efficient boilers. Currently, battery storage is the primary form of energy storage. The EU Emissions Trading System (ETS) is moderately employed in the industry by the professionals. A summarised overview indicating the top three practices within low-carbon technologies, based on survey results, is provided in Table 5.

Table 5: Overview of low carbon building practices in Italy

Low Carbon Building Technologies	Mean	Rank
Low carbon materials, components and technologies		
Prefabricated and modular systems	3.00	1
Recycled aluminium products	2.78	2
Natural insulation materials (such as cork, hemp, sheep wool, etc)	2.69	3
Recycled steel frames	2.69	3
Passive energy and technology applications		
Sun shading methods (i.e. use of balconies, hoods, overhangs to façade, louvers)	3.78	1
Advanced window technology: Using double or triple-glazed windows with low-emissivity coatings and inert gas fillings to improve thermal performance	3.64	2
Natural ventilation in buildings (i.e. courtyards, grill panels etc.)	3.48	3
Passive design applications		
Thermal insulation (i.e. insulation blocks, cavity insulation, etc.)	3.83	1
High performance glazing systems (i.e. triple glazing, low emissivity glazing, transparent insulation materials, etc.)	3.72	2
Orientation towards higher solar gain	3.48	3
Energy efficient systems		
Efficient Lighting Systems: LEDs, motion sensors	3.71	1
Energy efficient HVAC systems	3.66	2
Energy efficient boilers	3.53	3
Renewable energy systems		
Solar photovoltaics (i.e. PV solar panels)	3.67	1
Solar thermal (i.e. use solar thermal energy collectors)	3.12	2
Geothermal systems (i.e. use thermal energy trapped below the outer surface of the earth)	2.16	3

Energy storage systems		
Batteries	2.84	1
Thermal energy storage (TES)	2.16	2
Pumped hydro storage	1.78	3
Carbon allowances and carbon trading systems		
EU Emissions Trading System (EU ETS)	n/a	n/a

Carbon Estimating Tools

Carbon emissions—both operational and embodied—across all life cycle stages are a significant problem, for the Italian as well as global construction industry. Even with many regulations and tools available both at the Italian and EU levels, the current implementation of carbon estimation practices is limited. According to the survey, more than fifty percent of the respondents indicated not using any carbon estimating tools. A few respondents recounted that carbon estimation is outside their job responsibilities and is given to external or internal specialists with expertise in carbon assessment.

The survey results in Figure 6 illustrate that Edilclima and SimaPro are the most frequently used tools for operational carbon estimation, while One Click LCA, followed by openLCA are predominantly popular for embodied carbon estimations. Some respondents shared additional tools they use for carbon estimation. Two respondents mentioned using Termus Plus, an energy performance calculation software developed by ACCA software (Italy). In addition, one respondent use Termolog, a BIM-based energy software that incorporates requalification data by ENEA (developed by Logical Soft, Italy). Furthermore, few respondents mentioned Brightway, an open-source python-based software for LCA; Activity Browser, an advanced LCA tool built upon Brightway; and Mc4 Software, an energy calculation tool built on AutoCAD environment (from Italy). Interestingly, one respondent mentioned using Microsoft Excel for carbon estimation, which overall highlights a wide spectrum of available carbon estimation tools.

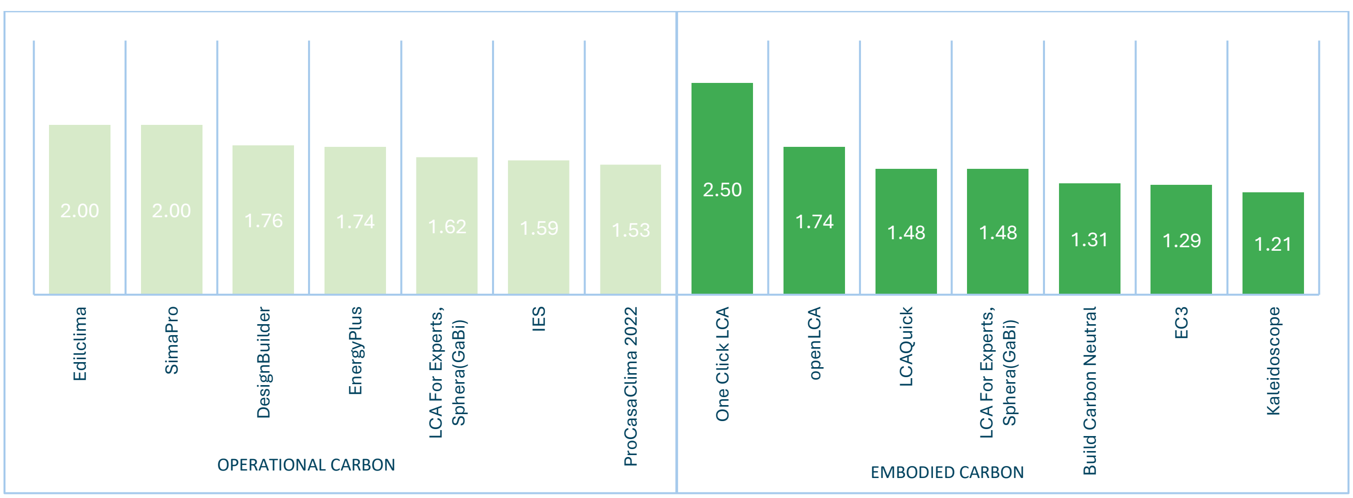

Figure 6: Use of Carbon Estimating Tools according to their mean values

Enablers and Barriers to NZCBs

In Italy, cost savings are mostly ranked higher and more influential than sustainability impacts. Thus, making financial constraints the primary barrier to the implementation of NZCBs. Additionally, the low and uncertain return on investment with higher initial costs further impedes the widespread embracement of NZCBs. Some respondents highlighted lack of stakeholder collaboration, as well as lack of available legislation and policies to support low-carbon buildings significantly discourages sustainability initiatives. Contrastingly, ineffective waste management practices and a lack of common standards and methods for carbon estimation were perceived as less significant barriers. The latter aligns with the observations from carbon estimation practices, where the use of varied tools was observed.

In Italy, most respondents agreed that robust policies and clear goals for low-carbon buildings represent the critical initiators for achieving NZCBs. Adaption of sustainability principles throughout the building lifecycle is important for the reduction of carbon in all the life cycle stages. Ranked in top 3, enhanced financial and investment opportunities, as well as enhanced expertise for low carbon practices, are also principle in enabling the implementation of NZCBs in Italy. Finally, integrated digital technologies and transparent mechanisms were perceived less influential enablers. A ranked summary of enablers and barriers in implementation of NZCBs in Italy, based on the survey, is provided in Table 6.

Table 6: Barriers and enablers to implementation of NZCBs in Italy

Barriers	Rank	Enablers	Rank
Prioritisation of saving costs over sustainability impacts	1	Robust policies and clear goals for low carbon buildings	1
Low and uncertain return on investment with higher initial costs.	2	Adaption of sustainability principles throughout the building lifecycle	2
Lack of stakeholder collaboration and integration, acting in their own silos with very little knowledge exchange.	3	Enhanced financial and investment opportunities	3
Lack of legislation and policies to support low carbon buildings.	3	Enhanced expertise for low carbon practices by building professionals	3
Industry actors lacking knowledge and skills on low carbon building design and construction methods.	4	Prioritisation of sustainability impacts over saving costs	4
Lack of direct financial incentives from the government.	5	Use of advanced carbon estimating standards and latest building codes	4
Lack of innovation towards use of less carbon intensive construction materials.	6	Incentives for innovation and active research	5
Ineffective supply chain practices.	7	Transparent mechanism of sharing data and information	5
Inadequate or inconsistent understanding of net zero concepts among stakeholders.	7	Mandatory disclosure of building efficiencies	6
Inadequate application of low carbon material and technologies.	8	Effective stakeholder integration and collaboration throughout the building lifecycle	7
Lack of prioritisation of low carbon research and innovation.	9	Increased awareness of low carbon practices by the stakeholders	8
Insufficient data/information about embodied carbon of construction materials.	9	Integrated digital technologies (eg- BIM, IOT, Digital Twins, AI) for building processes	9
Undeveloped or unclear building codes about low carbon buildings	9		
Lack of common standards and methods for carbon estimating.	10		
Ineffective waste management practices.	11		

NZCB Practices – South Africa

The South African buildings and construction sector accounts for 7% of the country's direct annual emissions. This includes emissions associated with materials, construction activities, and building operations. With South Africa’s growing urban population, it is imperative to reduce these emissions by ensuring buildings are well-insulated to reduce heating and cooling loads and promote the use of low-carbon materials. To support this transition, the National Building Regulations have been revised to include energy efficiency requirements and Energy Performance Certificates have been introduced in a phased approach. South Africa has an abundant supply of coal and relatively cheap electricity, which has historically masked the need for energy efficiency. However, the climate crisis is highlighting the need to reduce consumption and transition to renewable energy sources. Initiatives to support the transition to low energy buildings with low carbon materials have been developed by government, non-profit organisations and researchers. Current industry practices for NZCBs, including these areas, are presented here based on the survey results.

Profile of Survey Respondents

The survey was distributed to the South African construction professionals via industry professional bodies for Architects, Engineers, Quantity Surveyors, and Construction Project Managers. The online questionnaire survey received 59 responses from construction professionals in South Africa. Most of the professionals are Architects (78%), with the remainder constituted by Engineers, Project Managers, and other construction professionals. Most of the respondents do work the residential sector (n=47) and commercial sector (n=36) and have more than 20 years’ experience (60%). The majority of the respondents (63%) have not worked on low/zero or net zero carbon projects as per Figure 7, showing a low level of transition in the industry.

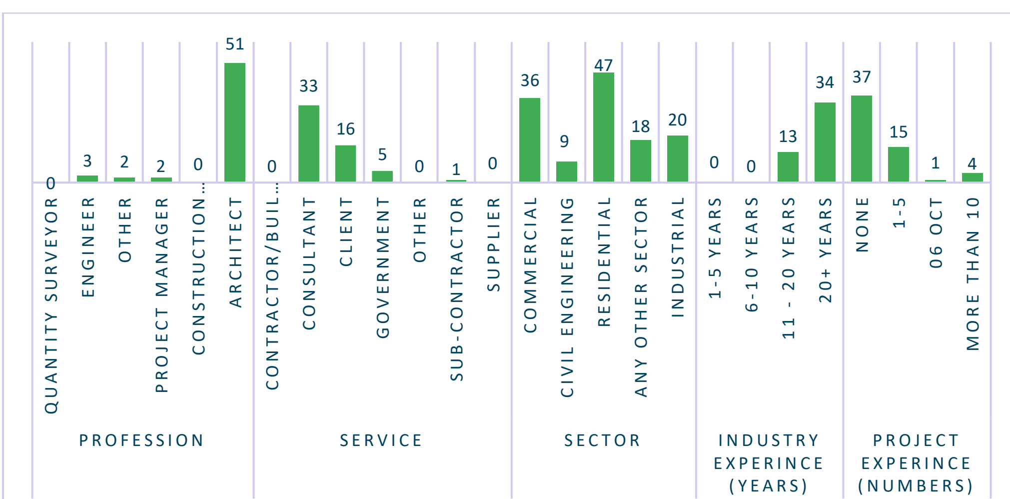

Figure 7: Profile of respondents in South Africa

Low Carbon Building Technologies

Low-carbon materials and technologies are essential in reducing carbon emissions. In South Africa, the most commonly used material technology to lower carbon, when analysing according to the weighted mean scale method, emerged to be the use of prefabricated and modular systems, the replacement of Portland cement with supplementary cementitious materials (SCMs), and the use of recycled steel frames, closely followed by the use of recycled aluminium products. A few respondents indicated the use of alternative materials such as rammed earth, light steel frame insulated structures, timber and recycled materials.

Energy efficient systems are the most commonly used low-carbon building practices in South Africa, especially since this is included in the requirements of the National Building Regulations. Sun shading methods (such as the use of balconies, overhangs and louvres) and natural ventilation are the top strategies employed. Other strategies mentioned include trombe walls and night flushing. The most used passive design application in South Africa is the use of high thermal mass, followed by the use of highly insulating materials. Either of these strategies are effective, dependant on the local climate. A summarised table, indicating the top three practices for each low carbon technology, based on survey results, is presented in Table 7.

Table 7: Overview of low carbon building practices in South Africa

Low Carbon Building Technologies	Mean	Rank
Low carbon materials, components and technologies		
Use of prefabricated and modular systems	2.52	1
Replace Portland cement with supplementary cementitious materials (SCMs)	2.12	2
Use recycled steel frames	2.07	3
Passive energy and technology applications		
Sun shading methods (i.e. use of balconies, hoods, overhangs to façade, louvers)	4.23	1
Natural ventilation in buildings (i.e courtyards, grill panels etc.)	4.15	2
Daylighting devices to get daylight inside the building (i.e. light tubes, rooflights, etc.)	3.32	3
Passive design applications		
Use of materials with high thermal mass for building envelope	3.92	1
Use of thermal insulation	3.85	2
Orientation towards higher solar gain	3.81	3
Energy efficient systems		
Energy efficient HVAC systems	3.29	1
Energy efficient boilers	2.97	2
Heat recovery systems	2.95	3
Renewable energy systems		
Solar photovoltaics (i.e. PV solar panels)	3.85	1
Solar thermal (i.e. use solar thermal energy collectors)	2.85	2
Wind turbines (i.e. wind power)	1.66	3
Energy storage systems		
Batteries	3.44	1
Thermal energy storage (TES)	1.88	2
Pumped hydro storage	1.46	3
Carbon allowances and carbon trading systems		
JSE Ventures Carbon Market	2.15	n/a

Carbon Estimating Tools

Carbon estimation, particularly the reduction of embodied carbon, which is often referred to as upfront carbon, is a growing concern in the South African construction industry. However, current practices for carbon estimating are significantly low. The vast majority (over 80%) of the respondents have never applied the common carbon estimating tools in practice, although a few reported using other tools, such as EDGE or Green Star rating, as a means of estimating operational carbon. DesignBuilder and Energy Plus emerged as the most popular tools for evaluating operational carbon.

In terms of embodied carbon, 90% of the respondents reported that they never use any tools to calculate the embodied carbon, clearly indicating that the South African industry is very immature in this regard, although a few reported that they are starting to explore some of the tools and one reported using EDGE as a tool for evaluating embodied carbon. These results are shown in Figure 8.

It was also noted that respondents indicated that there is a lack of local data available for estimating embodied carbon. It can also be noted that of the few respondents that use embodied carbon estimates, most consider the boundary cradle to gate and cradle to end of construction, equally.

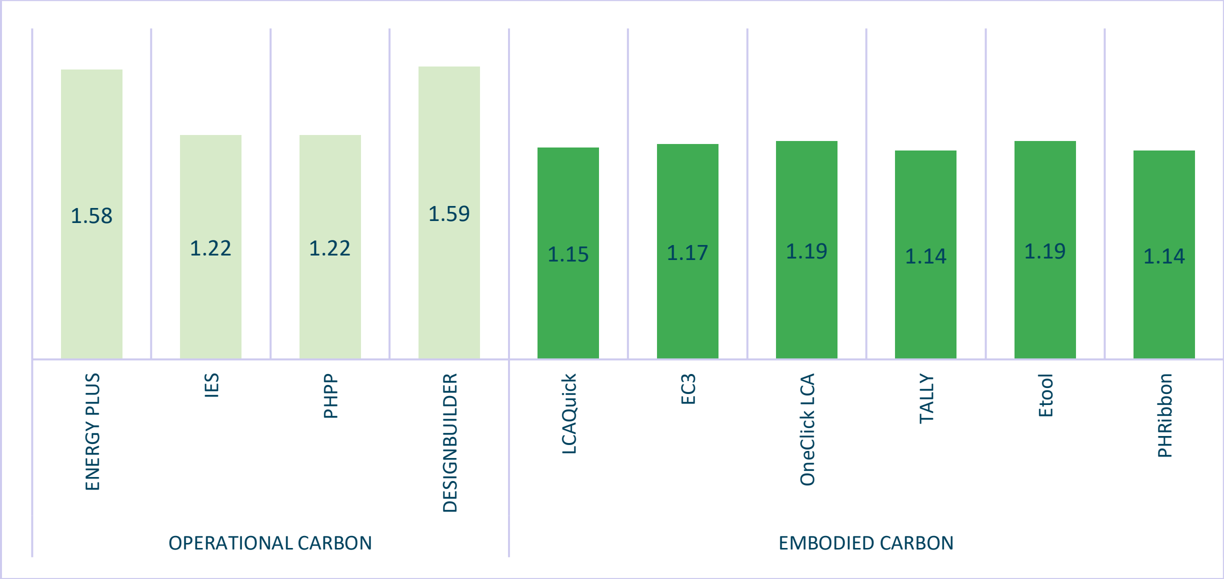

Figure 8: Use of Carbon Estimating Tools according to their mean values

Enablers and Barriers to NZCBs

In the South African construction industry, the most cited barrier is the inadequate application of low carbon material and technologies. This indicates a low uptake generally. However, more specifically, a low or uncertain return on investments with higher initial costs emerges as the most significant barrier, followed equally by a lack of legislation and policies to support low carbon buildings and a lack of prioritisation of low carbon research and innovation. This provides a clear message that research informed policy is needed.

Most respondents agreed that robust policies and clear goals for low carbon buildings would be the most important enabler. The strength of this view was closely followed by the view that mandatory disclosure of building efficiencies would enable lower carbon buildings. These views, paired with the top barriers indicate that the South African industry sees a clear role for government to play in supporting transition in the industry. Another top enabler emerged to be the use of digital technologies, such as BIM and digital twins. Increased awareness ranked as the lowest enabler, indicating that the industry is well aware of the need but lacks the support to transition. These results are represented in Table 8.

Table 8: Barriers and enablers to implementation of NZCBs in South Africa

Barriers	Rank	Enablers	Rank
Inadequate application of low carbon material and technologies	1	Robust policies and clear goals for low carbon buildings	1
Low and uncertain return on investment with higher initial costs	2	Mandatory disclosure of building efficiencies	2
Lack of prioritisation of low carbon research and innovation	3	Integrated digital technologies (eg- BIM, IOT, Digital Twins, AI) for building processes	3
Lack of legislation and policies to support low carbon buildings	4	Effective stakeholder integration and collaboration throughout the building lifecycle	4
Lack of innovation towards use of less carbon intensive construction materials	5	Transparent mechanism of sharing data and information	5
Lack of stakeholder collaboration and integration, acting in their own silos with very little knowledge exchange	6	Enhanced financial and investment opportunities	6
Insufficient data/ information about embodied carbon of construction materials	7	Use of advanced carbon estimating standards and latest building codes	7
Ineffective waste management practices	8	Adoption of sustainability principles throughout the building lifecycle	8
Undeveloped or unclear building codes about low carbon buildings	9	Incentives for innovation and active research	9
Lack of common standards and methods for carbon estimating	10	Prioritisation of sustainability impacts over saving costs	10
Industry actors lacking knowledge and skills on low carbon building design and construction methods	11	Enhanced expertise for low carbon practices by building professionals	11
Ineffective supply chain practices	12	Increased awareness of low carbon practices by the stakeholders	12
Prioritisation of saving costs over sustainability impacts	13		
Inadequate or inconsistent understanding of net zero concepts among stakeholders	14		
Lack of direct financial incentives from the government	15		

NZCB Practices – Sri Lanka

With the rapid economic growth, the construction industry has become a significant contributor to the global economy. Similarly in Sri Lanka, the construction sector significantly contributes to CO_2 emissions, highlighting the urgent need for implementing effective NZCB technologies. Further, understanding the impact of construction on the carbon footprint is also crucial for developing effective mitigation strategies. However, country-specific research and comprehensive data inventories on carbon emissions from Sri Lankan construction activities and reduction methodologies remain limited. Hence, this case study presents the current practices, enablers and barriers for NZCBs in Sri Lanka based on the survey results.

Profile of Survey Respondents

The questionnaire survey, which was conducted both physically and online, received 38 responses from building and construction industry professionals in Sri Lanka. Most respondents were Quantity Surveyors (34%), followed by Engineers (24%) and other industry practitioners. As per the services they provide, most of the respondents employed for consulting firms (47%). Further, most of them were from commercial sector (55%). Additionally, the respondents' industry experience and project experience were also analysed, considering both their years in the field and the number of projects involved (refer Figure 9). Accordingly, the majority has 1 – 5 years of industry experience and has involved 1 – 5 low/zero carbon or net zero carbon projects**.**

Figure 9: Profile of respondents in Sri Lanka

Low Carbon Building Technologies

Low-carbon building materials and technologies are the fundamental concepts of net zero-carbon building construction. This transition helps to reduce the carbon footprint and mitigate the negative environmental impacts of the built environment. In Sri Lanka, adopting low-carbon materials, components and technologies remains limited due to the lack of motivation and commitment towards the net-zero construction industry. However, the use of recycled steel frames has emerged as the most popular option based on the collected responses. Further, the replacement of Portland cement with supplementary cementitious materials (SCMs) and the use of recycled aluminium products are also practiced within the industry. As a tropical country, sun shading methods, such as balconies, hoods, louvres and daylight devices such as light tubes, and reflectors are widely utilised in the Sri Lankan construction industry. Additionally, the use of natural ventilation through courtyards and grill panels are also adopted as passive energy and technology applications. Energy-efficient systems represent another critical aspect in low-carbon buildings, which helps to reduce Scope 02 emissions. Accordingly, energy-efficient HVAC systems, cooling systems and boilers are some of the most preferred options. Further, since Sri Lanka receives sufficient solar gain throughout most of the year, solar power is the most prevalent renewable energy source in Sri Lanka. Accordingly, the use of photovoltaic and thermal power is widely spread within the industry. Table 9 represents a summary of the top three practices for each low carbon building technologies.

Table 9: Overview of low carbon building practices in Sri Lanka

Low Carbon Building Technologies	Mean	Rank
Low-carbon materials, components and technologies		
Use recycled steel frames	2.58	1
Replaced Portland cement with supplementary cementitious materials (SCMs)	2.50	2
Use recycled aluminium products	2.42	3
Passive energy and technology applications		
Sun shading methods (i.e. use of balconies, hoods, overhangs to façade, louvers)	3.42	1
Use daylight devices to get daylight inside the building (i.e. light tubes, reflectors, etc.)	3.08	2
Use natural ventilation in buildings (i.e. courtyards, grill panels etc.)	2.87	3
Passive design applications		
Use thermal insulation (i.e. insulation blocks, cavity insulation, etc.)	2.97	1
Change of location, landscape or shading to reduce energy load	2.92	2
Use materials with high thermal mass for the building envelop	2.21	3
Energy-efficient systems		
Energy efficient HVAC systems	3.21	1
Install low energy cooling systems	3.00	2
Energy efficient boilers	2.87	3
Renewable energy systems		
Use solar photovoltaics (i.e. PV solar panels)	2.92	1
Use solar thermal (i.e. use solar thermal energy collectors)	2.37	2
Use bioenergy or biofuels	0.87	3
Energy storage systems		
Batteries	1.66	1
Thermal energy storage	0.53	2
Pumped hydro storage	0.45	3

Carbon Estimating Tools

Carbon estimation can be identified as one of the prerequisites in moving towards a low-carbon building and construction industry. According to the responses, lack of awareness of carbon emission estimation and estimation tools and unavailability of local data are the most significant reasons for this low adoption of carbon estimating. Based on the survey results, EnergyPlus and DesignBuilder were identified as the most popular operational carbon estimation tools among the other operational carbon estimation tools. Further, some respondents indicated that both carbon and energy assessments were conducted simultaneously by using RETScreen. Additionally, the survey responses revealed that eQuest was used for energy and emissions modelling for new construction projects, in accordance with LEED certification requirements.

OneClick LCA is the most popular embodied carbon estimation tool based on the responses. Some responses pointed out the use of the Building SAT tool for embodied carbon estimation which is developed for the Sri Lankan context. Building SAT is a comprehensive whole-building life cycle assessment tool that can be used for any new construction, refurbishment, or already existing buildings. Additionally, REVIT-based life cycle carbon estimators were also mentioned as an option for embodied carbon estimation. Significantly, most of the responses emphasised the necessity of developing country-based emission estimation tools and encouraging carbon estimation in the Sri Lankan construction industry. The summary of the survey results is shown in Figure 10.

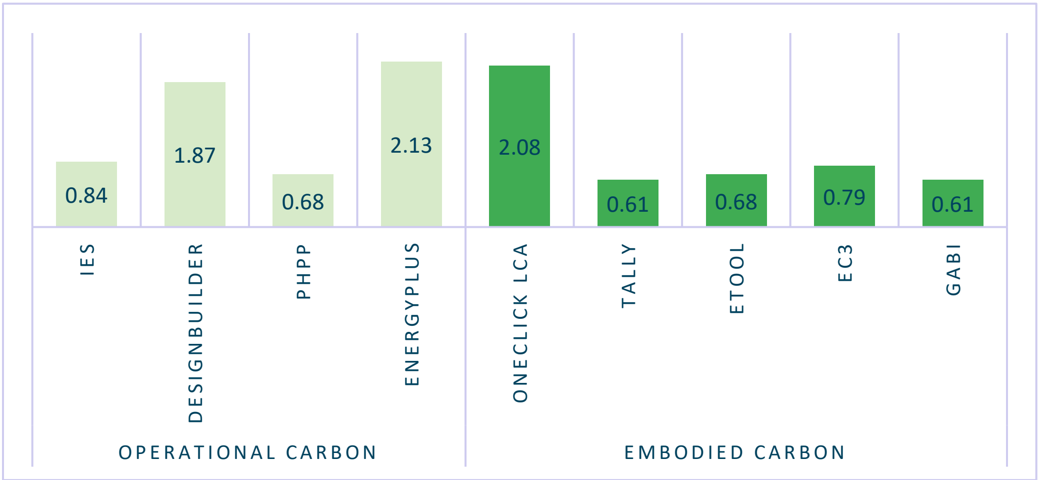

Figure 10: Use of carbon estimating tools based on their mean values

Enablers and Barriers to NZCBs

The adoption of net zero-carbon buildings in the Sri Lankan building and construction industry is highly limited due to the presence of numerous barriers. Among them, lack of direct financial incentives from the government was identified as the most critical barrier that hinders the successful implementation of NZCBs. Respondents also emphasised that the lack of legislation and policies to support low-carbon buildings and insufficient data/ information about embodied carbon of construction materials have restricted the widespread of sustainable practices within the industry. Further, respondents highlighted that the undeveloped or unclear building codes about low carbon buildings, low and uncertain returns on investment with higher initial costs and inadequate application of low-carbon materials and technologies also impede the implementation of NZCBs in Sri Lanka.

In contrast, this study identified several enablers of NZCBs. The adoption of sustainability principles throughout the lifecycle of the building stands out as the most influential enabler based on the responses. Further, robust policies and clear goals for low-carbon buildings, the use of advanced carbon estimation standards and latest building codes are among first five significant enablers which could impact positively on the transition towards NZCBs in Sri Lanka. Table 10 presents a list of enablers and barriers to the implementation of NZCBs in Sri Lanka, which were ranked based on survey results.

Table 10: Barriers and enablers to implementation of NZCBs in Sri Lanka

Barriers	Rank	Enablers	Rank
Lack of direct financial incentives from the government	1	Adaption of sustainability principles throughout the building lifecycle	1
Lack of legislation and policies to support low carbon buildings	2	Robust policies and clear goals for low carbon buildings	2
Insufficient data/ information about embodied carbon of construction materials	3	Use of advanced carbon estimating standards and latest building codes	3
Undeveloped or unclear building codes about low carbon buildings	4	Prioritisation of sustainability impacts over saving costs	4
Low and uncertain return on investment with higher initial costs	5	Integrated digital technologies (eg- BIM, IOT, Digital Twins, AI) for building processes	5
Inadequate application of low carbon material and technologies	6	Effective stakeholder integration and collaboration throughout the building lifecycle	6
Lack of innovation towards use of less carbon intensive construction materials	7	Enhanced expertise for low carbon practices by building professionals	7
Lack of common standards and methods for carbon estimating	8	Mandatory disclosure of building efficiencies	8
Industry actors lacking knowledge and skills on low carbon building design and construction methods	9	Enhanced financial and investment opportunities	9
Lack of stakeholder collaboration and integration, acting in their own silos with very little knowledge exchange	10	Increased awareness of low carbon practices by the stakeholders	10
Inadequate or inconsistent understanding of net zero concepts among stakeholders	11	Transparent mechanism of sharing data and information	11
Ineffective supply chain practices	12	Incentives for innovation and active research	12
Lack of prioritisation of low carbon research and innovation	13		
Prioritization of saving costs over sustainability impacts	14		
Ineffective waste management practices	15		

NZCB Practices – Hong Kong

Buildings account for over one-third of the global carbon emissions. In Hong Kong, this share is much higher, with the generation of electricity for buildings accounting for around 60% of carbon emissions. Researchers, industry practitioners, and government organizations are actively exploring various effective methods and pathways to reduce carbon emissions in the city. The government has implemented the Hong Kong Climate Action Plan 2050, promoting green building standards, retrofitting existing building structures for higher energy efficiency, and expanding the use of renewable energy. Key actions include the adoption of BEAM Plus certification, stricter energy codes, and incentives for sustainable construction. Additionally, smart technologies and district cooling projects are being introduced to further drive carbon reduction in the built environment. This section presents the current industry practices toward achieving NZCBs in Hong Kong based on the survey results.

Profile of Survey Respondents

A total of 61 responses were received from construction professionals in Hong Kong. The highest response rate came from project managers (38%), followed by engineers (23%) and quantity surveyors (16%). Most respondents work for contractors or builders (26%) and client firms (23%). The majority of respondents are based in the commercial sector (35%). Most participants have over 20 years of working experience (46%) in the construction industry, with many having participated in 1 to 3 projects (46%) identified as low/zero or net-zero carbon projects, as illustrated in Figure 11.

Figure 11: Profile of survey respondents in Hong Kong

Low Carbon Building Technologies

Low-carbon materials and technologies play a crucial role in reducing carbon emissions in Hong Kong's construction sector. Prefabricated and modular systems are the most popular low-carbon technologies adopted in Hong Kong, while recycled steel frames and recycled aluminum products are widely used low-carbon materials in the region. Passive energy and design applications are also common, with sun shading methods and thermal insulation ranked as the top practices.

Energy-efficient systems and renewable energy systems are key to lowering carbon emissions in buildings, and the Hong Kong construction industry uses these systems more commonly than other low-carbon building technologies. Energy-efficient HVAC systems and smart home technology systems are the most popular options for efficient energy use in Hong Kong. Solar photovoltaics are the most commonly used renewable energy system in Hong Kong's construction sector, while solar thermal and wind power are used at a moderate to low level. Even though energy storage systems are not widely adopted in Hong Kong's construction sector, batteries are the primary type of energy storage used. A summary, highlighting the top three practices for each low-carbon technology based on the survey results, is presented in Table 11.

Table 11: Overview of low carbon building practices in Hong Kong

Low Carbon Building Technologies	Mean	Rank
Low carbon materials, components and technologies		
Prefabricated and modular systems	2.67	1
Recycled steel frames	2.41	2
Recycled Aluminium products	2.38	3
Passive energy and technology applications		
Sun shading methods (i.e. use of balconies, hoods, overhangs to façade, louvers)	2.86	1
Natural ventilation in buildings (i.e. courtyards, grill panels etc.)	2.85	2
Daylighting devices to get daylight inside the building (i.e. light tubes, rooflights, etc.)	2.85	2
Passive design applications		
Thermal insulation (i.e. insulation blocks, cavity insulation, etc.)	2.96	1
High performance glazing systems (i.e. triple glazing, low emissivity glazing etc)	2.94	2
Change of location, landscape or shading to reduce energy load	2.59	3
Energy efficient systems		
Energy efficient HVAC systems	3.46	1
Smart home technology systems (i.e. control heating, lighting and power systems)	3.15	2
Low energy cooling systems	2.96	3
Renewable energy systems		
Solar photovoltaics (i.e. PV solar panels)	3.11	1
Solar thermal (i.e. use solar thermal energy collectors)	2.37	2
Wind turbines (i.e. use wind power)	2.09	3
Energy storage systems		
Batteries	2.80	1
Thermal energy storage (TES)	2.01	2
Pumped hydro storage	1.79	3

Carbon Estimating Tools

Operational and embodied carbon reduction is significant in achieving NZCBs globally. In Hong Kong, the reduction of embodied and operational carbon is a significant concern. However, carbon estimating practices in Hong Kong are considerably low. Most of the respondents have never or rarely applied carbon estimation tools in practice. Some of the respondents have provided insights into this low usage of carbon estimation. Key reasons include outsourcing carbon estimation, lacking reliable and effective tools, and making sensible estimations based on previous projects/existing data.

According to the available survey results, EnergyPlus is the most popular operational carbon estimating tool in Hong Kong, while OneClickLCA and LCAQuick are the most popular embodied carbon estimation tools. Additionally, some respondents shared other tools that are currently being used in the industry. These tools include bespoke estimation tools, the government's web-based application and the Construction Industry Council (CIC) carbon assessment tool. A summary of the survey results is illustrated in Figure 12.

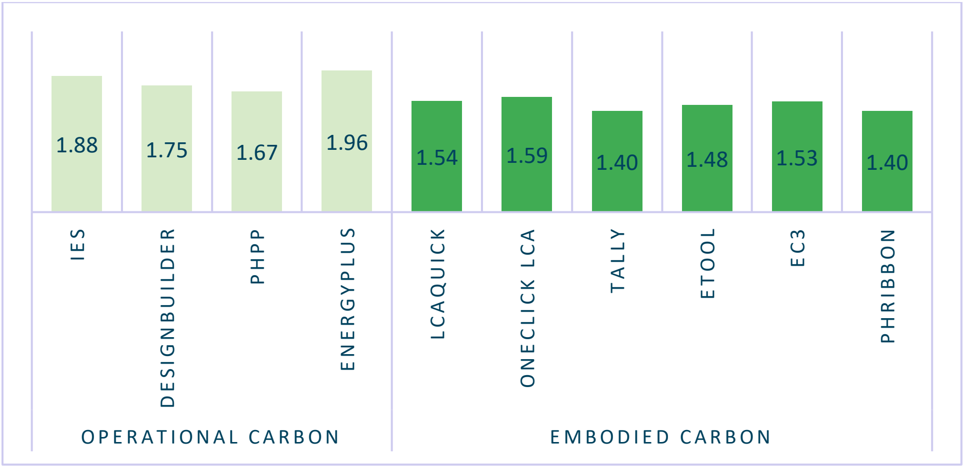

Figure 12: Use of Carbon Estimating Tools according to their mean values

Enablers and Barriers to NZCBs

Several barriers and enablers impact the achievement of NZCBs globally. The enablers and barriers can be specific and unique to different countries/regions. In Hong Kong, the lack of robust legislation and policies to support low-carbon buildings acts as a leading barrier to NZCBs. Also, cost savings are prioritised in the Hong Kong construction sector over sustainability impacts, which demotivates environmental initiatives. Furthermore, the lack of strong financial support from government bodies hinders the successful implementation of NZCBs in Hong Kong.

With the lack of robust legislation and policies to support low-carbon buildings being the greatest barrier to achieving NZCBs in Hong Kong, most respondents have agreed that robust policies and clear goals for low-carbon buildings are the leading enabler in achieving NZCBs. Also, industry awareness and collaboration by stakeholders rank among the top three enablers in the Hong Kong construction industry. However, the prioritisation of sustainability impacts over cost savings ranked as the least important enabler, despite cost prioritisation being ranked among the top three barriers within the region. A ranked list of enablers and barriers in achieving NZCBs in the Hong Kong construction sector is presented in Table 12.

Table 12: Barriers and enablers to implementation of NZCBs in Hong Kong

Barriers	Rank	Enablers	Rank
Lack of robust legislation and policies to support low carbon buildings	1	Robust policies and clear goals for low carbon buildings	1
Prioritisation of saving costs over sustainability impacts	2	Increased awareness of low carbon practices by the stakeholders	2
Lack of direct financial incentives from the government	3	Mandatory disclosure of building efficiencies	3
Low and uncertain return on investment with higher initial costs	4	Use of advanced carbon estimating standards and latest building codes	4
Lack of stakeholder collaboration and integration, acting in their own silos with very little knowledge exchange	5	Enhanced financial and investment opportunities	5
Undeveloped or unclear building codes about low carbon buildings	6	Incentives for innovation and active research	6
Insufficient data/ information about embodied carbon of construction materials	7	Integrated digital technologies (e.g.- BIM, IoT, Digital Twins, AI) for building processes	7
Ineffective waste management practices	8	Enhanced expertise for low carbon practices by building professionals	8
Lack of prioritisation of low carbon research and innovation	9	Adaption of sustainability principles throughout the building whole lifecycle	9
Lack of innovation towards use of less carbon intensive construction materials	10	Effective stakeholder integration and collaboration throughout the building lifecycle	10
Ineffective supply chain practices	11	Prioritisation of sustainability impacts over saving costs	11
Industry actors lacking knowledge and skills on low carbon building design and construction methods	12	Transparent mechanism of sharing data and information	12
Lack of common standards and methods for carbon estimating	13		
Inadequate or inconsistent understanding of net zero concepts among stakeholders	14		
Inadequate application of low carbon material and technologies	15		

NZCB Practices – United Kingdom

The United Kingdom's net zero carbon design agenda prioritise strategies such as the fabric-first approach, adherence to Passivhaus principles, and the integration of renewable energy systems. While these strategies provide a strong foundation, persistent performance gaps and operational challenges highlight the need for improved construction practices and more rigorous policy enforcement. Although a survey was initiated, the results are not reported due to very low response rate. Instead, a brief literature review highlighting the current status of NZCBs in the UK is presented here.

Low Carbon Building Technologies

A fabric-first approach remains central to net zero carbon design, focusing on high-performance insulation, airtight construction, and passive design strategies to minimize operational energy demand in the UK. The Passivhaus standard, which integrates super-insulation, airtightness, and heat recovery ventilation, has demonstrated effectiveness in reducing space heating requirements significantly. Beyond these measures, renewable energy integration—particularly through solar photovoltaics—plays a crucial role in net zero carbon strategies.

Growing attention to embodied carbon has led to an increased use of bio-based and low-carbon materials. Hemp-lime bio-composites, for example, have been suggested as a means to achieve carbon-negative buildings (Jankovic et al., 2021). Offsite construction is also gaining traction as a strategy to enhance quality control, reduce waste, and improve energy efficiency while lowering embodied carbon (Warren et al., 2024). To further reduce carbon intensity, alternative binders such as calcined clay and limestone are being explored in concrete production. Additionally, timber construction is increasingly recognized for its ability to lower embodied carbon while contributing to carbon sequestration (Drewniok et al., 2023).

The adoption of low carbon building technologies in the UK is largely driven by regulatory pressures and the push toward zero-carbon homes (Lees & Sexton, 2014; Bevan & Lu, 2012). However, house builders often opt for a narrow range of technologies that fit within existing design and production frameworks, with solar-based solutions becoming increasingly prominent (Lees & Sexton, 2014). Emerging technologies such as thermal energy storage, heat pumps, and grid-responsive controls (Ma et al., 2023) show significant promise, but their implementation is influenced by socio-technical structures and institutional practices (Bevan & Lu, 2012). Achieving decarbonization at scale will require a holistic approach that integrates multiple technologies and fosters collaboration among stakeholders (Ma et al., 2023).

Carbon Estimating Tools in Design

The UK construction industry is adopting a range of carbon estimating approaches to support net-zero carbon design and construction. These methods aim to quantify both embodied and operational carbon emissions to inform better decision-making throughout the building lifecycle.

For embodied carbon estimation, widely used tools include the Inventory of Carbon and Energy (ICE) and guidance from the Royal Institution of Chartered Surveyors (RICS) (Victoria et al., 2016). These methodologies help assess the carbon footprint of materials and construction processes, ensuring that projects align with net zero objectives. Innovative methods such as the Supply Chain-based Embodied Carbon Estimating Method (SCEEM) offer more accurate assessments than traditional tools like Blackbook and eToolLCD (Rodrigo et al., 2021). Furthermore, early-stage EC prediction models are being developed to optimize designs for both carbon and cost efficiency, leveraging design and morphological parameters (Victoria et al., 2015).

Dynamic simulation modelling is increasingly employed to achieve net-zero operational emissions by optimizing energy performance. Additionally, industry-standard databases are used to evaluate the embodied emissions of various building materials (Jankovic et al., 2021). These approaches collectively contribute to the UK's goal of decarbonizing the built environment.

Enablers and Barriers

Despite advancements in net zero carbon design, significant challenges persist across policy enforcement, industry capacity, and economic feasibility.

Performance Gaps and Policy Limitations: Studies of residential projects across the UK reveal that operational energy use often exceeds design predictions by 20–25%, with average carbon emissions reaching 20.2 $kgCO_2e/m^2/year$. Key contributors to this discrepancy include poor building envelope performance—such as insufficient airtightness and insulation—as well as inefficiencies in community heating systems and energy storage solutions, where mean self-consumption rates remain low at 23% (Oreskovic et al., 2021). Although national policies such as the zero carbon homes target, UK Green Building Council frameworks, the Future Homes Standard, and Building Regulations exist, their effectiveness varies. Many policies remain under development, lack enforcement mechanisms, or fail to address critical technical and organizational barriers. Research by Briggs (2008) highlights ongoing issues, including non-compliance with Building Regulations, the widespread use of low-efficiency boilers, inadequate insulation, and improper installation of glazing. Beyond technical challenges, cultural and industry-related obstacles also hinder progress. Resistance to change, scepticism regarding long-term policy commitments (Jankovic et al., 2021), and limited industry willingness to exceed regulatory standards (Heffernan et al., 2015) remain significant barriers to achieving net zero carbon goals.

Industry Capacity and Skills Gaps: The construction industry faces a shortage of skilled labour in critical areas such as airtight construction, renewable energy system installation, and the application of low-carbon materials. Additionally, many design professionals lack the expertise needed for accurate energy performance modelling, which contributes to the ongoing discrepancy between predicted and actual energy performance which mirrors challenges experienced in other countries. A stronger focus on both operational and embodied carbon assessment is necessary to enhance decision-making throughout the building lifecycle.

Economic and Market Barriers: Net zero carbon strategies commonly used worldwide in buildings include embodied carbon reduction, operational carbon reduction, increased renewable energy supply, and carbon offsetting and storage (Tirelli & Besana, 2023). However, barriers such as higher initial costs and lack of standardization hinder widespread adoption in the UK context (Satola et al., 2022). High capital costs, financial feasibility concerns, and market demand limitations present further challenges to net zero carbon implementation, particularly in the residential sector. The upfront costs associated with advanced energy efficiency measures and renewable energy systems often deter developers and homeowners. To address these economic constraints, new financial models and incentive structures are required to make net zero carbon buildings more viable. Raising awareness about the long-term cost benefits of energy-efficient buildings could also help drive demand (Warren et al., 2024).

In summary, while the UK has made significant progress in net zero carbon design and construction, persistent challenges related to performance gaps, policy enforcement, industry skills, and financial feasibility must be addressed. A successful transition to a net zero built environment requires an integrated approach that combines technological advancements, robust policy frameworks, workforce training, and economic incentives. The UK can move closer to its net zero carbon ambitions and ensure a more sustainable future through a combination of upskilling and improving design and construction practices and by strengthening regulatory oversight.

References

- Bevan, W. and Lu, S., 2012, September. A multidisciplinary literature review of low and zero carbon technologies into new housing. In *Proceedings of the 28th ARCOM Conference* (pp. 1435-1444).
- Drewniok, M.P., Dunant, C.F., Allwood, J.M., Ibell, T. and Hawkins, W., 2023. Modelling the embodied carbon cost of UK domestic building construction: Today to 2050. *Ecological Economics*, *205*, p.107725.
- Heffernan, E., Pan, W., Liang, X. and De Wilde, P., 2015. Zero carbon homes: Perceptions from the UK construction industry. *Energy policy*, *79*, pp.23-36.
- Jankovic, L., Bharadwaj, P. and Carta, S., 2021. How can UK housing projects be brought in line with net-zero carbon emission targets?. *Frontiers in Built Environment*, *7*, p.754733.
- Lees, T. and Sexton, M., 2014. An evolutionary innovation perspective on the selection of low and zero-carbon technologies in new housing. *Building Research & Information*, *42*(3), pp.276-287.
- Mike Briggs BSc, M.C.M.I., 2008. Zero-carbon construction. *Perspectives in Public Health*, *128*(1), p.16.

- Oreskovic, L., Gupta, R. and Strong, D., 2021. In-use energy and carbon performance of a true zero carbon housing development in England. *Science and Technology for the Built Environment*, *27*(10), pp.1425-1439.
- Rodrigo, M.N.N., Perera, S., Senaratne, S. and Jin, X., 2021. Review of supply chain based embodied carbon estimating method: A case study based analysis. Sustainability, 13(16), p.9171.
- Satola, D., Wiberg, A.H., Singh, M., Babu, S., James, B., Dixit, M., Sharston, R., Grynberg, Y. and Gustavsen, A., 2022. Comparative review of international approaches to net-zero buildings: Knowledge-sharing initiative to develop design strategies for greenhouse gas emissions reduction. *Energy for Sustainable Development*, *71*, pp.291-306.
- Tirelli, D. and Besana, D., 2023. Moving toward net zero carbon buildings to face Global Warming: A narrative review. *Buildings*, *13*(3), p.684.
- Victoria, M., Perera, S. and Davies, A., 2016. A pragmatic approach for embodied carbon estimating in buildings. *NewDist*, (Special Issue 2).
- Warren, L., Dawodu, A., Adewumi, A.S. and Quan, C., 2024. Can the UK deliver zero carbon ready homes by 2050?. *Sustainability*, *16*(13), p.5820.

Conclusions

The report outlined the findings of the global survey conducted in 6 different countries on the NZCBs (Australia, New Zealand, Italy, South Africa, Sri Lanka, and Hong Kong), including a literature review to represent UK. Most participants were from construction-related professions, with a smaller number from other roles such as academia and sustainability management. Quantity surveyors, architects, engineers and project managers showed the highest interest in the survey and participated more than other construction professionals in most countries. Interestingly, the majority of respondents from New Zealand belonged to other categories, such as carbon consultants and commercial managers.

The results conclude an increasing and varied adoption of low carbon building technologies across countries with key trends. Overall, passive design and technologies, energy efficiency and renewable energy systems are most common and popular low carbon building technologies across all countries. Passive design practices—especially sun shading and thermal insulation—are widely applied in all countries, suited to local climates. Energy-efficient systems, particularly LED lighting and HVAC upgrades, are the most consistently adopted practices across all countries. Solar photovoltaics are the leading renewable energy source used by all countries. Prefabricated and modular systems are widely used in Italy, South Africa, and Hong Kong. In terms of low carbon materials, engineered timber leads in New Zealand, while recycled steel and aluminium are common in Italy, Sri Lanka, and Hong Kong. Although some advanced materials like geopolymer concrete are rarely used, the overall trend reflects growing commitment to low-carbon construction, with slight differences influenced by local industry practices.

Carbon estimation practices remain low globally, with limited use of tools. Common barriers include lack of awareness, limited local data, and carbon assessment often falling outside professionals' roles. All six countries reported low levels of adoption, even though tools like eTool, EnergyPlus, and OneClick LCA are known by most countries. Italy shows slightly broader adoption with tools like SimaPro and Edilclima, while some countries rely on bespoke or government-provided tools—for example, Hong Kong's government carbon calculator. Overall, operational carbon tools are used slightly more than embodied carbon tools, highlighting the need for localised tools and greater industry engagement.

The enablers and barriers to NZCBs are varied by the region or country. However, most of the countries reported similar barriers such as lack of financial incentives, legislation and policies to support low carbon buildings and prioritisation of saving costs over sustainability impacts are more significant than other barriers. Notably, South Africa ranked the financial incentives as the least significant barrier. Instead, the lack of supportive policies, limited innovation, and challenges in applying low-carbon technologies were identified as the major obstacles.

In conclusion, this report highlights the growing adoption of low-carbon building technologies, the limited application of carbon estimation practices, and the varying enablers and barriers to NZCBs across the participating countries. The survey results provide insights into the current stage of the decarbonisation process and offer valuable guidance for stakeholders in shaping the next phase of low-carbon construction practices.